PhD Student
Matteo DEL GIUDICE

Supervisor
Prof. Anna Osello

POLITECNICO DI TORINO
SCUDO – Scuola di Dottorato

Ph.D. Dissertation

Smart data management with BIM for Architectural Heritage

April 2016

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Ing. Matteo DEL GIUDICE

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1. Acknowledgements

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2. List of abbreviations

Acronym	Full Name
.3DS	3D Studio max format file
AEC	Architecture Engineering and Construction
AIA	American Institute of Architects
AR	Augmented Reality
BIM	Building Information Modelling
BHIMM	Built Heritage Information Modelling/Management
BMS	Building Management Systems
BOMA	Building Owners and Managers Association
BSI	British Standard Institution
CAD	Computer Added Drawing
CIC	Construction Industry Council
CIPE	Interministerial Committee for Economic Planning
CoRENet	Construction and Real Estate Network
DIM	District Information Modelling
DIMMER	District Information Modelling and Management for Energy Reduction
.dwg	AutoCAD drawing
EAM	Energy Analysis Model
ERP	Enterprise Resource Planning
EUPPD	European Union Public Procurement Directive
.fbx	Filmbox
FM	Facility Management
.gbXML	Green Building eXtensible Markup Language
GIS	Geographical Information System
GUIs	Graphic User Interfaces
HBIM	Historical Building Information Modelling
iBIM	Integrated Building Information Modelling
ICT	Innovation and Communication Technology
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IT	Information Technology
JSON	JavaScript Object Notation
.KML	Keyhole Markup Language
LODs	Levels of Detail/Development
LOI	Level of model information
MR	Mixed Reality
NLA	Net Lettable Area
NUA	Net Usable Area
.NWC	Navisworks Cache Files file format.
.NWD	Naviswork estension file format
OTTV	Overall Thermal Trasmission Value
PAS	Publicly Available Specification

Acronym	Full Name
pBIM	proprietary Building Information Modelling
PR1MA	Perbadanan Perumahan Rakyat 1 Malaysia
.rcp/.rcs	Recap format file
RDBMS	Relational Database Management System
ROI	Return of Investment
SEEMPubS	Smart Energy Efficient Middleware for Public Spaces
SIM	System Information Model
SQL	Structured Query Language
TLS	Terrestrial Laser Scanner
UBM	Unified Building Model
UNI	Ente Nazionale Italiano di Unificazione
VR	Virtual Reality

3. List of figures

4. Abstract

In the last years smart buildings topic has received much attention as well as Building Information Modelling (BIM) and interoperability as independent fields.

Linking these topics is an essential research target to help designers and stakeholders to run processes more efficiently. Working on a smart building requires the use of Innovation and Communication Technology (ICT) to optimize design, construction and management. In these terms, several technologies such as sensors for remote monitoring and control, building equipment, management software, etc. are available in the market.

As BIM provides an enormous amount of information in its database and theoretically it is able to work with all kind of data sources using interoperability, it is essential to define standards for both data contents and format exchange. In this way, a possibility to align research activity with Horizon 2020 is the investigation of energy saving using ICT. Unfortunately, comparing the Architecture Engineering and Construction (AEC) Industry with other sectors it is clear how in the building field advanced information technology applications have not been adopted yet. However in the last years, the adoption of new methods for the data management has been investigated by many researchers.

So, basing on the above considerations, the main purpose of this thesis is investigate the use of BIM methodology relating to existing buildings concerning on three main topics:

- *Smart data management for architectural heritage preservation;*
- *District data management for energy reduction;*
- *The maintenance of highrises.*

For these reasons, data management acquires a very important value relating to the optimization of the building process and it is considered the most important goal for this research. Taking into account different kinds of architectural heritage, the attention is focused on the existing and historical buildings that usually have characterized by several constraints.

Starting from data collection, a BIM model was developed and customized in function of its objectives, and providing information for different simulation tests. Finally, data visualization was investigated through the Virtual Reality (VR) and Augmented Reality (AR). Certainly, the creation of a 3D parametric model implies that data is organized according to the use of individual users that are involved in the building process. This means that each 3D model can be developed with

different Levels of Detail/Development (LODs) basing on the goal of the data source.

Along this thesis the importance of LODs is taken into account related to the kind of information filled in a BIM model. In fact, basing on the objectives of each project a BIM model can be developed in a different way to facilitate the querying data for the simulations tests.

The three topics were compared considering each step of the building process workflow, highlighting the main differences, evaluating the strengths and weaknesses of BIM methodology. In these terms, the importance to set a BIM template before the modelling step was pointed out, because it provides the possibility to manage information in order to be collected and extracted for different purposes and by specific users. Moreover, basing on the results obtained in terms of the 3D parametric model and in terms of process, a proper BIM maturity level was determined for each topic.

Finally, the value of interoperability was arisen from these tests considering that it provided the opportunity to develop a framework for collaboration, involving all parties of the building industry.

5. Introduction

Nowadays **data management** is becoming one of the major challenges for the contemporary society, expecially regarding the AEC Industry. Unluckily, it focuses on new buildings without paying attention to the cultural building heritage that composes the major part of public and private real estate. Due to world environmental and economic conditions, focusing on Europe and especially on Italy, a change of the development strategies of the society starting from the built environment in which people live is required. So, the need to **refurbish existing buildings**, transforming them into smart buildings, is another essential requirement in the last years.

To achieve these goals, European Parliament voted to modernize European public procurement rules by recommending the use of electronic tools such as building information electronic modelling, or BIM, for public works contracts and design contests [1]. The adoption of the directive, officially called the European Union Public Procurement Directive (EUPPD) means that all the 28 European Member States may encourage, specify or mandate the use of BIM for publicly funded construction and building projects in the European Union by 2016.

Adding to this, through the Horizon 2020 program, the European Commission is driving the member states to convert the existing cities into Smart Cities in order to reduce the energy consumption by actively involving the citizens. This raises the problem of how to handle large amounts of data from multiple buildings in order to perform energy simulations by environmental monitoring and its digital visualization. So, the creation of a digital parametric model that acquires information not only related to a single building but also to the power and thermal distribution networks connected to it becomes fundamental.

The term 'smart buildings' describes a suite of technologies used to make the design, construction and operation of buildings more efficient, applicable to both existing and new-build properties.

Currently, each city is composed by several buildings of different typologies. Considering different architectural heritage, it is possible manage several data organizing them in different ways, starting from the urban scale arriving to the building scale. Actually, many researcher investigated these issues for the development of the smart city.

Of course, different people are involved in a city and for this reason they require different kind of information, Concerning their specialization and their life. Such as an example, while public administrators require data at urban scale to manage the city regarding buildings, mobility, lightings, services, energy utility professionals needs alphanumerical data coming from city/district/building electrical and heating network, designers manage data at building scale for the creation/renovation of the various buildings. All these data can be stored in a 3D parametric model, that can be queried to extract data for various objectives following **Building Information Modelling (BIM)** methodology.

BIM can be defined as a set of processes applied to create, manage, derive and communicate information among stakeholders at various levels, using models created by all participants to the building process, at different times and for different purposes, to ensure quality and efficiency through the entire building lifecycle [2].

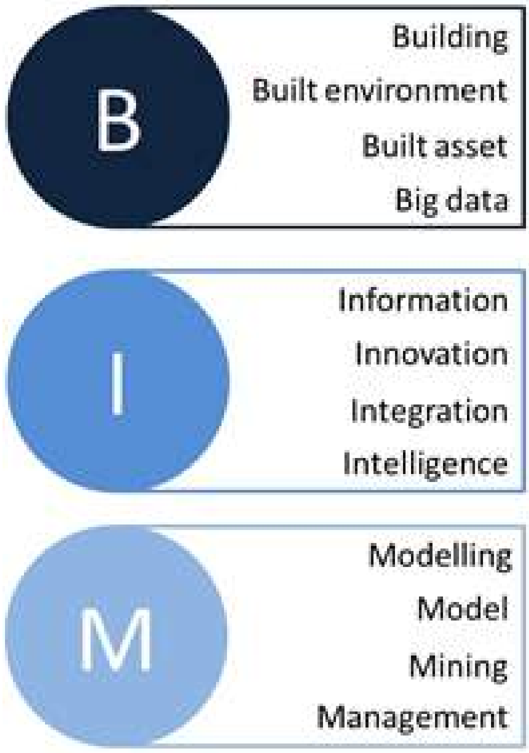


Figure 1 Different kinds of meaning for B.I.M.

From this point of view, the data sharing between different professionals and datasets plays a keyrole. Through multiple dimensions of interoperability (the technological dimension, the organizational dimension and the procedural dimension) [3] should be possible share information avoiding waste of time and costs. The concept of **interoperability** must therefore be associated with the BIM as a fundamental component for the optimization of data management.

It is clear how Innovation Technology (IT) can give an important contribute in order to optimize data management. Unfortunally, comparing the AEC industry with other sectors it is clear how in the building field advanced information technology applications have not been adopted yet. However in the last years, the adoption of new methods for the data management has been investigated by many researchers.

On the basis of the above considerations, this thesis investigates the use of BIM for existing buildings concerning on three main topics:

1.1 Smart data management for architectural heritage preservation;

1.2 District data management for energy reduction;

1.3 The maintenance of highrises based on malaysian experience;

Evaluating the role of each step in the building process workflow that will be described head, a rank will be developed in order to highlight which phase impacts more in term of effort considering the different objective of each topic.

Moreover the maturity level of BIM will be considered in order to discover the reached degree of the use of this new methodology concerning this topic.

To achieve this result will be take into account the PAS 1192-2:2013 requirement [4] for the definition of the BIM maturity levels synthetized by the figure below [5].

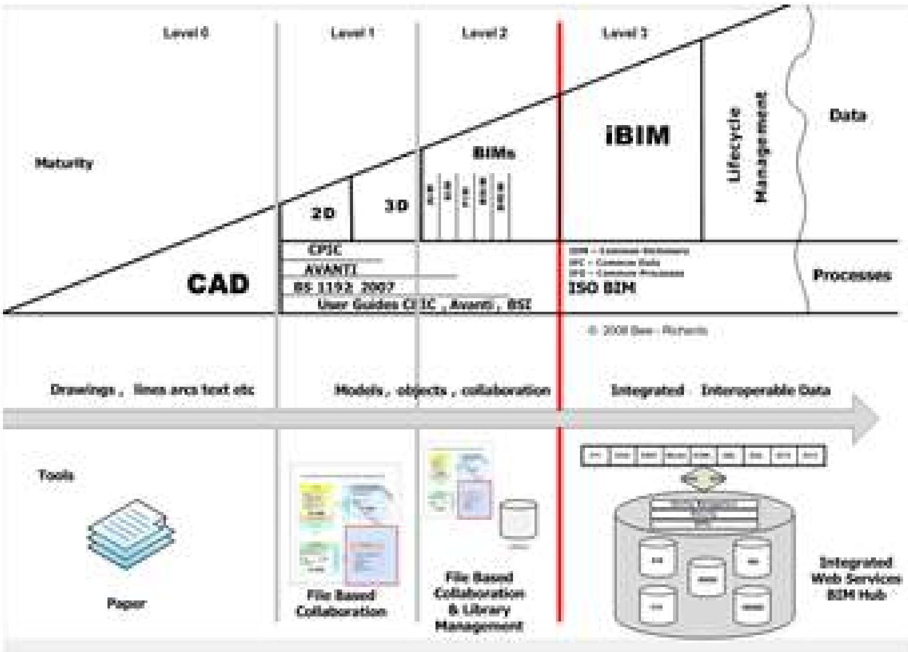


Figure 2 BIM maturity levels for the UK government

They are established by the British government in order to ensure clear articulation of the levels of competence expected and the supporting standards and guidance notes, their relationship to each other and how they can be applied to projects and contracts in industry.

The BIM maturity level definition refers to level of implementation of BIM in the AEC industry and they are defined below:

- Level 0: Unmanaged CAD probably 2D, with paper (or electronic paper) as the most likely data exchange mechanism;
- Level 1: Managed CAD in 2 or 3D format using BSI1192:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by standalone finance and cost management packages with no integration;
- Level 2: Managed 3D environment held in separate discipline “BIM” tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as “pBIM” (proprietary). The approach may utilize 4D programme data and 5D cost elements as well as feed operational systems.
- Level 3: Fully open process and data integration enabled by “web services” compliant with the emerging IFC/IFD standards, managed by a collaborative model server. Could be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes.

Basing on the several case studies selected for the three topics, each step of the building process workflow is evaluated, developing a rank in order to highlight which phase impacts more in term of effort considering the different objectives of each topic. Starting from data collection, a BIM model was developed and customized in function of its objectives, and providing information for different simulation tests. Finally, data visualization was investigated through the VR and AR.

Certainly, the creation of a 3D parametric model implies that the data are organized according to the use of individual users that are involved in the building process. This means that each 3D model can be developed with different LODs basing on the goal of the data source.

Along this thesis the importance of LODs is taken into account related to the kind of information filled in a BIM model. In fact, basing on the objectives of each project a BIM model can be developed in a different way to facilitate the querying data for the simulations tests.

The three topics were compared considering each step in order to highlights the main differences, basing on the different objectives of each arguments. Moreover, through these topics the highlighting of strengths and weaknesses of

BIM was possible. In this terms, the importance to set a BIM template before the modelling step was pointed out, because it provides the possibility to manage information in order to be collected and extracted for different purposes and by specific users.

Moreover, basing on the results obtained in terms of the 3D parametric model and in terms of process, the proper level of maturity of BIM was determined for each topic.

Finally, the value of interoperability was arisen from these tests considering that it provided the opportunity to develop a framework for collaboration, involving all parties of the building industry.

5.1. Smart data management for architectural heritage preservation;

The aim of this topic is to introduce a new and innovative methodology based on BIM, capable of improving the current sustainable preservation policies of the architectural heritage, here including monitoring, management and retrofit.

The enhancement of existing buildings requires more complex instruments and entails an information and knowledge management throughout the whole building process.

For this reason, Historical Building Information Modelling (HBIM) methodology for the existing architectural heritage can be considered the right innovative methodology that takes into account these topics, providing several information. A 3D parametric model can provide geometric and alphanumeric information that can be used to improve a building project.

Actually many researchers have investigated the HBIM field, performing historic 3D objects libraries [6]. considering HBIM role as dataset for documentation and conservation [7] and exploiting the potentiality of BIM for spaces management.

This is an interesting discussion that involves the architectural heritage research field. Many researcher consider HBIM as novel prototype library of parametric objects, based on historic architectural data, in addition to a mapping system for plotting the library objects onto laser scan survey data. It consists of building full 3D models including detail behind the object's surface, relating to its methods of construction and material make-up. In this case the advantage of HBIM over other modelling approaches is that the end result generates automated conservation documentation. [6].

Other researches affirm that BIM can be used as 3D digital semantic models organized as cognitive systems with geo-object items in a 3D Information System.

Models are an excellent means of understanding architecture, describable as a collection of structural objects, and identified through a precise architectural vocabulary. In this perspective, modeling does not follows exclusively a logic belonging to geometric criteria, rather this is a prerequisite upstream of a methodology based on architectural element as the basic unit and its construction methods as organizational tool, exactly as it is in classical architecture [8].

Although this HBIM idea can be considered as an accurate instrument to reproduce architectural objects that collect a detailed description of the components and the geometrical rules needed to generate 3D objects, it clashes with the concept of replicability of the data that characterizes BIM. Indeed, BIM objects are usually generated one time to be used several times in the same or in different projects. Performing a 3D object based on a fixed classical rules means that it can be used only for projects where the real buildings are composed exactly by these components. Otherwise, although the architectural order is evident, this object cannot reflects perfectly the reality and it needs to be further customized, repealing the development of an objects library based on a predefined architectural rule.

Moreover, the use of a 3D parameter object with an high level of detail can be not always the right choice relating to the aim and the LODs of each project. In this way in one project. As an example, In the case of a project focused on energy saving, it is not essential to insert a BIM object with an high level of geometrical information, whereas it should be simplified in the geometrical way and enriched in the alphanumerical way, adding thermal and physical properties.

Considering the Built Heritage Information Modelling/Management (BHIMM) Italian national project, various case studies was selected: early the building school “Artistico Primo” and to “Valentino Castle” (in which the Faculty of Architecture of Politecnico di Torino is located), then the attention is mainly focused on the “Albergo dei poveri” building, built in XVII century, which is located in Genoa (Italy). It is characterized by complex architectural elements different from each other e.g. vaults, irregular load bearing walls.

The use of BIM method for the renovation of historical buildings highlighted several aspects of the research fields related to the building process:

- the data collection step for the knowledge of the case studies;
- the data restitution step focused on the development of a BIM model, considering the high level of complexity regarding the modelling phase;
- the data management of a large quantity of data coming from different datasets;

- the LODs of the BIM model taking into account the role of interoperability;
- the data visualization through the V/AR.

The use of a point clouds obtained from Terrestrial Laser Scanner (TLS) and photogrammetry tecniques, was investigated in term of, amount of data, acquisition speed, measurement accurancy, and have characterized the development of a 3D parametric model.

The expected result is to precisely define what data and how they are to be included in the HBIM model to be transmitted through interoperability among different software used (architectural, structural, etc.), without replicate information. In this perspective it becomes of particular relevance the representation of the parametric model data in relation to the LODs of the project.

5.2. Smart district data management for energy reduction

This argument aims to investigate the way to link different datasets involved at urban and building scale for the development of a smart city, focusing on energy saving.

Many researchers are investigating on this field, underlining the need to develop a digital model able to contain heterogeneous data, which can be exploited for many purposes including: i) the design or refurbishment of buildings; ii) maintenance and monitoring of energy consumption.

The different datasets created to store urban, system and building data have different characteristics because they are related to different information: BIM is usually used for the architectural scale while Geographical Information System (GIS) is adopted for the urban and geographic scale.

The connection of the both environments should be done in geometric and alphanumeric information level. Unfortunately, the data sharing between the two worlds is not easy and for this reason interoperability between BIM and GIS, nowadays, is one of the major challenges that face building information systems and practitioners.

These issues are addressed by District Information Modelling and Management for Energy Reduction (DIMMER) European project that aims to develop a **web-service oriented**, open platform with capabilities of **real-time district level data processing and visualization** will be developed. Thanks to the web-service interface, applications can be developed exploiting such an **interface to monitor and control energy consumption and production from renewable sources.** Starting from a BIM model it is possible to share information with other datasets to develop a DIM model that is able different kind of information at different scale that can be extracted for different uses such as energy simulation.

For this project Turin (Italy) and Manchester (UK) districts were selected as two demonstrators for the validation of the DIMMER platform, basing on the criteria of heterogeneity, complementarity and replicability.

In fact, in order to define a very representative demonstrator (easy to be replicated at European level) based on the characteristics of the city of Turin, three main elements have been analyzed, compared and linked as key drivers for selection:

- **Energy resources**, distinguishing between non renewable (like oil, diesel and gas), renewable (like solar, photovoltaic and electricity), and low carbon (district heating) resources usable in an urban area.
- **Level of distribution of the energy**, at city, district and building level.
- **Typologies** of users (if residential or non-residential) and buildings (if public or private). Furthermore, for the buildings also several other parameters like construction period, use, material and orientation, have been considered.

The two sites have different characteristics both in terms of energy distribution as well as building usage, materials and construction period. A special mention is required for the energy networks. More specifically, as far as real-time data collection, focus is applied to the heat network (i.e. district heating) for the Turin district, while Manchester concentrates on electricity and gas distribution. For both sites, access to historic energy and utility consumption data in general is available.

The contribution of this thesis regards:

- The creation of BIM models with a proper LODs for the development of a DIM model that contains heterogeneous data arriving from GIS, System Information Model (SIM) and Building Management Systems (BMS) datasets;
- The Development of the Energy Analysis Model (EAM) starting from a BIM model in order to the energy simulations at building level, validating the DIMMER strategy in term of energy reduction;
- The role of interoperability between different software concerning the data sharing for energy simulations.

5.3. Smart data management for the maintenance of highrises

In recent years, economic and population growth in Southeast Asia, especially in Malaysia is evident. This has a strong influence on the AEC Industry which is one of the sectors that has been developing most. Relating to this, the use of BIM methodology can be adopted to optimize the management of the Malaysian real estate.

The enhancement of BIM implementation in the Malaysian construction industry is due to the positive effects of BIM applications in construction projects [9], such as visualizing project models, previewing design clashes analysis, and assisting in preparing project design, cost estimation, and project scheduling [10] [11]. The implementation of BIM in the Malaysian construction industry is expected to increase due to its benefits to construction projects.

Through the Erasmus Mundus experience the Malaysian architectural heritage was investigate considering as an opportunity to evaluate the potentiality of BIM in a growing country. In fact, this topic aims to investigate BIM methodology applied to Malaysian architectural heritage focusing on existing buildings, expecially on the renovation and the space management. Adding to this, a part is dedicated for the development of a BIM template due to the fact that this experience has generated a collaboration with Perbadanan Perumahan Rakyat 1 Malaysia (PR1MA) that is a corporation established on 1 January, 2013, under the PR1MA Act 2012. It is the sole authority empowered to plan, develop, construct and maintain affordable housing or townships built under its programme. PR1MA is at the same time a quasi-regulator as it would be regulating and enforcing the standards for these developments. PR1MA had been mandated to build 500,000 affordable houses by 2018 in the 2013 Budget.

Considering that the Malaysian architectural heritage is composed by many new buildings, especially skyscrapers, and existing buildings which are divided in high rises, the traditional and colonial houses, two main case studies were considered:

- **University Kuala Lumpur city campus building**, located in Kuala Lumpur, was taken into account as a case study. It has a rectangular shape and it is composed by 31 floors. This is a skyscraper existing building and it is the main campus of UniKL;

- **1926 Heritage Hotel**, situated in the centre of Georgetown, Penang. Built in 1926, it served as a home to the British colonial officers and local administrators. Today, it has been refurbished into a Heritage Hotel with most of its Anglo-Malay architectural essence still intact.

6. Methodology

The awareness toward the value of Architectural Heritage currently experiences a moment of increasing interest. Of course, architectural heritage is distributed around the word and is characterized by different aspects such as the shape, the height, the architecture, the structure, the materials, etc.

As said before, the attention is manly focused on the refurbishment of existing buildings in a smart city that is mainly focused on data management. A representation of the idea that has characterized this thesis is visible below.

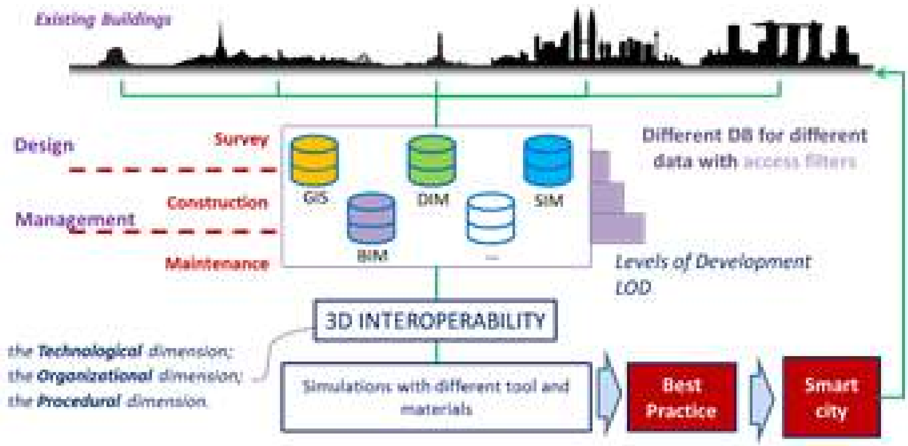


Figure 3 Description of city data management

Considering a city, it is characterized by large amount of data belonging to different scales and to different sectors. In fact, it can be stored in several datasets and in different ways, depending on the scale and the data typology (urban/district/building). From this point of view it is possible to affirm that a city can be considered a melting pot rich of Big data, that can be defined as extremely large data sets that may be analyzed computationally to reveal atterns, trends, and associations, especially relating to human behaviour and interactions[1]. It is high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation[2].

For this reason, the building industry is taking greater into account the development of 3D parametric models (e.g. GIS, DIM, SIM, BIM) to optimize city data management. 3D models are able to collect different kind of data, many of us linking graphical data with the relatives attributes. The generation of different databases implies that the data are organized according to the use of individual users that are involved in the building process. This implies that each 3D model can

[1] http://www.oxforddictionaries.com/definition/english/big-data
[2] http://www.gartner.com/it-glossary/big-data/

be developed with different LODs basing on the goal of the data source. Currently, several definition of LODs are available in the BIM research field and the most significant ones are described below.

The American Institute of Architects (AIA), gives particular attention to the choice of the Level of Development and the Level of Detail because the meaning of two types of levels is different:

- *Level of Detail* is essentially how much detail is included in the model element.
- *Level of Development* is the degree to which the element's geometry and attached information has been thought through the degree to which project team members may rely on the information when using the model.

Summarizing, Level of Detail can be thought as input to the element, while Level of Development is reliable output [12].

Figure 4 LODs documetation of AIA and BIM forum

The Level of Detail should be understood as the amount of information, graphics and non-graphics, including other components. The Level of Development instead shows how much of that information is reliable at that stage.

For this reason it is possible to associate to *Detail* the meaning of input, while to *Development* the meaning of reliability.

PAS 1192-2:2013 (UK) [4] provides two different definition of LODs taking into account the type of information:

- *Level of model detail (LOD)*, description of graphical content of models at each of the stages defined for example in the CIC Scope of Services.
- *Level of model information (LOI)*, description of non-graphical content of models at each of the stages defined for example in the Construction Industry Council (CIC) Scope of Services.

In figure below is visible the reference to the British requirement.

Figure 5 An extract of PAS 1192-2:2013

The concept of Level of Development is applied for both: as far as parameter can be filled, it is not necessarily reliable for the purposes of the model. The Level of Development requirement is necessary to allow the users involved in a BIM process to split the skills. For this reason in several countries a BIM Execution Plan is going to be adopted. In this document each stakeholder indicates, in the various phases of the project, the level of definition that will reach in their delivery.

The use of this kinds of these classifications is not considered yet as a requirement for existing buildings and it usually has some difficulties to be adopted for the definition of the design phase and the model definition because several times project models at any stage of delivery invariably contain elements and assemblies at various levels of development. However, the LODs definitions can be considered a good guideline for the development of the model in term of graphical and non-graphical information in order to establish contents for the creation of 3D parametric models. For each project the right level of development needs to be established in order to respect its requirements. Then, a proper level of detail is established for the creation of a BIM model.

So, a necessary step required to obtain a smart city consists of the connection between datasets in order to monitor, to visualize and to improve the efficiency of the urban environment in different fields facilitating the data sharing.

This role is fulfilled by Interoperability. In the last years it is considered as a field of study in response to the increasing heterogeneity and incompatibility of information systems introduced by technological innovation within networked organizations [3]. Interoperability can be described according to different sizes including the technological dimension, the organizational dimension and the procedural dimension. The contextual dimension encompasses these three dimensions and acts as a mediating force in the overall deployment of the project delivery environment.

In this thesis the concept of Interoperability will concern 3D Interoperability considering expecially the technological domain, bearing in mind that without the other dimensions it is not possible to achieve the best share of information.

Currently, the information exchange is achieved through the interoperability of software that is defined as "the need to pass data between applications, and for multiple applications to jointly contribute to the work at hand" [13]. "Detailed technical standards are required to unambiguosly define the requirements of specific information exchanges as user of the exchange standards will do so with various types of software. [...] At present, data exchanges between two application are typically carried out in four ways: direct; proprietary links between specific BIM tools; proprietary file exchange formats, primarily dealing with geometry; public product data model exchange formats like Industry Foundation Classes (IFC), or Green Building XML (gbXML) based exchange format" [2].

Referring to each project objectives, the interoperable process was investigated in order to perform different kind of data manipulation and simulation with different tools. This step was performed in order to establish a sort of best practice for the achievement of a smart city.

So, the obtained results return to the citizens in form of games through the data visualization. Considering people as active part of the building process, they become aware and are encouraged to change their behavior in order to obtain a smart city

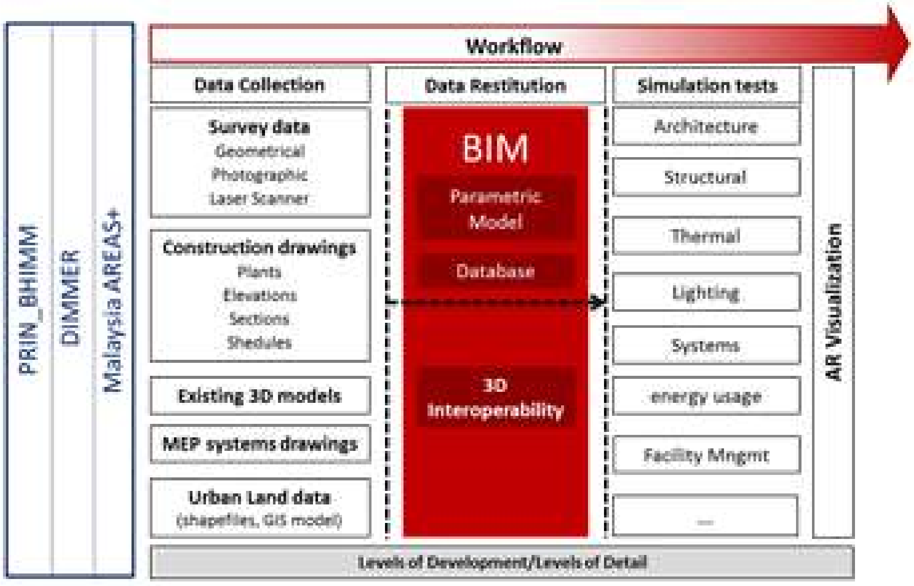


Figure 6 Schema of a part of Building process workflow

Concerning the projects highlighted in the introduction, the development of the BIM models for the smart data management starts from the *Data Collection* as visible in fig.05 which represents a part of the building process. In this phase it becomes really important to manage a big amount of data coming from different sources, as e.g. archive documents, geometrical, photographic or TLS survey. For each case studies the Reverse modelling technique was investigated using different tools e.g. Faro Scene, Agisoft Photoscan, Autodesk Recap.

The presence of multiple documents referring to the same building can ensure that the professional is able to create the BIM model reproducing as close as possible the reality. The analysis of the various sources twisted with the different kind of survey has provided the ability to verify the quality of the information from older documents or provenance uncertain.

After this phase, the *Data Restitution* step has been started with the development of the 3D parametric model created with Autodesk Revit. Where possible and and depending on the purpose of the project, a correct template was chosen to simulate a real case of refurbishment following rules that are really applied for the data management of different actors involved in a construction process, such as the real estate manager, the energy providers, etc.

Adding to this the BIM model was developed as basis for design and data exchange: the Worksets tool was used to simulate the work sharing data in a professional work team. In fact, the creation of local models connected with only one central model allows the professionals to visualize in real time the project, checking the interferences between different components.

So, data coming from different sources were inserted in Revit environment in different worksets in order to display clearly the interferences, making the file lighter in term of megabyte and easier for the management of the BIM objects.

Then, basing on the goals of each model, the import/export step is necessary for the *Simulation test* step. Obviously, in this phase Interoperability plays a key role as establishes the data flow for the different software considered highlighting the strengths and weaknesses of the data sharing.

Then, *Data visualization* was investigated using AR. For this work was tested the AR with marker through ARmedia software and markerless technology using Aurasma software.

6.1 BIM for architectural heritage preservation

The development of BIM technologies for existing buildings is becoming one of the main topics of recent years within the construction industry. The current economic conditions in which is Italy impose a review on the management of the national architectural heritage in order to streamline and speed up the process relating to operational management of buildings in terms of maintenance, restoration, energy efficiency, services , optimization of the spaces, etc.

Since the BIM process is based on the development of a 3D parametric model that is gradually enriched and interrogated during the different phases, in this scope is particularly useful.

Taking into account the whole building process described in Figure 2 it is possible to affirm that the survey phase is essential in order to know the original conditions of the asset to redevelop. In this phase it becomes really important to manage a big amount of data coming from different sources, as e.g. archive documents, geometrical, photographic and laser-scanner survey. The survey of an historic building and its context could be considered as a necessary step of the building process of requalification because it allows to know all aspects of the building.

The diagram in Figure 5 shows that in existing buildings, the BIM methodology is placed between the output arising from the survey, and the input necessary to the generation of different kind of outputs such as drawings, schedules, 3D filtered models for specific simulations and for data visualization.

It is so necessary to obtain several documents that have to be analyzed and interpreted in order to become the vehicle for the realization of the parametric model, tool useful not just during the first phases, but also in the last ones of building management and maintenance.

For these reasons and in order to optimize the data utilization, it is better to establish a hierarchy of the information that will be take part in the BIM process: through an adequate predisposition it will be indeed possible to easily and accurately extract information and obtain the necessary inputs for specific analysis as e.g. structural and lighting simulations, space management, etc.

So, as said in the introduction, each flow of information begins from the definition of the Level of Development that have determined the proper Levels of Detail of the BIM models elaborated for this work.

Figure 6 below, aims at underline the process that starts from the acquisition of information related to the real word and arrives to the development of different data sources able to store several information making it part of the digital world.

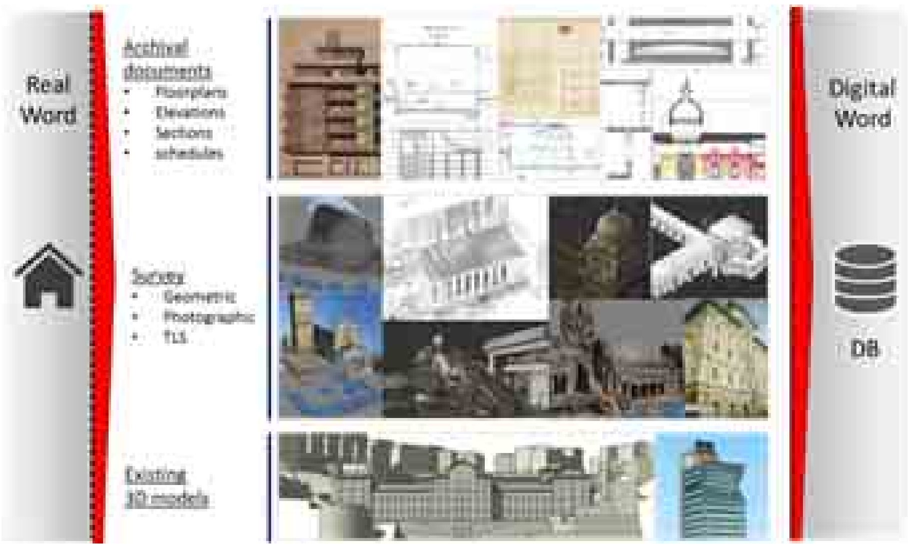


Figure 7 General schema of the Data collection step

The challenge consists of develop a Digital world that approximates reality more closely. Reaching this goal, it is possible to use digital world to run many simulations in order to optimize data management finding innovative solutions for the development of a smart city.

The digitalization of the architectural heritage is influenced by several properties such as:

1. Complexity in size and shape

2. Morphological complexity (level of detail)

3. Diversity of raw materials

Additionally, size, budget and applicability are some of the most important factors in choosing an appropriate digitization method, and since there is not an all-in-one solution in digitalization, the problem of 3D digitization of architectural heritage cannot be always addressed by using one technique.

Various techniques were investigated and different technologies have been tested: some based on laser scanning, others on surveying-photogrammetric techniques, some using simple empiric methodologies and others based on imaging techniques [14].

The choice of the proper survey method is related to the objective of each 3D model and depends on the kind of architecture.

Below are described the used survey methods for the digitalization and the knowledge of different case studies.

Empiric technique

This method is simple, productive, portable and of low cost. On the other hand, it is of low accuracy and rather demanding in terms of time of physical presence on site. It can be successfully applied when a monument has low façade complexity, or there is a need for recording a sectional plan or sections of the interiors.

During the recording of monuments by using the empiric technique, measurements of distances between characteristic points on the surfaces of the monument are taken by hand [15].

Surveying technique

Surveying techniques implement a 3D orthogonal coordinate system by using complicated and high accuracy measuring devices. This method, mainly, uses a Total Station, a device for measuring angles and distances of characteristic points on the surface of the monument, which are further on transformed into coordinates in reference to the initial orthogonal coordinate system.

The main advantage of such a method is its high accuracy and objectivity of its measurements.. It is not only reliable but it also provides an easy process of the measuring data. Although the method requires long periods of physical presence on site, it is the only one that can be used under challenging situations such as complex morphology of the monument and difficulty to access specific areas of the site. It is thought of as the ideal method for producing high accuracy models of scale 1:50 or smaller [15].

Laser scanning techniques

Laser scanners can actually be considered as advanced geodesic stations and can be used to measure topographic quantities. These devices can be used to measure the direction of a fictional optical line joining the characteristic points on a surface of a monument to a reference point on the measuring device.

Additionally these scanners can estimate their distance from these points. By applying the known triangulation principle they produce Cartesian coordinates automatically.

The main advantages are high accuracy and productivity, as well as the large volume of produced measurement data in a fraction of time (Figure 5). It is both reliable and objective. But it is also considered as a high cost method with portability and autonomy difficulties. It can be applied on almost any monument digitization, but the measurements' accuracy is affected by very bright light [16].

Photogrammetry

Photogrammetric modeling of buildings having great cultural value is becoming a common task during the last years. It is not only a correct way of buildings' documentation but also a fast and simple way to the restitution of their basic geometric and thematic information.

Common digital photos can be used, under suitable conditions, for measurements that can be of the accuracy obtained by the topographic methods. By applying orientation processes and transformations of digital photogrammetry it is possible to deduce 2D or 3D coordinates from one or two photos

The method is objective and reliable and can be aided by CAD software. It is relatively simple and of low cost. On the other hand it has to be combined with topographical or empiric measurements and the final outcome is a function of the time spent. It can be used for complex objects with high surface detail, but since it is based on photos, there is a need for adequate space (distance from the monument). It is also useful when direct access or contact to the monument is prohibited. It can be used to record stages of the monument during different time periods. When combined with accurate measurements it can produce models of high accuracy for scales of 1:100 and even higher [15] [17] [18].

In order to develop a 3D parametric model able to represents the real building, collecting information about it, the three case studies are represented below:

The first one is the most recent and it is a school built in 80s of the twentieth century with a precast structure which requires significant energy efficiency improvement and an interior and exterior modernization. In addition, this school represents a well-defined and recurrent structural type, so it can be used for structural verification, simulating its behavior in different seismic areas of the national territory.

Figure 8 General view of Primo Liceo Artistico statale case study

The Valentino Castle is Politecnico's historical site. Its origins date back to the beginning of the XVI century. In 1564 it was purchased by Emanuele Filiberto of Savoy, and later King Carlo Emanuele I gave it to Maria Cristina of France, who chose it as her favourite residence and stayed there with her court for a long time.

The castle was completely restored from 1621 to 1660 by Carlo di Castellamonte and then by his son Amedeo. The castle has two very different facades: the main one, facing Torino, has the architectural features of XVII century French castles and Italian baroque buildings, while the one facing the river Po is characterized by fired brick. Two grand staircases lead to the first floor, where thirteen rooms with their rich stuccoes and commemorative allegorical fresco paintings are the evidence of the ancient splendour of the XVII century. The building is characterized by a non-insulated, highly massive envelope, and the systems have been realized taking into account the building's conservation requirements. This site is approximately 20.000 m^2 [2].

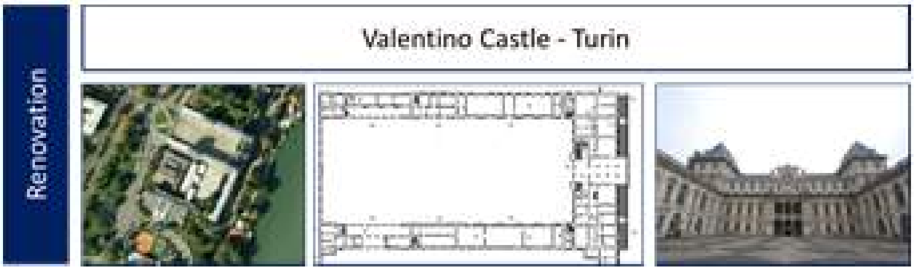


Figure 9 General view of Valentino Castle case study

Albergo dei Poveri of Genoa is a large charitable complex built in the XVII century outside of the city walls, which radically modified a natural valley. The architectural complex was later incorporated in the expansion of the modern city and lost only around 1999 its original role, which lasted over three centuries. At the end of the Nineties of the past century, the complex has been almost completely abandoned and assigned by the legitimate owner to the University of Genoa through a specific Loan for Use for 50 years [19].

Figure 10 General view of Albergo dei Poveri case study

These buildings are different each other in term of architecture, components, material etc.

Primo Liceo artistico Statale high school case study

The building identification was based on three essential features, recurring on national territory: i) public building easily accessible ii) replicability iii) the possibility of involving users sensitized through specific activity. From these three elements, and after a series of general evaluations, has been decided to focus on building schools. Another motivation of this selection was the new 'National Plan for school construction' which must be approved by the CIPE (Interministerial Committee for Economic Planning). The plan will include funds for the modernization and rehabilitation of existing assets (also for the implementation of safety of buildings) and for construction and completion of new school buildings, which must to be made in accordance with criteria of energy efficiency and reduction of pollutant emissions, encouraging the involvement of public and private capital.

In order to achieve these objectives, BIM methodology plays key role, creating a single database and exporting the information necessary for the implementation of specific calculation such as structural, lighting, heating, etc. Obviously, in this context, interoperability between software is essential, and it is described ahead. The development of a BIM model of the “Artistico Primo” building school aims at lighting simulation for the validation of the national requirements.

The first step consisted on the survey of the existing building and the acquisition of archival data. From the sources analyzed and from the survey executed on site, information have been obtained concerning the construction type used and the construction details. The structure is composed of precast elements such as columns and beams. The floor is made with TT beams, conversely, the plinths and the connecting beams are cast in situ. Numerous inspections have been carried out to perform a geometric survey which allowed to confirm or vary the assumptions obtained from the analysis of the archival documents. The second phase has been the realization of the 3D parametric model (Autodesk Revit 2013) using LOD 200.

Figure 11 3D parametric model of Primo Liceo Artistico statale

After the modeling stage, the model was exported into a specific calculation software such as Autodesk Ecotect Analysis for preliminary lighting tests. In order to perform specific calculations. To avoid the loss of data a lot of test have been carried out through the following formats: .ifc, .gbXML, .3DS, .fbx..

Unfortunately, the use of .ifc and gbXML formats, produced some problems: in fact, the software considered the import completed, but nothing was visible. So, to be able to proceed with a better export/import process, the model was exported into 3DStudioMax, using the format .fbx. Then the model has been exported in .3ds format and opened in Ecotect. Many imported elements have been converted in surfaces during the import phase: however these elements were still perfecty coincident and coherent. After the import phase, it has been possible to carry out the lighting analysis relative to the selected classroom.

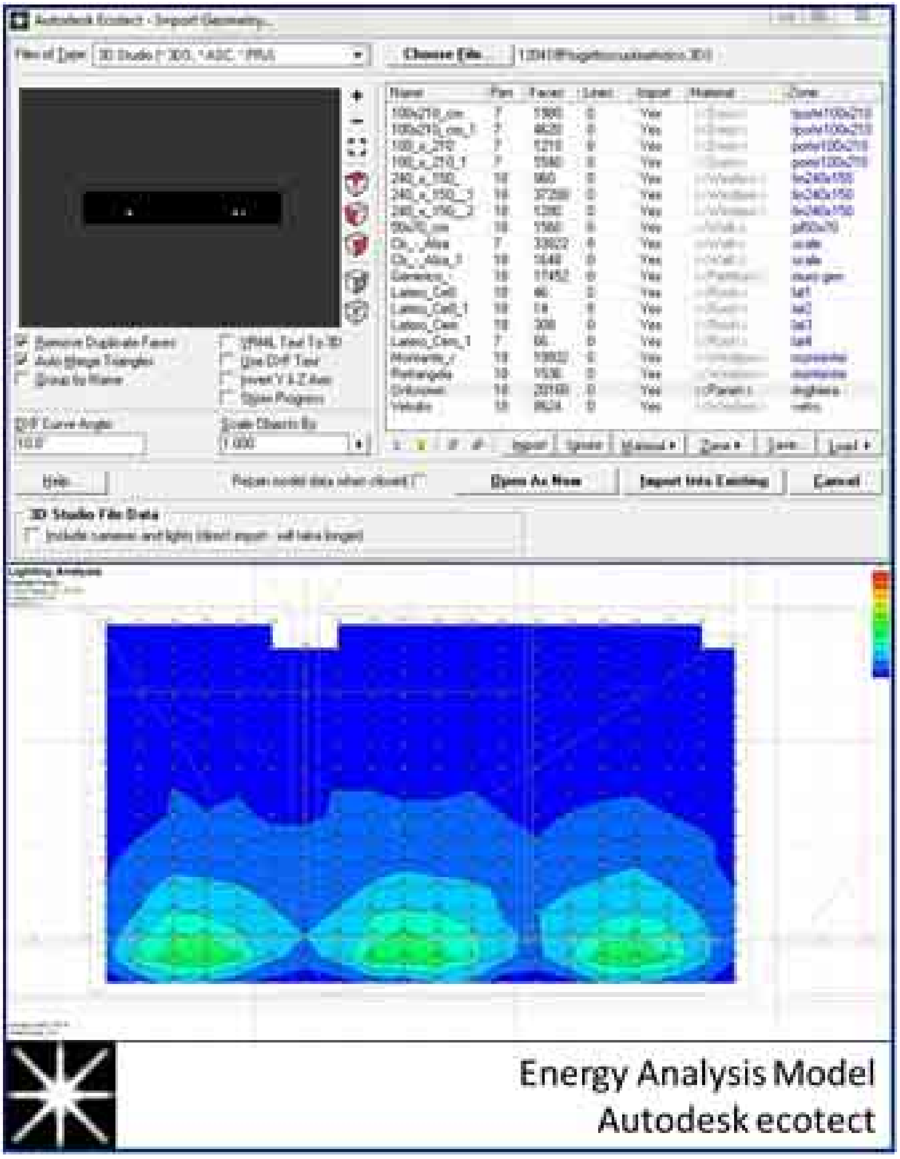


Figure 12 Import process into Autodesk Ecotect and Lighting simulation

So, through this methodology is it possible to affirm that it can be adopted with sufficient easiness, defining the intervention criteria for the redevelopment of existing buildings in terms of energy, systems, structural and architectural.

The valentine castle case study

Since it is an historical buildings a particular attention has been given to the Data collection step.

In fact, considering the whole building process it is possible to affirm that the survey phase is essential in order to know the original conditions of the asset to renovate and could be considered a necessary step of the building process of renovation because it allows to know all aspects of the building.

In this phase it becomes really important to manage a big amount of data coming from different sources, as e.g. archive documents, geometrical, photographic and TLS survey.

It is so necessary to obtain several documents that have to be analyzed and interpreted in order to become the vehicle for the development of the parametric model, tool useful not just during the first phases, but also in the last ones of building management and maintenance.

For these reasons and in order to optimize the data use, the creation a 3D parametric model needs to be organized in a proper way, creating an information hierarchy. Through an adequate predisposition it should be possible to easily and accurately extract information and obtain the necessary inputs for specific analysis as e.g. structural and illuminating calculations, rooms management, etc.

In this perspective the representation of the parametric model becomes of particular relevance in relation to the LODs of the project, taking into account the difference between parametric model and real building and the role of survey.

Since this research presents as cornerstone the historical heritage (that, for its nature is often made up of irregular elements or articulated geometries) and since the parametric software find a synergetic support on tridimensional models, the way considered in order to obtain geometrical data is the execution of a survey for the generation of a point clouds, using the empiric technique and photogrammetry.

In Valentino Castle, two parts were investigated:

- A major port of considerable architectural interest located inside the Valentino Castle;
- A grand staircase facing on the river Po and leading to the first floor.

Concerning the major port, the aim of the BIM model is related on the enrichment of a simple door created in Autodesk Revit with the addition of decoration elements. This object seems accurately modelled but in reality there is just an overlay of a mesh on the surface of the wall that hosts the door object.

Photo-modeling was accurate and there was no need to integrate it with survey data directly.

16 photos were included in the program Autodesk 123D Catch for an output consisting of 6150 vertices. Obtained the photographic model, it was exported into into MeshLab for the generation of the mesh. Then it was exported again in a .dxf format to be imported in the parametric software for the development of the family.

Below there is an example of the workflow explained above.

Figure 13 Workflow for the generation of the major port of Valentino Castle

The staircase survey has been carried out with the photomodeling technique: 20 photos have been shot from different points of view and being careful of taking clear pictures, without contrasts, over-or underexposed. Pictures have been the input data for the Autodesk 123D Catch software, which furnished a staircase model made up of 16781 vertexes.

Nevertheless, since in reason of the large staircase dimensions and the difficulty in shooting optimal pictures, the photographical model presents some uncertainties, the knowledge moment has been completed with a geometrical direct survey. The 3D parametric model was generated using Autodesk Revit 2013.

Considering on the dense point clouds import step into Revit, several problems were encountered due to the management of a large quantity of data. The entire point clouds was divided into different parts creating different object families that later were loaded in a project file. Once the importation phase was concluded, the modelling step was started. In this case the focus is on the development of a graphical data source useful for the renovation. The figure below show the workflow explained above.

Figure 14 Workflow for the generation of the grand staircase of Valentino Castle

Several steps were followed for the generation of a BIM model related to the staircase and for each step data was imported\exported using different formats such as .dwg and .obj. Levels of reference and horizontal and vertical sections have been created in order to test the accordance between model and point clouds.

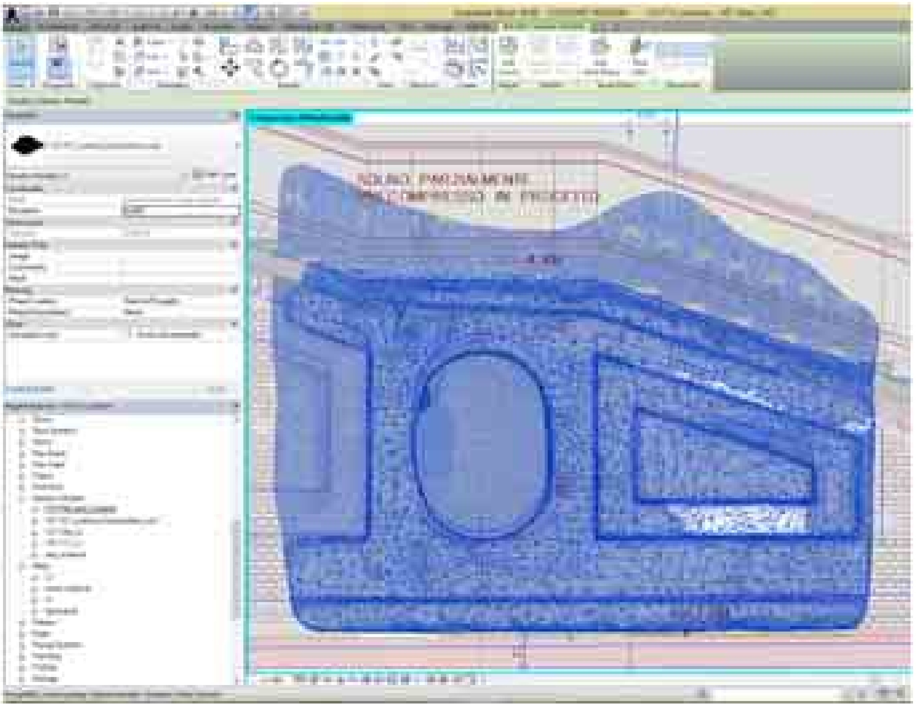


Figure 15 Mesh of a part of grand staircase in the Revit environment

In this phase it is clear, how the use of heterogeneous data becomes important in term of reproducibility of the virtual model more similar to the reality. Overlaying different data allows the professional to check archival documents with the survey data improving the model accuracy. The issues related to this are based on the data formats of each source and the management of the amount of data. This argument will be explained in ahead.

The modelling step was tested in order to automate the process of generation of the BIM objects starting from a mesh generated by a point clouds.

Though this case study the automatization of the BIM objects generation was tested. Unfortunately, the mesh is not recognized as one single surface and for this reason wan not possible to extrude directly the object. To goal this objective the creation of several profiles based on many sections along the mesh was needed as visible in figure below.

Figure 16 Development of a BIM object of a degradation

Adding to this, for data management related to the degradation (definition, quantification, causes and restoration techniques) a specific field was created as visible in the figure above on the right side. It was thus possible to enrich the database using the classification proposed by the Recommendation Normal 1/88 and by the UNI 11182:2006 law.

In this last step the use of the 3D parametric model as a relational database was highlighted. In fact, information related to the degradation degree can be quantified thanks to the generation of BIM objects that can be enriched through the addition of additional parameters. This field can be potentially filled by other professionals that manage different data sources related to the cultural heritage preservation. Currently, it is possible to visualize/edit/update BIM model developed with Revit as a relational database through RevitDBlink using Relational Database Management System (RDBMS) such as for example Microsoft Access, SQL server, PostgreSQL.

From this point of view it is clear how BIM model is a flexible instrument that can speed up the building process also in term of renovation.

The Albergo dei poveri case study

For this case study, the worklow starts from an archival research based on the work done by the University of Genoa. As said before, the Albergo dei Poveri of Genoa, is a large charitable complex built in the 17th century outside of the city walls, which radically modified a natural valley. Later, the architectural complex was incorporated in the expansion of the modern city and lost only around 1999 its original role, which lasted over three centuries. Currently is part of University of Genoa real estate [19]. Below there is a figure that shows on the left a plant of the building related to Barabino architect and on the right a particular detail of a statue made by Giovanni Battista Barberini representing Angelo Spinola, one of the benefactors of the building, that shows the plant of the building.

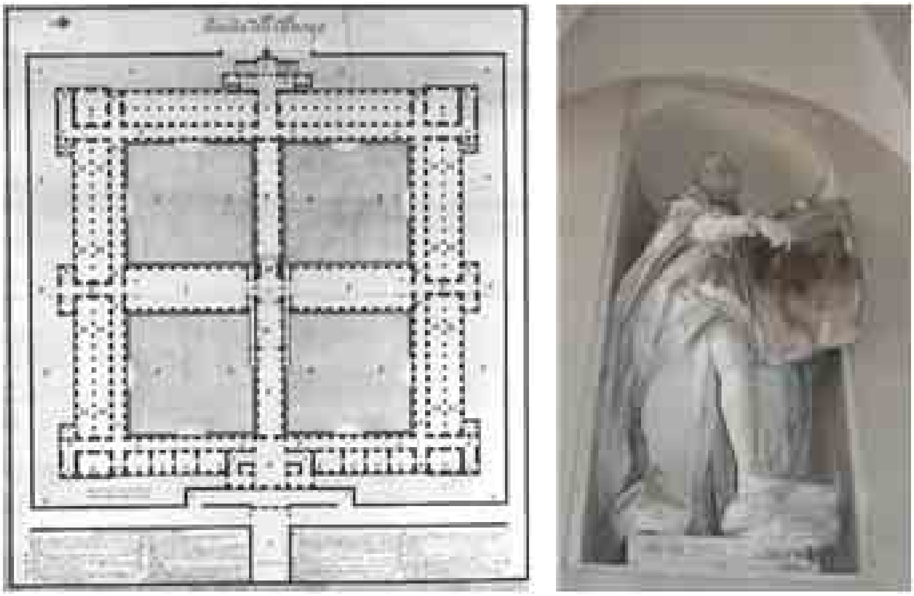


Figure 17 Historical plant of Albergo dei Poveri with its representation on a statue

So, in order to reuse this historical building as part of the university campus, the need to link several heterogeneous information coming from different historical data sets gave rise to adopt BIM for the development of an instrument for able to manage a large amount of heterogeneous data.

So, the first step consisted on the choice between the development of a simple BIM object library rich of complex components or the investigation on a BIM methods related to develop a BIM model not only focused on the modelling step, but rather as a database able to collect several information that can be linked with others stored in different data source.

For this case study the focus is related to the development of a graphical database useful for the space management of the various areas of the building taking into account the architectural value.

Below the activity workflow is represented in the figure below.

Figure 18 Workflow for the creation of a BIM model of Albergo dei Poveri

This building is a complex building with a significant number of rooms. For this research three spaces were taken into account as representative spaces of this type of architecture: the hall before the chapel, the adjacent corridor and the building's entrance hall. The last one was investigated in particular way for the development of the BIM model.

Data collection is the first step for the development of the HBIM model. A TLS survey was done with a photographic survey. It was developed in two days. Through the FARO laser scanner Focus^{3D}, 38 scans were necessary to obtain an homogeneous point clouds.

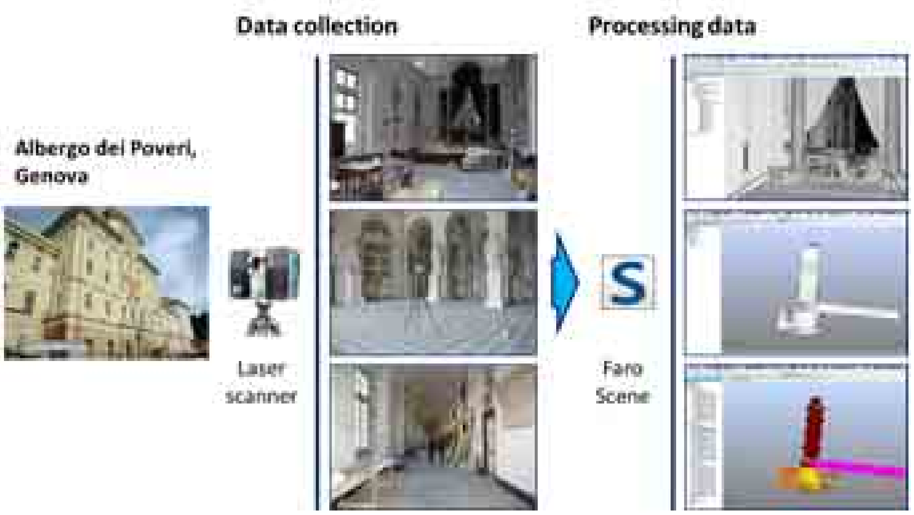


Figure 19 Data collection and Processing data schema

The first processing data of the initial point cloud had approximately 233 million points with a weight of about 3.5 GB. After the alignment of the various scans and the cleaning of the cloud from the unnecessary points, their number dropped to about 18 million with a reduction in terms of hard disk space. The operative version of the cloud collects 9.872.470 points and weighs about 250 MB. It is clear that a large amount of data like this needed the presence of an hardware with high performance.

At first the cloud of points and saved in lsproj format, creating a scan project that is a main file that contains all the shared data (the scans) of the project. Unfortunately this choice did not lead to large benefits except to facilitate the visualization of the spaces, offering the availability to focus on different parts of the point clouds without loading all data each time. So, the point clouds was manipulated with Autodesk Recap PRO 2015 as visible in figure below.

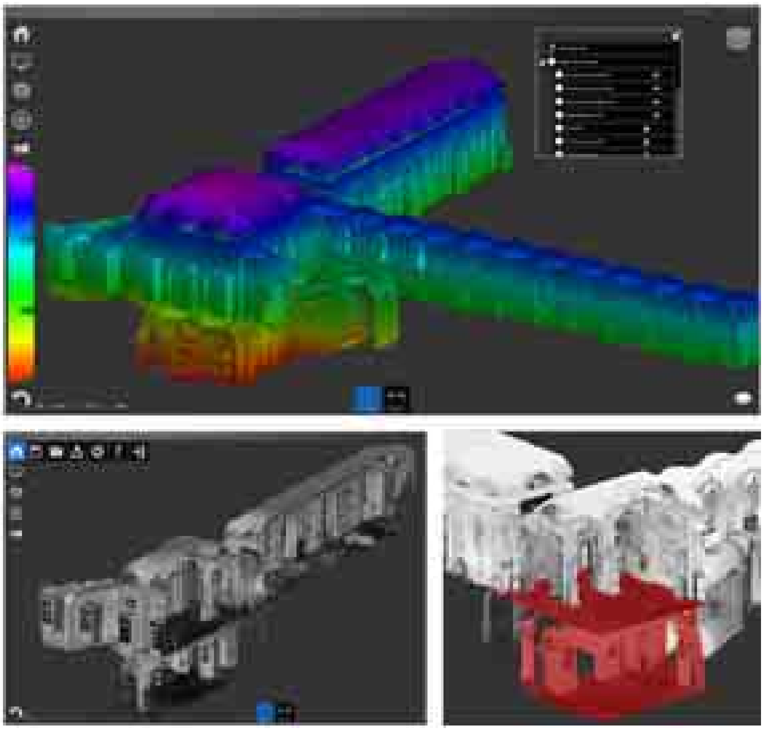


Figure 20 Point Cloud data management in Autodesk Recap

Several standard exchange format have been tested such as Isproj, las, pcg, ptg, pts. The Export/Import Process for the management of the Point Clouds is visible below.

Figure 21 Inport/Export process for the point clouds usage

Then it was subdivided in a logical way in various regions, grouping points according to building elements that they represent.

Initially, the cloud was loaded entirely inside Revit in .rcp format, however this generated a very "heavy" file in terms of disk space and hardware acceleration for the graphics card, causing a negative result in terms of performance of the project file. For this reason the point clouds management through the creation of sub-regions is the right choice in terms of display and of information management to proceed with the modeling step.

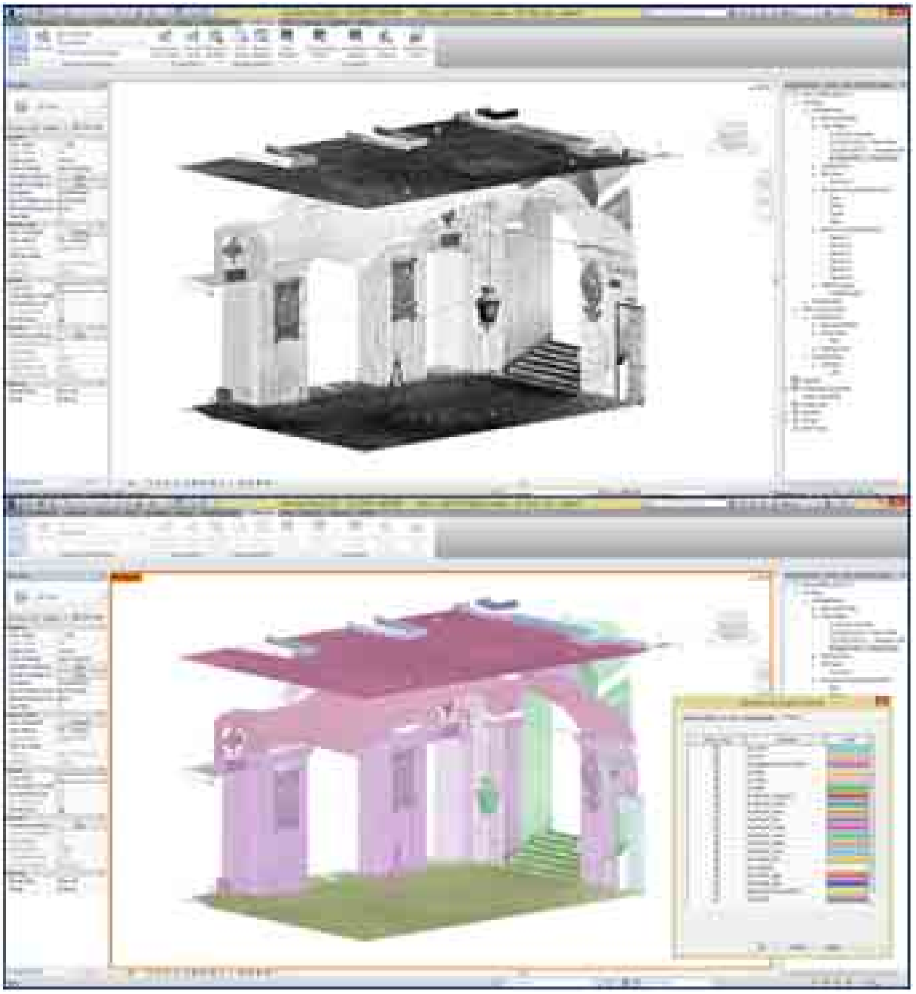


Figure 22 Workest tool use for the point clouds in Revit

Moreover, to simulate a real situation and to optimize the information sharing between different professionals involved in a project *worksets* has been created, developing the information exchange idea. Worksharing is a design method that allows multiple team member to work on the same project model at the same time. Worksets are like boxes in which divide different parts of the project, like for example internal walls, external walls, roof, slabs and also the point clouds' survey; they give the possibility to the various subjects to work each on a local model tied to a central model that is updated constantly through the synchronization of files.

Before to start with the modeling step it was essential to organize all data available to us using them properly and smoothly, arriving to the development of the 3D model of the existing condition. The BIM model was organized according to the discipline, the building sector (Architectural, Structural, System, etc.) and the different phases of work In order to optimize the data management in the Revit environment, the *Project browser* was customized to view the information in the preferred way.

Before starting with the modeling step was carried out a verification of consistency between existing 3D model made with Sketchup and the point clouds. Some parts of the existing 3D model were imported in .dwg format into Revit (Figure 23) in order to verify the goodness of the previous model, creating a base for the creation of parametric objects.

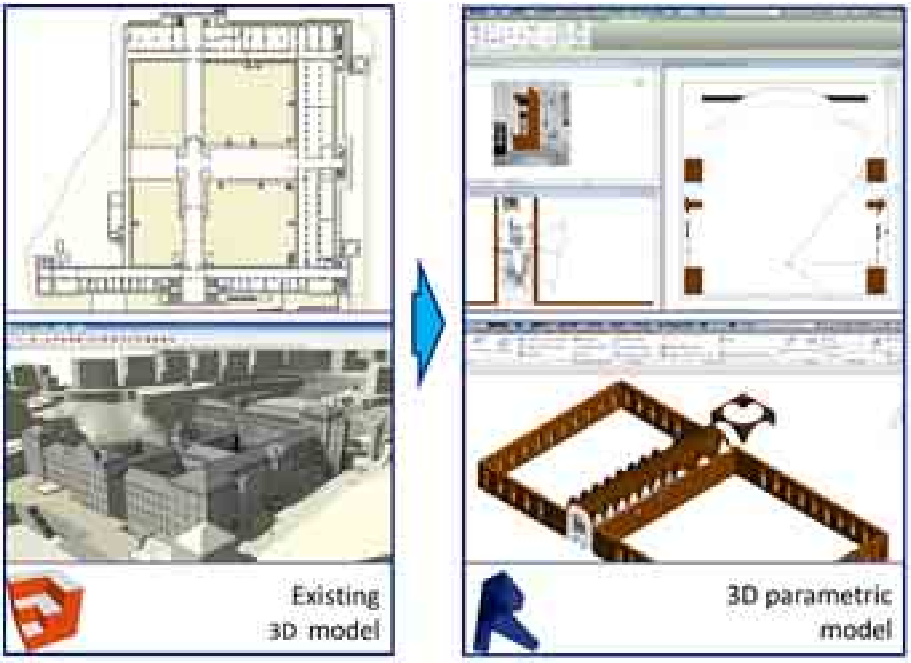


Figure 23 Heterogeneous data comparison into Revit

The existing 3D model was created in a general way, without paying attention to any geometrical survey. Developing different sections and levels the difference with the point clouds was highlighted as visible in the figure above in top right corner.

The main dimensions, such as length and width of the main environments were respected, but the height of the rooms is very different with a gap of 1,5 m. One factor that has contributed to the error is the presence of the vaults.

Then the modelling started focusing on the definition of kind of modelling for each building component. In order to follow correctly the point cloud survey, several factors were taken into account such as the object typology, the level of precision, the performing speed, the skill level and the level of detail.

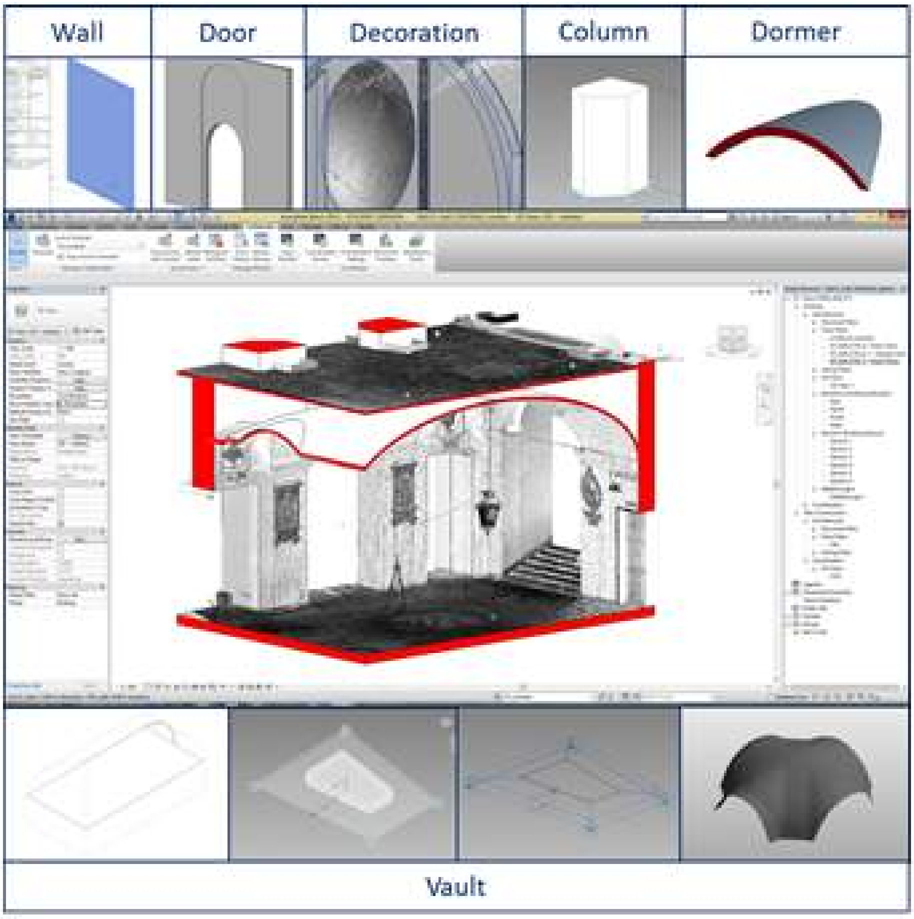


Figure 24 View of HBIM objects developed for the Albergo dei Poveri

It is clear that to approximate the point cloud the modelling step was performed and each object was customized properly. As visible from the table below, most of the objects was created as a loadable family, trying to respect as much as possible the criteria of replicability. However, as this is an historic building, some items have been customized specifically. Each object was described by a proper table that is visible below.

HBIM Objects		Building components								
		Wall	Door	Decoration	Columns	Dormer	Vault 1	Vault 2	Vault 3	Vault 4
Object characteristics	Family typology	System	Loadable	In-Place	Loadable	Loadable	In-Place	Loadable	Loadable	Loadable
	Level of precision	Low	Medium	Medium	High	High	Low	High	High	Very high
	Performing speed	Quick	Quick	Quick	High	High	Quick	Medium	Medium	Quick
	Skill level	Beginner	Beginner	Average	Expert	Expert	Beginner	Expert	Expert	Beginner
	Room adapt	High	High	Low	High	Low	High	Low	High	High
	LOD	1	1	1	2	2	1	2	2	2*

Figure 25 Characteristics of the HBIM object used

Focusing on the Vault objects, four tests were performed in order to investigate the better way to develop a complex building component like this. These tests allowed to discover the potentialities of the modeller that had as goal the generation of *Rooms* that are one of the most important object for the space management.

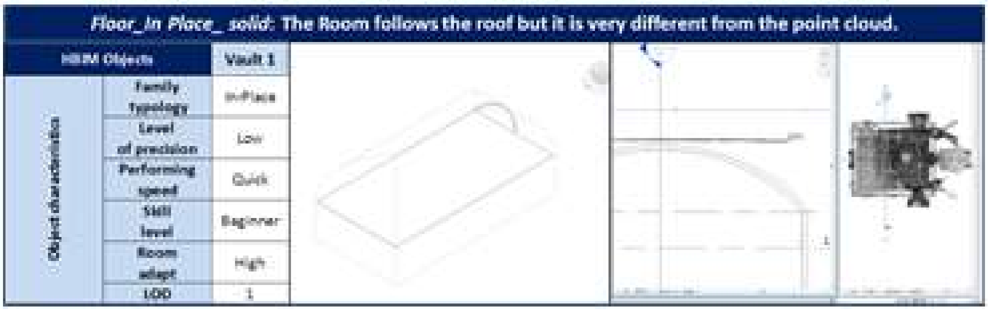


Figure 26 Test 1: Schedule of Vault 1

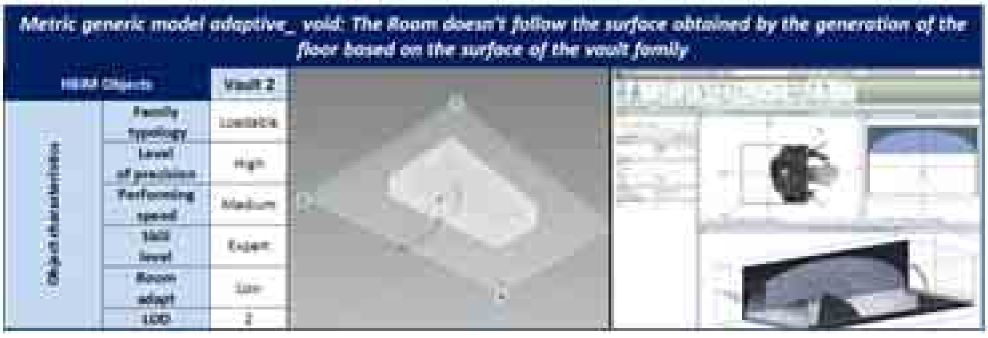


Figure 27 Test 2: Schedule of Vault 2

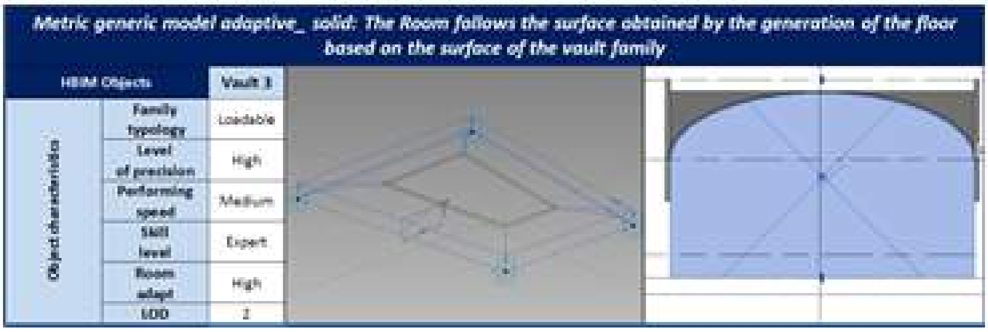


Figure 28 Test 3: Schedule of Vault 3

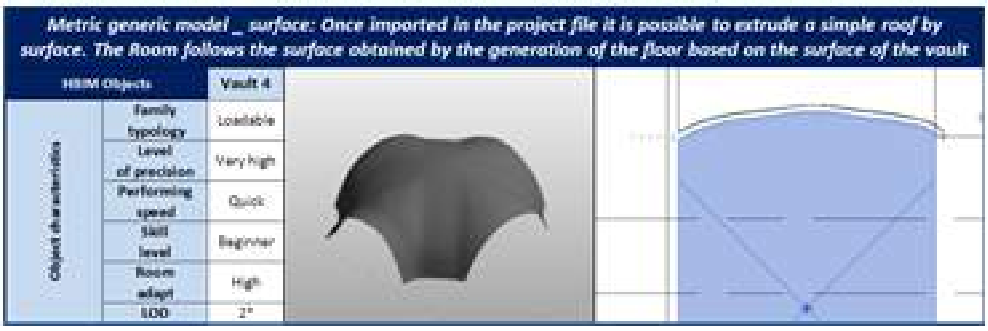


Figure 29 Test 3: Schedule of Vault 3

Test 4 is characterized by a different process of the BIM object generation and it is explained below.

Although the performing speed resulted as *Quick* and the Skill level as *Beginner* the Level of precision is *Very high.* This due to the use of interoperability as visible in the figure below.

Figure 30 Interoperable process for the automatic creation of the vault

A vault can be generating using another software that is Rhinoceros as a bridge. The point cloud was imported into Rhinoceros using a .pts format and a surface was generated. Later, it was imported into the *Conceptual mass Revit family* through ACIS.sat format and then it was loaded into the project file. Though the *Floor by face* command a system floor has been generated. In this way the *Room* object approximate exactly the floor surface. In this case the LOD is considered 2 because the object itself is easy but it is enriched by the interoperability value. It is clear that this test requires the knowledge of the various software available in the market and the standard exchange formats that are supported in the export/import process. From this test was investigated the automatization process for the BIM object generation, starting from a TLS survey. Obviously, this method needs to be improved due to the fact that during these steps several information is missed such as the coordinate system of the point clouds. Moreover, the necessary steps required to automate the object generation is still too high, but this way should be considered as a prospective for the building optimization process.

Data visualization was tested using VR. The aim of this step is the visualization of the Point Clouds survey and the BIM model with the use of mobile devices such as smartphone or tablets. This kind of visualization allows the professionals to check, measure and share data with all the stakeholders involved in a project, starting from the surveyor that is interested to the goodness of geometrical data arriving to the restorer that is able to highlight different part of the displayed model communicating information in real time with the other partners. So, the importance of interoperability is enhanced because the data workflow through different software and different devices justifies its added value in the building process concerning the data management.

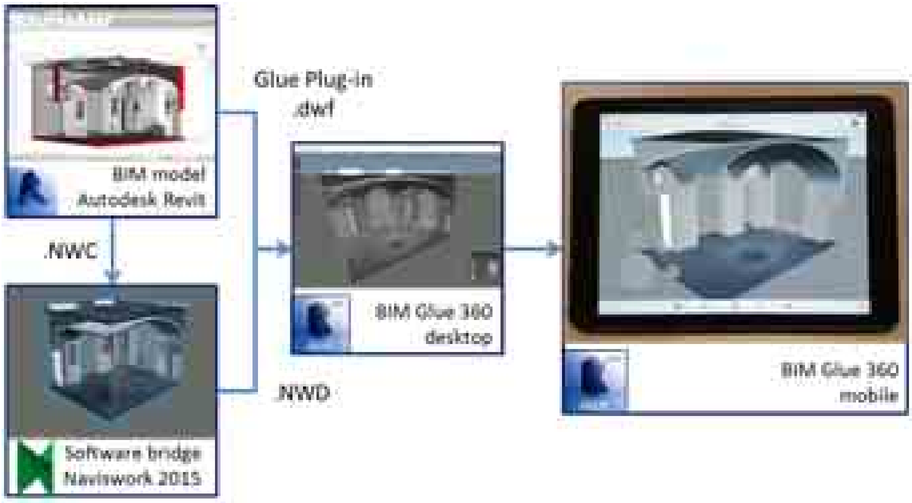


Figure 31 Interoperability process for Data visualization

The BIM model was exported both directly using the Glue Plug-in and Autodesk Naviswork Manage 2015.

In the first case the model was correctly exported, missing the point cloud data. Then, the model was exported at the beginning into Naviswork using Navisworks Cache Files (.NWC) file format.

Then the model was saved in Naviswork extension (.NWD) file format to be loaded in the cloud of BIM Glue 360 Desktop. Downloading BIM Glue 360 for iPad , it is synchronized with the cloud of Glue an it was possible to display BIM data measuring the model. In this way, a chance to manage BIM models is created, providing the possibility to verify in situ or in a different place the goodness of the model comparing it with the reality.

Unfortunately, the data flow needs to be improved because some data relating to the point clouds was missed and several times the point clouds was not displayed correctly due to the large amount of data and the standard exchange format. As for the Revit, Recap (.rcp, .rcs) file formats was used, to optimize the visualization on tablets the Point clouds files were exported again in .pts formats as visible in the Figure below.

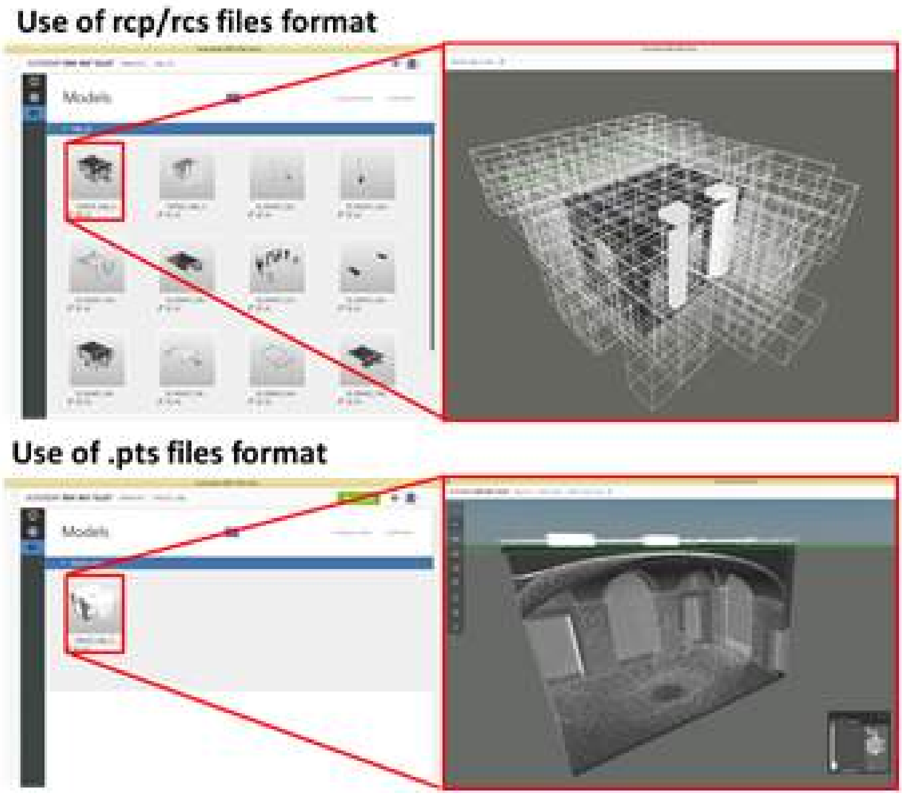


Figure 32 Interoperability errors of the point clouds into BIM Glue 360 mobile

Data visualization needs to be improved due to trough different kinds of tools should be possible to improve the efficiency of each project, disseminating results in different way enhancing the work developed following the topic of the shared data.

6.1.1 List of relative paper published

- **Del Giudice M.**, Osello A., The enhancement of architectural heritage through HBIM and interoperability. In: XXXVIII International Conference of Professor of Disciplines of Representation UID – Florence 2016. Abstract submitted

- Osello A., Uffredi V., **Del Giudice M.**, Rapetti N., Il BIM per il patrimonio edilizio storico, realizzazione di un database per la manutenzione. In: XXXVIII International Conference of Professor of Disciplines of Representation UID – Florence 2016. Abstract submitted

- **Del Giudice M.,** L'impostazione di un modello BIM per un edificio esistente. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 40-49, 2015. ISBN 978-88-579-0478-8.

- **Del Giudice M.,** La gestione delle nuvole di punti con il BIM. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 76-83, 2015. ISBN 978-88-579-0478-8.
- Isabella Bianco, Carlo Caldera, **Matteo Del Giudice**, Andrea Maria Lingua, Anna Osello, Paolo Piumatti, Pablo Angel Ruffino, Marco Zerbinatti, A digital process for conservation to traditional stone heritage, In PPC Conference 2014, Monza and Mantua, Italy, 5-9 May 2014.
- **Del Giudice M.**, Osello A., BIM FOR CULTURAL HERITAGE In CIPA 2013, Strasbourg, France, 2 – 6 September 2013
- Bianco I., **Del Giudice M.**, Zerbinatti M., A database for the architectural heritage recovery between Italy and Switzerland. In: In CIPA 2013, Strasbourg, France, 2 – 6 September 2013.
- Anna Osello, Carlo Caldera, Bernardino Chiaia, Daniele Dalmasso, Sanaz Davardoust, **Matteo Del Giudice**, Anna Pellegrino, Pablo Ruffino, Structural and energy calculations for the redevelopment of existing buildings. In XXXV International Conference of Professor of Disciplines of Representation UID – Matera, Italy. PATRIMONI E SITI UNESCO MEMORIA, MISURA E ARMONIA, 2013, pp. 739-746. – ISBN 978-88-492-2728-4
- Marco Zerbinatti, Isabella Bianco, Cristina Boido, **Matteo Del Giudice**, Paolo Piumatti, Pablo Ruffino, Survey and parametric modelling for historic architectural heritage. In XXXV International Conference of Professor of Disciplines of Representation UID – Matera, Italy. PATRIMONI E SITI UNESCO MEMORIA, MISURA E ARMONIA, 2013, pp. 993-999. – ISBN 978-88-492-2728-4

6.2 BIM for district data management

The DIMMER project represents an Evolution of the use of BIM, extending its use from buildings (building scale) to district (urban scale), simultaneously expanding the areas of study thanks an interdisciplinary use of ICT based on interoperability. The project started from the results of the SEEMPubS (Smart Energy Efficient Middleware for Public Spaces – September 2010 – August 2013) project, in which, different technologies for energy monitoring and control have been tested/developed, in conjunction with specific activities aiming to raise end-users' awareness of energy-related issues.

The basic concept behind District Information Model (DIM), introduced for the first time by the DIMMER project, is to implement the BIM philosophy and extend it to a district level, using common data at both building and district scale, involving a plurality of users, starting from both technical and social aspects.

A DIM model can be compared with a Unified Building Model (UBM) [20] where several information is collected coming from different data source, such as BIM service, GIS service, SIM service described with geometric and alphanumeric data. The main difference is the development of a multi-service platform where data come both from the real-time monitoring and digital data.

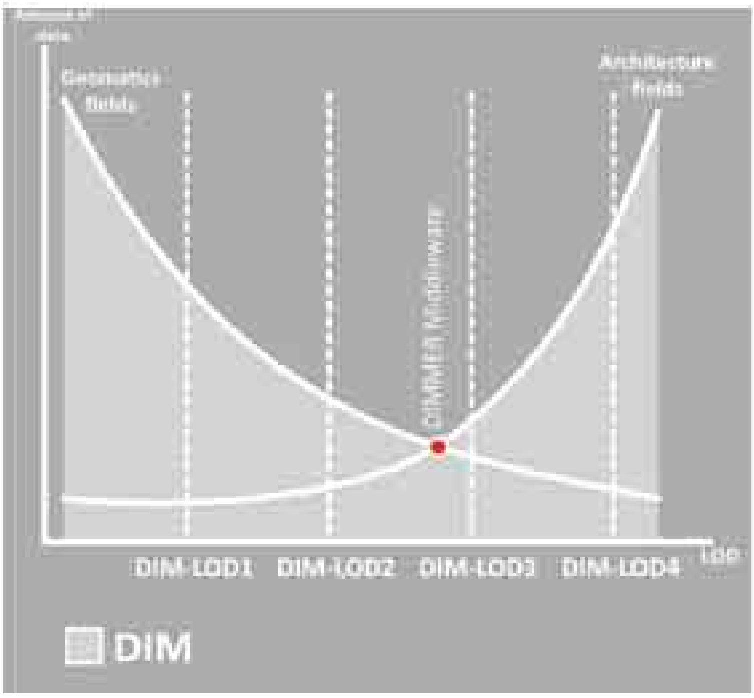


Figure 33 The DIM chart

DIM can be represented with the chart above where the area under Geomatics and Architecture fields ideally represents different levels of information of the district model. The junction of both curves represents the DIM concept where all the information is shared between the two systems working on the "smart interoperability" exploiting DIMMER Middleware.

Therefore, DIM should not be regarded as a fixed 3D model but rather a dynamic model where, relating to the users, it can be reached with different data. So, a DIM model is not just an overlay of the different 3D models described below, but it is mainly a common platform where many information (coming from different datasets and with different data format) are linked each other.

This common platform aims at the data sharing optimization for the energy reduction, collecting and providing data on the single buildings and the district as a whole, including information on their energy requirements. In fact, one of the main innovations introduced by the DIMMER project is the middleware able to simultaneously handle data from different heterogeneous domains, focusing on:

- **Analysis** of environmental condition due to geographic and morphologic characteristics at both building and urban scale;
- **Interoperability** between different data sources;
- Integration of **real time data** from building scale (BIM) to urban scale (DIM);
- Use of **web-based interface** to improve people's awareness on energy saving/efficiency, using virtual and augmented reality.

Potential users of the DIMMER technology have been identified (Public administrators, Energy utility professionals and Estate managers) in order to guarantee different information based on a well-defined multi-scale geometric data usage (from building scale to urban scale and vice-versa). In fact, for each user different kind of information have been identified/modelled and different visualization tools are under test/development. Information is extracted using different DIM Levels of Detail (DIM-LOD) based on the users' needs, as detailed below in this chapter and as summarized in Fig. 33.

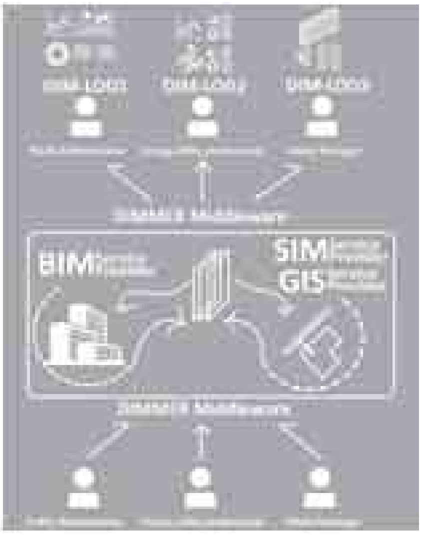


Figure 34 A possible usage of the DIMMER middleware by different users (for both, data input and output)

District data are stored in different databases that can share information through the DIMMER Middleware, exploiting the web services provided by both BIM and GIS Service Providers.

In this way, the different actors playing in a Smart City scenario can access several kinds of information that will be described ahead.

Due to the heterogeneity of the data and conflicting values, the information that model the district as a whole has been exported in different Database Management System (DBMS) where users need to visualize and manage several information with different levels of information. Querying data, that is visualized in different ways.

As the DIMMER consortium is composed by several partners that have different roles, this contribute regards the DIM parts composed by the development of BIM data source, the GIS data source, and the Energy Analytical Model (EAM) for the building simulation engine.

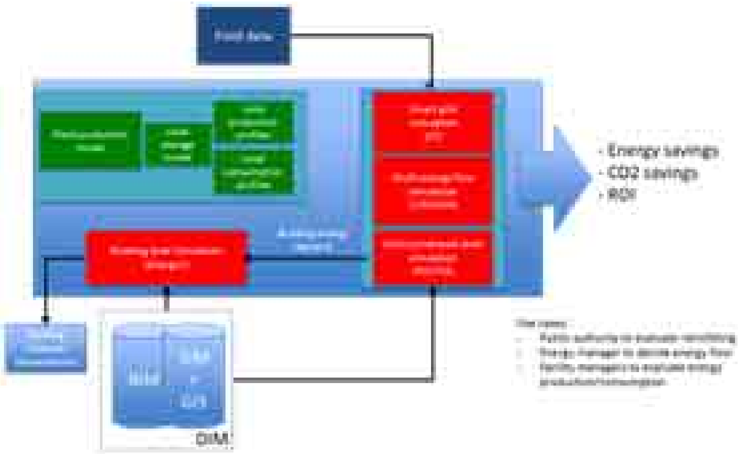


Figure 35 Simulation engine scheme in the DIMMER Deliverable D 3.3.1

Figure xx describes the interaction between simulation components provided by the partners. Simulation components are colored in red. Models related to energy production and consumption blocks are in green. Field data taken from real measurements are represented by a blue box. The overall simulator has a network simulation part composed by the three red blocks on the right side: smart grid simulation, multi-energy flow simulation and district network simulation. Here, special attention will be given to the Building level simulation where 3D parametric models are used to validate of a DIMMER strategy that is based on the "peak shaving" of energy request.

Two demonstrators were selected in Turin (Italy) and in Manchester (UK) and the figure below represents the selected buildings.

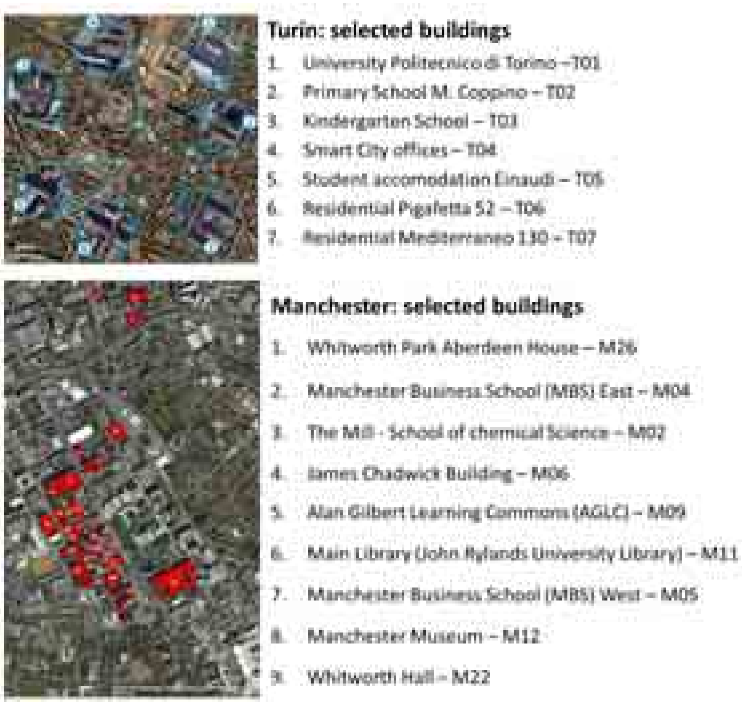


Figure 36 The selected buildings for the two DIMMER Pilots

For this thesis the attention is focused on the Turin Pilot but the same methodology was followed for either case study.

Ahead is synthetized a description of the workflow followed for the development of a DIM.

The development of a DIM starts from the archival document research to carried out to better know the construction typology of the different buildings. The most important documents are collected in order to create an historical database to link historical data with the 3D parametric models developed subsequently with Autodesk Revit, and ESRI ArcGIS 10. For this step the web picture platform Flickr was used as a data source to find and use the document easily as visible in the figure below.

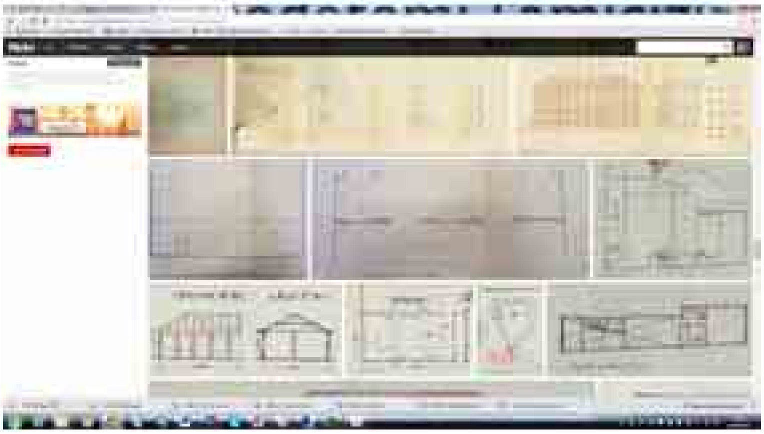


Figure 37 Visualization of archival documents collected using Flickr website

A district level, a GIS model of the district and the district heating network was developed as visible in the figure below.

Figure 38 GIS model in ESRI ArcGIS considering the construction period

Adding to this a district/network simulation level was created, composed by a compact model representing each building that interacts with the district heating network.

Then, a BIM model was developed and it was organized into different domain (architectural, mechanical, electrical, etc.) based on well-defined rules. After this a simplified model was generated. It collects geometric and alphanumeric information that can be used to analyze the main aspects of the building's performance, with a particular emphasis to energy efficient and sustainable design and management. For instance, using the sun's path, it is possible to create solar studies by placing the sun at any point along its daily path, and at any point along its analemma.

After the generation of a simplified parametric model, the model was enriched using simple objects like roof, wall, floors and opening, adding other information such as material and stratigraphy of wall, floor, roof, openings, etc. An example of BIM model is visible in the figure below. Moreover, BIM model of each building was developed taking into account a proper LOD for the district scale.

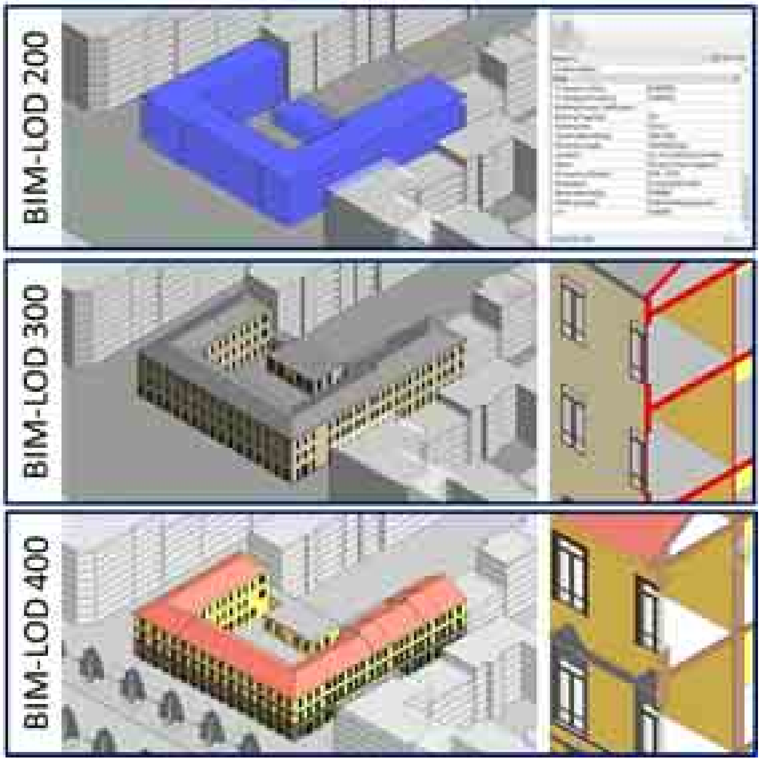


Figure 39 The BIM-LODs

For each BIM-LOD different information was added, starting from general information about the building such as the *Gross volume*, the *Gross floor area*, the *Gross surface area,* arriving to the stratigraphy and the *Physical and Thermal properties* of the materials applied to each component.

The second step is related to the generation of the EAM model using the BIM model. This is due to the fact that a proper model, with filtered information on the energy field, is needed for energy simulations. Through the interoperability process, the BIM model is imported in a simulation engine such as Energy Plus (open source) or ApacheSim (proprietary).

Currently, the software's market provides several Graphic User Interfaces (GUIs) such as Design Builder, Open Studio or IES Virtual Environment. They are user-friendly for the professional and for this reason several tests were investigated to find the best way to communicate data from a 3D parametric software to an energy software, considering the missing of data . In this case many standard exchange format were tested such as Industry Foundation Classes (IFC), green building eXtensible Markup Language (gbXML).

The IFC specification is developed and maintained by buildingSMART International as its "Data standard". Since IFC4 it is accepted as ISO 16739 standard. [21].

The gbXML open schema helps facilitate the transfer of building energy properties stored in BIM models to engineering analysis tools [22]

Below there is an example of the export step from Revit, using gbXML format.

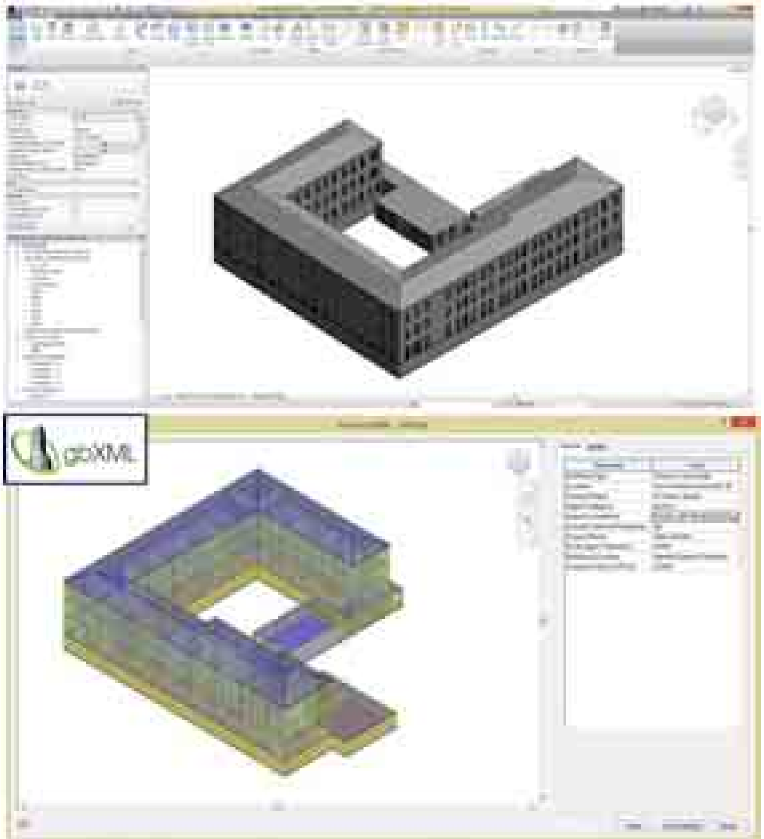


Figure 40 The Coppino EAM generation with gbXML

At building level, the energy demand of each building is monitored and stored in the DIMMER middleware. The energy reduction strategy needs to be checked at building level through the control of energy behavior of each building that takes place in the Building level simulation that is described by the charts below.

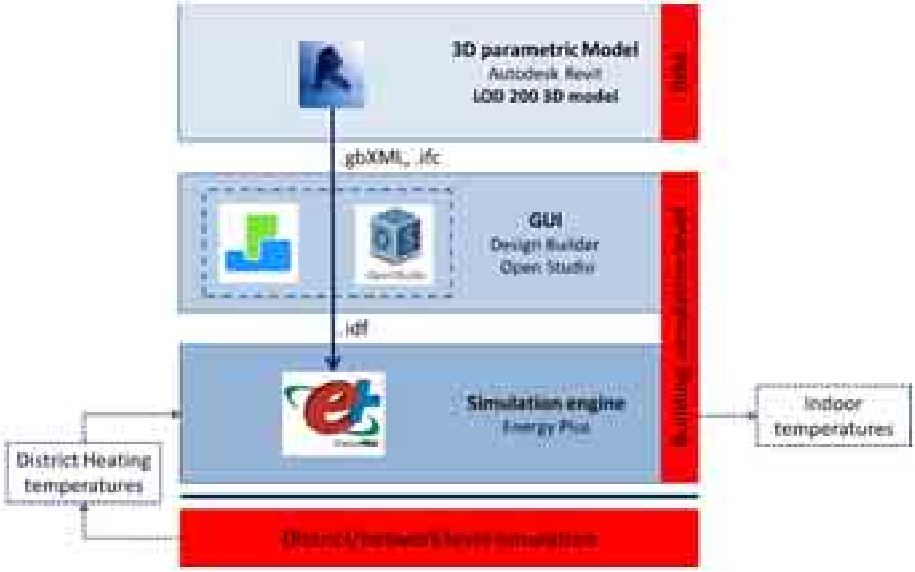


Figure 41 Interoperability process for Building simulation level

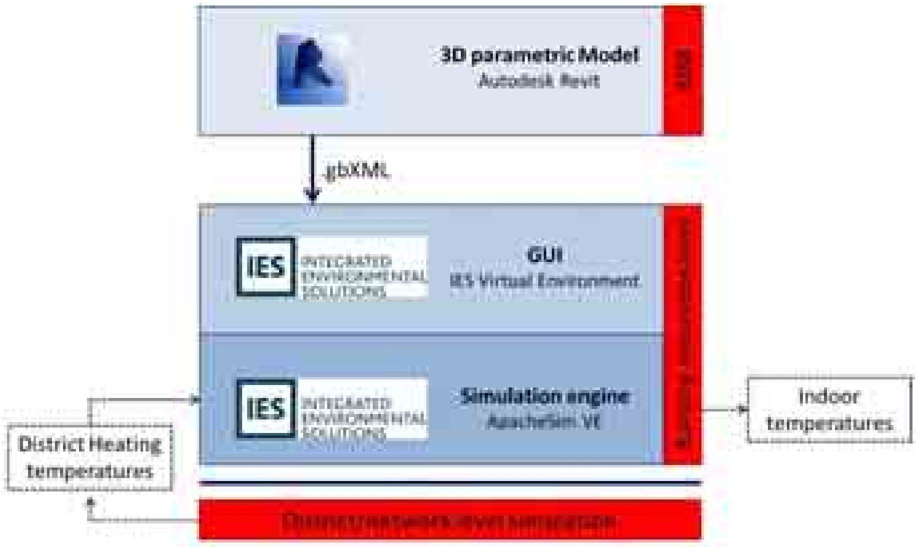
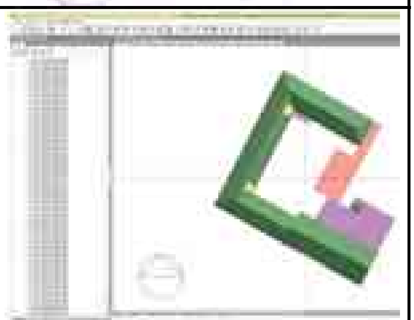


Figure 42 Interoperability methodology for Building simulation level using IES VE

In order to obtain the EAM, the BIM model is exported into different specific software through interoperability. Below there is an example of this step.

Figure 43 Interoperabilty tests using gbML and IFC formats in different software

This step is one of the most important point for the DIMMER project. The choice of the tools is related to the information life cycle. All domains, that work stand alone to create an iterative process, require a data flow. Although hypothetically this phase should be guarantee from standard formats exchange (e.g. IFC, .gbXML), there are still many problems due to loss of data rather than the failure to import data. Some interoperability errors are synthetized in In the table below.

INTEROPERABILITY ERRORS	
Errors description	Errors visualization
The roof is considered a shading and does not have roof properties.	
The orientation is correct but the external shading objects are missing.	

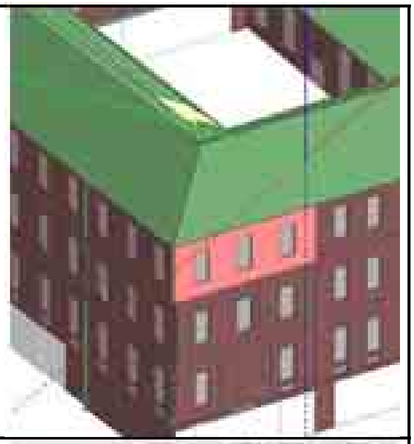
Some architectural components are missed or imported incorrectly and The window frame is missing. The glazing surface considered is not related to the architectural objects but the energy model settings present in the Revit environment.	
Sometimes the material characteristics are missed.	

Figure 44 Table of Interoperabilty errors

As said before. both the gbXML and ifc standards are supported by the software, however the application converts BIM objects in different ways missing several information.

Using gbXML the objects are transformed in analytical surfaces with some thermal properties, but room thermal characteristics are not linked to them.

Using ifc, the objects geometry looks like the source model, but in reality the object is synthesized into an empty box, only composed by an exterior shell that is useless for the energy simulation. For that reason ifc format was excluded from the other tests.

Through IES Virtual Environment that allows to model the building and the systems performing energy simulations using the ApacheSim Calculation engine. Since IES uses a not open source software, it has not been proposed as main software for the DIMMER project, but it was tested in same way. Several interoperability errors were observed. As an example, voids (as stair cases) and parts of the roofs or other construction elements such as curtain walls and columns were recognized with many geometrical errors, creating air gaps. Another limit of the software is related to the material properties of the walls that are correctly imported but to the external walls it is then possible to associate only one type of construction element.

As discussed so far shows that interoperability has to be tested continuously because the software are constantly updated and the version of the software this factor influences the goodness of this process.

In particular a crucial role is played by the exchange format. From the tests carried out arises that there is a considerable difference between the use of .ifc and .gbxml. It has been observed that even if the first one is a an opensource and widespread exchange format, the second one preserves more information about the data of the model (i.e. Room names, thermo-physical properties of the materials, geometrical data).

	Geometrical data	Material data	Thermal zone identification	data re-association velocity	Total score
Design Builder - gbxml	2	2	2	2	8
IES VE - gbxml	2	2	2	2	8
Open studio - gbxml	2	0	2	0	4
Open studio - ifc	1	1	0	0	2

Worst	0
Medium	1
Best	2

Figure 45 Score table for the energy software ranking

Figure xx reports a score table that classify the energy software based on Geometrical an Material data, Thermal zones, velocity of data re-association, evaluating the interoperable process in a scale from 0 to 2. As result, Design Builder and IES VE through gbXML reach the same score. However, it does not mean that are the same; in fact, the first one, compared to the second one, uses an open source simulation engine and for this reason it still seems to be the best choice for the project. Basing on this analysis, Design Builder was chosen.

The model was built knowing that, if necessary, further refinements of the model can be operated in a second time directly in Energy Plus. The commercial software Design Builder allows to manage the geometry of the building, the thermal properties of the construction elements and the configuration of the systems. The results that this software returns come from Energy Plus calculations run in background. EAM is organized by stories, each one subdivided in thermal zones that correspond to the real layout of the rooms.

Unfortunately, one of the limits of Interoperable process is the impossibility to import in the energy model the information of the systems modeled in the parametric software. As a consequence, in this first stage model, the heating system was modeled again in the GUI interface, imposing a supply thermal flow at a fixed flow rate and a fixed temperature. The temperatures of the thermal flow, exiting from the heat generator and reaching the final thermal units installed in the rooms, may be imposed in the model by setting a schedule. Ahead, it will be possible to compare the indoor simulated tempertartures with the monitored ones to validate the strategy of the energy saving at the district level. In this model there are no thermostats on purpose, so the temperature of the rooms is free to fluctuate not being influenced neither by the internal gains, nor by the solar gains and or by the fluctuation of the outdoor temperature.

EAM model is then completed in Design Builder considering the specific use of the building, adding the occupancy and activity profiles of the users, and editing the real characteristics of the heating system. The figure below shows the . Coppino simulation results obtained with the Energy Plus Simulation Engine.

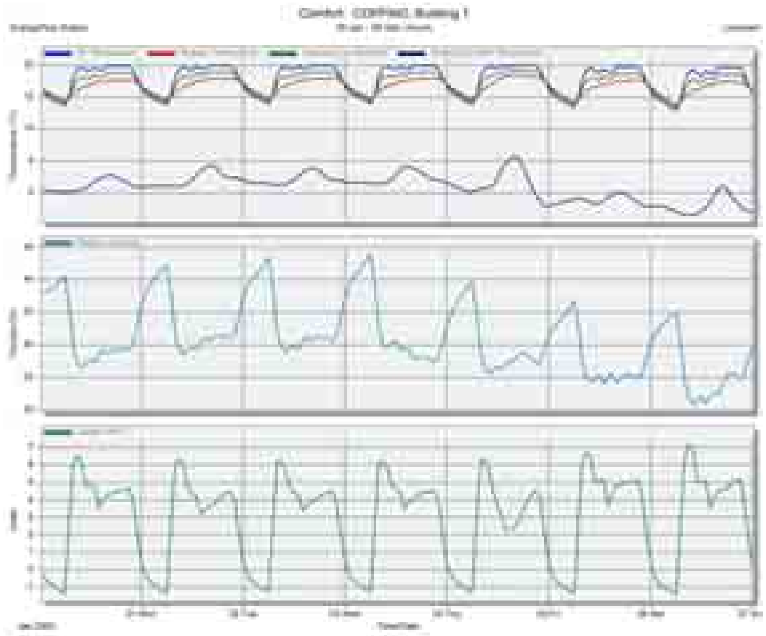


Figure 46 DesignBuilder simulation results of Coppino file

Design Builder permits to export the energy model in an .idf format that can be opened and edited directly into Energy Plus.

At the end of the Energy Plus simulations a set of data in .csv format is obtained. Then, this kind of data can be then easily elaborated in environments for numerical computation such as Matlab. In this way it is possible to make a comparisons between the district simulation level.

Finally, the EAM can run basing on the data of the building energy demand recorded in the district monitoring.

This model approximate the real world and it is used to simulate the buildings and the district energy behaviour. Obviously, although they are very close to reality, gaps are always present comparing them with the real case studies. For this reason, the EAMs can be validated comparing the indoor temperatures collected by the sensors installed on purpose for the DIMMER project in the pilot buildings with those obtained by the energy simulation.

At this point, the energy reduction strategies can be evaluated taking into account the profiles of indoor temperature. Sensor data collected and stored in the Middleware platform are extracted and plotted using Microsoft Excel as visible in figure below.

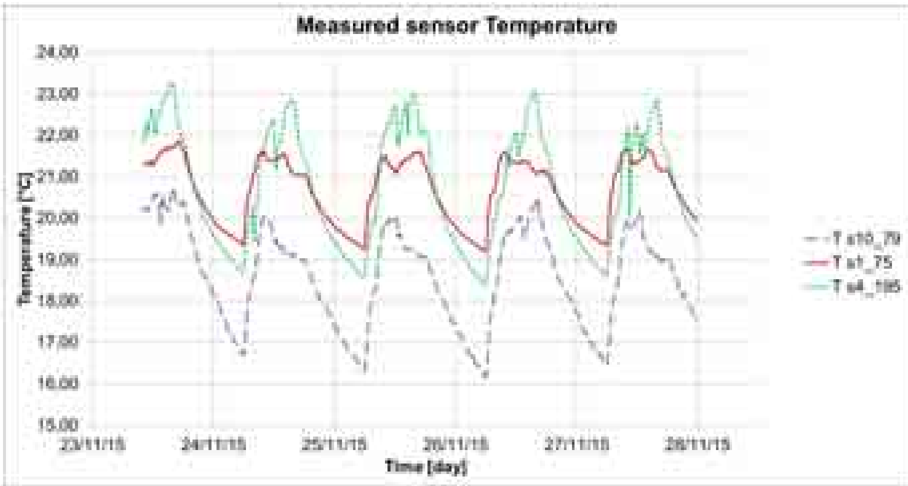


Figure 47 Charts of measured temperature by the sensors

Obviously, also in this step, sensors had detected different amount of data, generating some problem for the comparison among them and with the simulated data. Once overcame this problem, measured and simulated data were compared in order to validate the 3D parametric model with the reality concerning thermal comfort and energy consumption. Thanks to an iterative process, the validation model phase takes place comparing the model to real energy behaviour in order to tune the model step by step. What said before is described by the chart below.

Figure 48 BIM use in the DIMMER project

So, the BIM model provides different information for several uses such as the validation of the DIMMER strategy that is mainly based on the energy saving at district level through the adoption of innovative technologies that optimize the data management. Adding to this at building level, BIM model allows professionals to simulate different scenarios of building refurbishment that can be evaluated considering the Return of Investment (ROI). For example, a real estate manager could use BIM model and the DIMMER platform to simulate a certain building renovation checking the energy usage, the thermal comfort and the ROI, according to his needs.

In term of data standardization, through the BIM model it is possible to generate accurate materials and objects libraries related to a suitable building typology that can be used by different professionals for their needs. So, it is possible affirm that a method for continual data cross-check and update in order to assure that the integrated model is as accurate as possible for any use (energy performance, thermal comfort, lighting and management) was developed.

Usually, BIM and GIS operate in seemingly separate spheres but each has value to the other if they could exchange data effectively. The parametric models created with both BIM and GIS have different characteristics because they refer to different information. The connection of both environments should be done exploiting both geometric and alphanumeric information.

The integration of the model must consolidate the data flow in order to guarantee an iterative process, where the different domains exchange data in a loop, which static and dynamic data update themselves into an algorithmic process. Such as an example, if data sensors could influence on data coming from parametric model used for energy analysis, on the other hand, results coming from energy analysis could interact with parametric model in order to generate changes. This brings about interesting considerations on the standards to be used in the integrated model in order to optimize the BIM process developing a smart building and consequently a smart district.

Currently the term ‘smart buildings’ describes a suite of technologies used to make the design, construction and operation of buildings more efficient, applicable to both existing and new-build properties. These might include BMS that run lighting, heating and cooling systems according to occupants’ needs or software that switches off all PCs and monitors after everyone has gone home. Of course, BMS data can be used to identify additional opportunities for efficiency improvements.

Adding to this, a smart building need to take into account more properties than what said before:

- the method used to make the building, starting from the design phase arriving to management phase (following BIM idea);
- people who live in each building, especially their awareness regarding to the energy efficiency in private and public spaces. This phenomenon can occur in different ways, through the data visualization using VR and AR.

Currently, several definition of AR are present such as:

- […]AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world [23];
- We define Augmented Reality (AR) as a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it. [24]

Perhaps the better definition is based on the Reality-Virtuality (RV) Continuum where is described the Mixed Reality (MR) as one in which real world and virtual world objects are presented together within a single display, that is, anywhere between the extrema of the RV continuum. Augmented Reality allows you to view directly a particular scenario real enriching data with virtual, as if overlapped additional layers, for example, two-dimensional elements, three-dimensional, video, animations and sounds [...]. [25] [26].

So, through a gamification approach AR can play a key role in the education field in order to transmit knowledge to young generations and to increase people awareness, expecially on energy saving. The creation of games with AR able to improve consciousness in the young generation aimed at disseminate the results of the DIMMER European project following the example of Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) that focuses on energy saving at building level for public buildings. In that case a SEEMPubSdicE game was developed using AR that amplified the sensory perceptions of the players and allowed the possibility to interact with virtual characters of the project: wireless sensors, temperature sensors, light bulbs, etc.

Figure 49 The SEEMPubSdicE game

Related to the DIMMER project, the game conception has been reached by the collaboration between Politecnico di Torino and Primo Liceo Artistico Statale, as well as the staging of a theatrical show about these issues. In this way a connection between university and high school has been established about current research topics and the uses of new technologies for pedagogical purposes. AR was investigated in order to promote an interactive game for children in which the differences between good and bad practices in terms of sustainability and energy efficiency are discussed. It indeed turns out to be an effective means of communication with immediate impact on children learning.

In fact, the introduction of technology in education is becoming an essential support to engage and motivate them about specific topics [27].

In order to disseminate the methodology about the DIMMER 3D parametric models and sensors networks, different channels of communication have been exploited, including games and theatrical shows for children and young students (8-16 years old), who will be the future "Smart Users". The goal is to improve awareness in a funny way, easy to be learned in everyday life. In order to enhance education in an optimal way, AR and gamification have been combined for the creation of two games such as "ECO card" game and "The DIMMER'S Wheel" and the "ToBeSmart" show focused on energy saving.

The application of the behavioural change among the young generation can be possible by introducing innovative technologies in the educational sector and by connecting the latter to the research field. Nowadays, teenagers use technology in a very intuitive manner. This approach simplifies their assimilation of concepts and allows them to have fun while learning about energy usage. As a result, the students of Primo Liceo Artistico have transferred the classes and workshops contents into the children's cards game and the theatrical show described before. Energy saving strategies and air pollution reduction have been promoted at different levels of awareness in a simple and friendly mode to make all generations smarter.

For the case study this purpose has been reached by involving the students in the creation of 3D models and their related AR markers. The game has been conceived by using simple and not expensive technologies, as shown in Figure below.

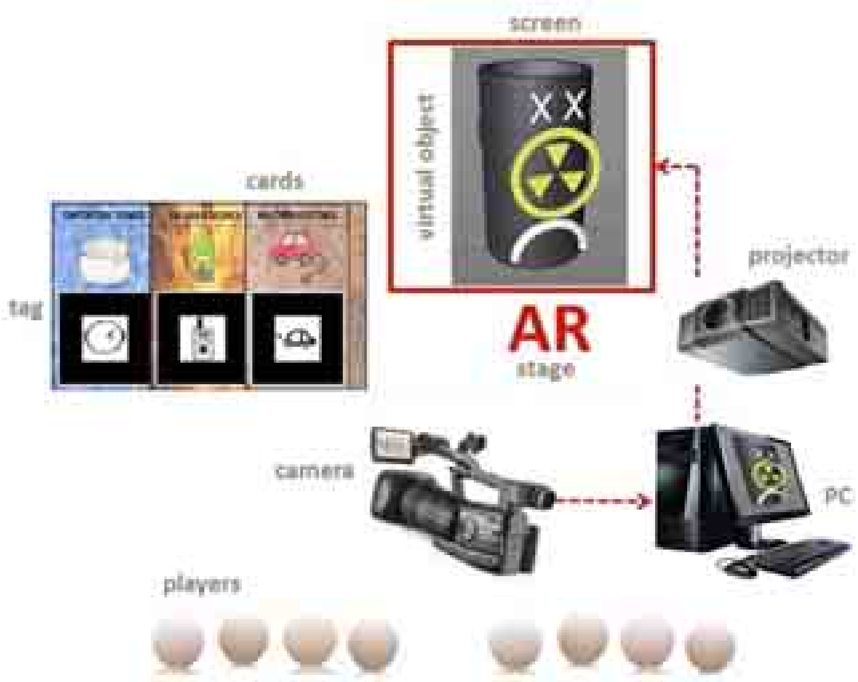


Figure 50 Example of the use of the proposed technologies for a game

The base-components which are necessary to make the whole process work are:

- Hardware: personal computer, monitor or display screen, camera;
- Software: app or software running locally;
- Markers: physical objects or places where the real and virtual environments are fused together.

The camera gets the information represented by each marker and by means of a specific software (AR Media) each tag is coupled with its respective 3D model realized with Autodesk 3ds Max Design. The Mixed Reality is then visualized on a display screen.

The main point of these games is the importance of clean energy generation, so the winner is the one who saves more energy and not the one who picks up the higher number of cards. In this way children learn easily to think to a long-term future and realize immediately the value of taking good practices instead of bad ones referring to their behavior towards the environment.

In both the games awareness in terms of sustainability is always present in addition to the perspective of winning by saving clean energy and refuting pollution, some advices or reminders are explained at the bottom of ‘energy element’ cards or in the games’ rules , in order to integrate learning at every phase of the game. The key element that allows to maximize the desire effect of children’s consciousness is the use of AR by adding markers to the cards and to the wheel that are located in specific coloured cards and sectors of the wheel. As visible in the figure above, the basic idea consists in the generation of a link between a 3D model with a marker that is customized in order to recognize easily the kind of energy element for the “ECO card” game, and the number of the Turin building case studies for “The DIMMER’S Wheel”. While playing the game, a video camera gets the markers of the dropped cards, making 3D models appear on the screen according to the connection previously explained.

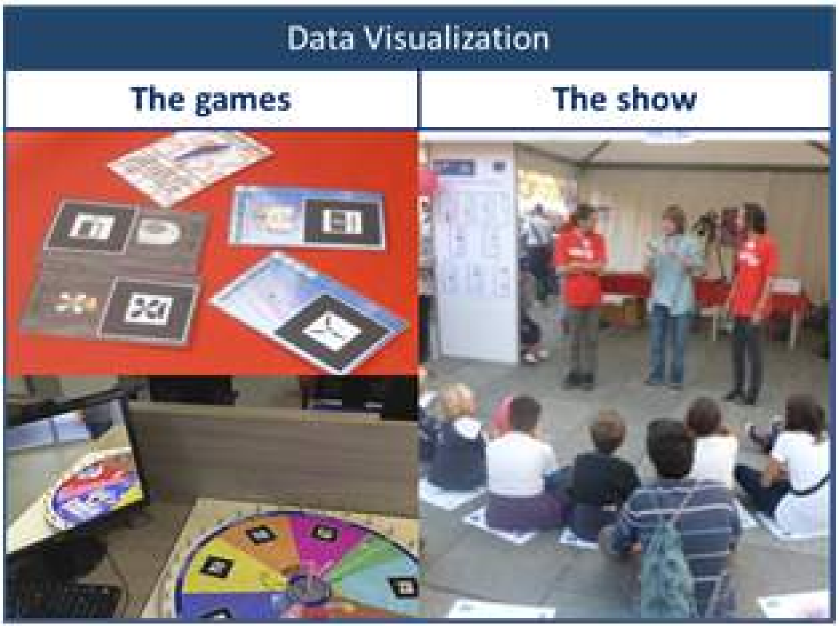


Figure 51 The games and the show executed in the 2014 Researchers’ Night

AR has turned out to be a relevant achievement for the development of smart cities when used for dissemination, becoming part of a complex process that requires an interdisciplinary strategy of all parties involved, allowing for a simple and optimal way to disseminate

6.2.1 List of relative papers published

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- Osello A., **Del Giudice M.**, Rapetti N., District Information Models. The DIMMER project: BIM tools for the urban scale. *Under review*

- Rapetti N., **Del Giudice M.**, Osello A., From District Information Model(DIM) to Energy Analysis Model (EAM) via Interoperability. In ECPPM 2016. Abstract submitted

- **Del Giudice M.**, Rapetti N., Osello A, Ugliotti F. M., Acquaviva A., Patti E., Brundu F. G., BIM and interoperability for data management and visualization at urban scale, In MSSCE 2016. Abstract submitted

- **Del Giudice M.**, Il GIS per la gestione dei dati alla scala urbana/edilizia. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 258-267, 2015. ISBN 978-88-579-0478-8.

- **Del Giudice M.**, L'utilizzo della AR per la responsabilizzazione degli utenti con un approccio al gioco. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 286-291, 2015. ISBN 978-88-579-0478-8.

- Anna Osello; Andrea Acquaviva; Daniele Dalmasso; David Erba; **Matteo Del Giudice**; Enrico Macii; Edoardo Patti, BIM and Interoperability for Cultural Heritage through ICT. In: Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modeling, and Representation / Stefano Brusaporci, 2015. IGI Global, pp. 281-298. ISBN 1466683791

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- Osello A., **Del Giudice M.**, Patti E., BIM and GIS for district modeling In: ECPPM 2014, 17 – 19 September 2014, Wien, Austria.
- Vincenzo Corrado, Alfonso Capozzoli, Anna Osello, **Matteo Del Giudice**, Davide Bavastro, Laura Rietto, Elisa Vigliani, From the architectural model to the energy model: the use of BIM for the evaluation of the energy performance of buildings. In: BSO 2014, 23 – 24 June 2014, UCL, London, UK.
- Osello A., Dalmasso D., **Del Giudice M.**, Erba D., Ugliotti F.M., Patti E., Davardoust S., Information interoperability and interdisciplinarity: the BIM approach from SEEMPubS project to DIMMER project, In: Territorio Italia, Agenzia delle Entrate, ISSN 2240-7707. 2013.
- Chiara Aghemo, Laura Blaso, Daniele Dalmasso, David Erba, **Matteo Del Giudice**, Anna Osello, Giovanni Fracastoro, Anna Pellegrino, Pablo Ruffino, Interoperability between building information models and software for lighting analysis. In BSA 2013, Bozen, Italy, Jan30 - 31, Feb 1 2013.
- Osello A., Acquaviva A., Pellegrino A., Candelari E., Chiesa G., Dalmasso D., **Del Giudice M.**, Erba D., Mannanova K., MD Rian I., Noussan M., Patti E., Pippione M., Serra A., Shaghayegh R., Tomasi R., Multidisciplinary team activity using BIM and interoperability. A PhD course experience at Politecnico di Torino. In: Le vie dei Mercanti XI Forum Internazionale di Studi, Aversa-Capri, 13-15 June, 2013. ISBN: 9788865422908.
- **Del Giudice M.**, Boido C, Caso studio 12. L'impostazione di un database per l'interpretazione critica dei dati In: Osello A., Il futuro del disegno con il BIM per ingegneri e architetti, ed. Dario Flaccovio Editore, Palermo, pp. 175-184, Maggio 2012.
- Boido C., **Del Giudice M.**, Dalmasso D., Osello A., BIM and interoperability: A database to collect data errors and solutions. In: ECPPM 2012, Reykjavik, July 24-27, 2012.
- Acquaviva A., Blaso L., Dalmasso D., **Del Giudice M.**, Fracastoro G., Lo Verso V., Macii E., Osello A., Pace A., Patti E., Pellegrino A., Piumatti P., From historical buildings to smart buildings via middleware and interoperability. In: International Conference on Computing and Building

Engineering, ICCCBE2012, Moscow, June 27-29, 2012. ISBN: 9785930938814.

- Acquaviva A., Blaso L., Dalmasso D., **Del Giudice M.**, Fracastoro G., Lo Verso V.R.M., Macii E., Osello A., Patti E., Pellegrino A., Piumatti P., Energy consumption management using CAFM and BIM. In: Le vie dei Mercanti X Forum Internazionale di Studi, Aversa-Capri, May 31, June 1-2, 2012. pp. 213-222. ISBN: 9788865421284.

6.3 BIM highrises maintenance

This chapter aims to show a multidisciplinary methodology for the refurbishment of Malaysian existing buildings considering both high rises and historical buildings such as traditional malaysian houses. From this point of view

Figure 52 General view of the malaysian architectural heritage

1926 Heritage Hotel case study

The structure was built in 1926, it served as a home to the British colonial officers and local administrators and currently, it has been refurbished into a Heritage Hotel.

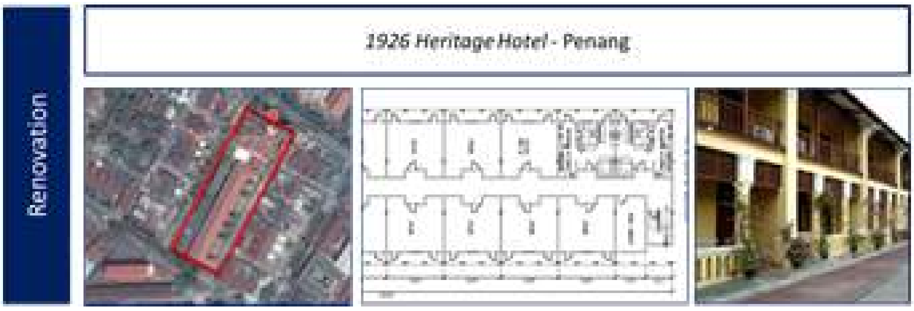

Figure 53 General view of 1926 Heritage Hotel case study

The aim of this subject is focused on the refurbishment of the buildings through the development of a BIM model and the EAM model for Overall Thermal Trasmission Value (OTTV) calculation.

Taking into account the whole building process (Figure 5)it is possible to affirm that the survey phase is essential in order to know the original conditions of the asset to be redeveloped.

In order to optimize the data management, a data hierarchy was established to easily and accurately extract information from a BIM model, obtaining the necessary inputs for specific analysis as thermal and lighting calculations. For this reason, the representation of the parametric model data in relation to the LODs project becomes particularly important.

The followed methodology is described by the figure below.

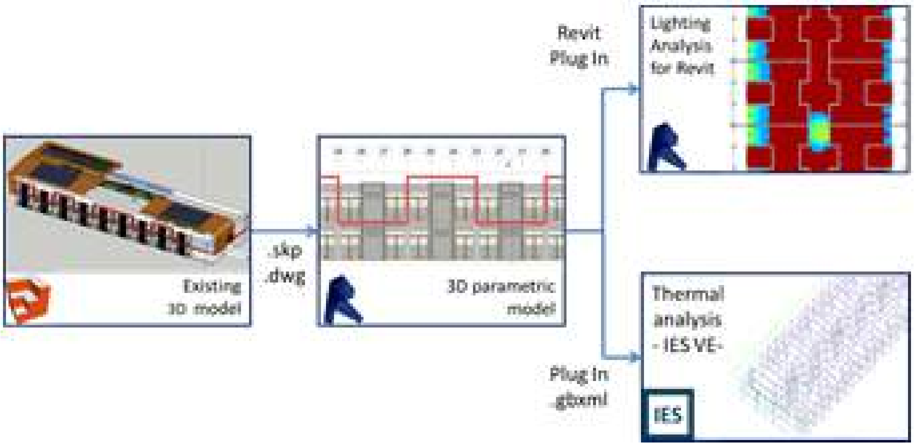

Figure 54 Interoperabilty process for Daylighting analysis and OTTV calculation

The first step considered was the acquisition of archival data. These data were essential to analyze the building in its entirety. From the sources analyzed, information has been obtained concerning the type of construction used and the construction details. The structure is composed of precast elements such as columns and beams. The second phase is the development of the parametric model. This step started analyzing and importing into Revit a Google SketchUp 3D model. Once imported the 3D model into Revit the association of the thermal properties to the objects was done.

Then, in the simulation step two software were tested: IES Virtual environment and Lighting analysis for Revit” plug-in.

In the first case, the model was exported using gbxml format for the OTTV calculation. Instead, through the Revit plug in the model was simulated directly in the Revit environment. It is clear that in the first case several data was missed comparing with the second one. However, the Revit plug in provides a preliminary lighting results, while IES VE is able to perform specific calculations. An example of the obtained results is visible in the pictures below.

Figure 55 Results of OTTV calculation and Daylighting analysis

For these calculation the Room command was used in order to optimize the interoperability process. Moreover, the model has been correctly oriented in accordance with the geographical coordinates and the cardinal axes, modeling the shading elements able to influence the test.

The obtained OTTV values were validated by a manual calculation performed using Microsoft excel. The two values are slightly different, due to the geometrical errors that occur during the export/import process. Obviously the model needs to be implemented in order to improve the energy analysis, avoiding errors related to export/import steps.

It is evident this case study highlights the value interoperability relating to thermal simulation. Through the interoperable process it is possible run simulations many times speeding up the process and obtaining good results also in term of time and cost saving.

University Kuala Lumpur city campus building,

This paragraph aims to show a multidisciplinary methodology for the refurbishment of existing buildings such as high rises like the UniKL city campus, focusing on the maintenance and the space management for the development of a smart city.

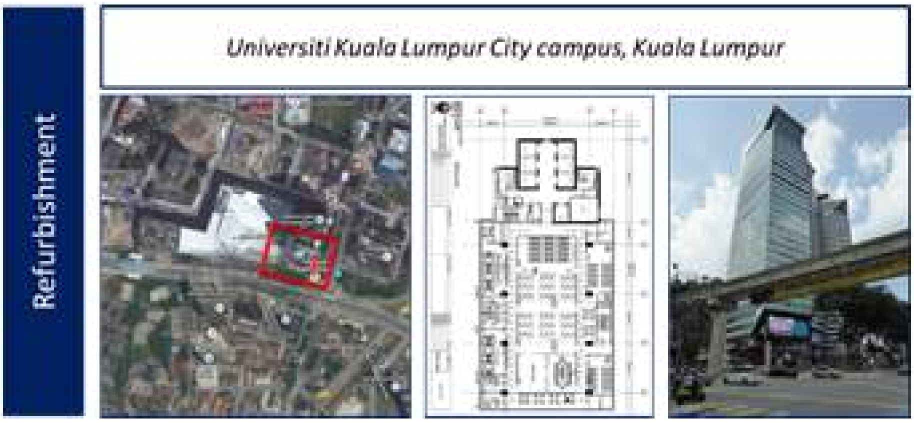

Figure 56 General view of 1926 UniKL city campus case study

As this high-rise is considered an university building where every day many students come there to follow lessons, issues such as energy saving, daylighting, facility management need to be investigated for the development of a smart building. Referring to the SEEMPubS European project, which was focused on the reduction of energy usage and $C0_2$ footprint in existing public buildings and spaces without significant construction works, the creation of a BIM model can be one of the most important steps for the smart refurbishment of the building.

As said in the previous chapters, the development of a 3D parametric model about an existing building requires several information coming from different sources, such as archival research documents, different kinds of survey, CAD drawings, pictures, etc. Merging this kind of data in one dataset is a research challenge and interoperability become very important in term of data exchange. This topic is fundamental also in term of data visualization: the use of AR has been tested with different applications to display data coming from the BIM model. In this way should be possible to visualize all data filled in a graphical database and to extract them in different ways generating a smart data management. The development of a BIM model started from the Data Collection step that is visible in the figure below.

Figure 57 Data Collection step for UniKL city campus

It was characterized by a photographic survey, the acquisition of the construction drawings and the analysis of the existing 3D models provided by Google Earth.

For this project a points cloud survey was developed starting from a photographic survey that it was done using a camera with GPS integrated.

A .KML format file was generated and it was visualized on Google Earth. In this way checking the survey was easier to discover places where the pictures were done and where more photos are needed. Adding to this, another survey with drone was developed in order to collect more data for the development of the points clouds for the upper part of the high rise. The DJI Phantom drone was used for the flight and a GoPro camera has been connected with it for taking videos from which the images were extracted.

The points cloud generation was done processing these pictures with different software applications such as Autodesk Recap 360 and Agisoft Photoscan that differ in term of data processing. The first one is very user friendly and is web based. The second is more accurate in term of topographic data and points cloud density, but requires good hardware because it works on the local laptop. Concerning the archival research, overall 128 CAD drawings were found related to the architectural, structural and system part of the building.

The analysis of the various sources twisted with the photographic survey has provided the ability to verify the quality of the information from older documents or provenance uncertain.

Then the modelling step started from the BIM standard investigation in the south east Asian region.

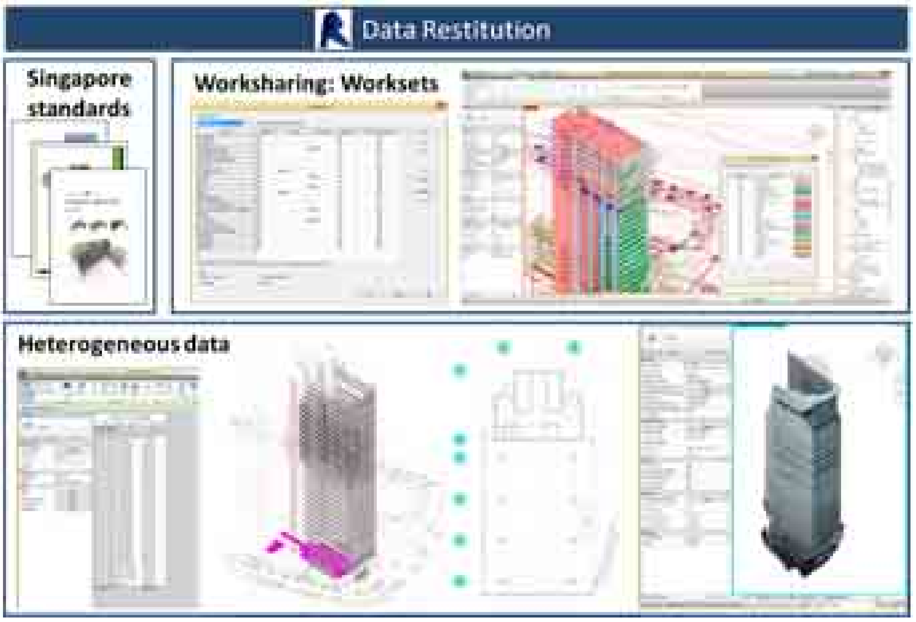

Figure 58 Data Restitution step for the creation of BIM model

Since there is no BIM standard for the AEC malaysian Industry, Singapore BIM standard was investigated and adopted for the development of a BIM model.

Currently, the Construction and Real Estate Network (CoRENet) is the main organization involved in the development and implementation of BIM for government project. Through the use of IT, the purpose of CoRENet is to provide the necessary infrastructure for the fast and seamless exchange of information among all parties in building projects, as well as the regulatory authorities [2].

The Singapore BIM standard was then customized considering the Malaysian building industry.

The BIM model was developed as basis for design and data exchange: the Worksets tool was used to simulate the work sharing data in a professional work team as visible below in Figure 58.

The creation of local models connected with only one central model allows the professionals to visualize in real time the project, checking the interferences between different components. So, data coming from different sources were inserted in Revit environment in different worksets in order to display clearly the interferences, making the file lighter in term of megabyte and easier for the management of the BIM objects.

As the development of the BIM model of UniKL building is focused on maintenance, the space management and the lighting simulation a proper rank of LODs was followed, referring to the AIA LOD requirements [12]. For this project, LODs have been investigated, trying to enrich the protocol form inserting the LOD 000 where there is just the point cloud survey which is able to give geometrical and photographic information. Currently, LODs requirements are referred to new buildings, so for this work new LOD range has been studied and it is visible in figure below

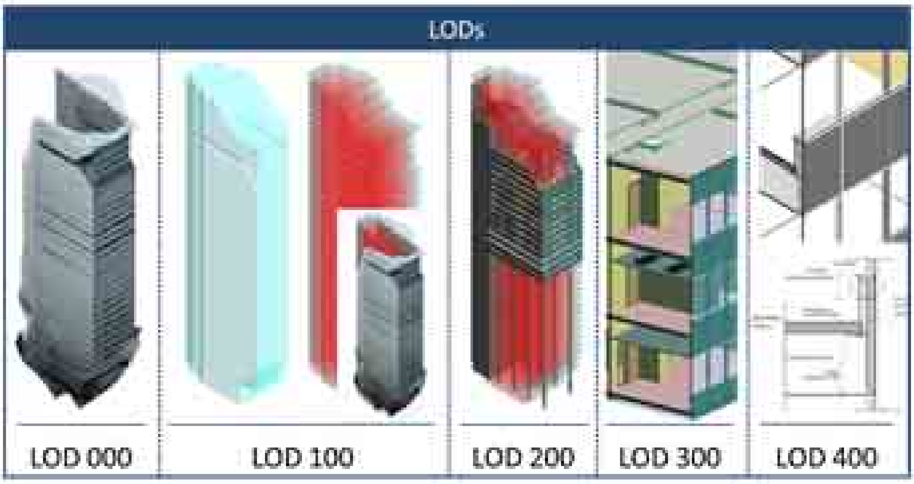

Figure 59 The BIM-LODs for existing buildings

Concluded the modelling step the 3D parametric model was enriched with alphanumerical information related to the *Room* that have been used for the volume and the area calculations.

Adding to this project parameters such as, *Room_Use*, *Room_Category* and *Room_Typology*, were inserted to customize these objects, enriching the model with information coming from the facility manager.

For this reason a key schedule was created in order to optimize the filling of the fields regarding Facility Management (FM).

Figure 60 Visualization of space management related to UniKL

The addition of these parameters highlights the ability of BIM to answer at complex queries, providing to add graphical information, colouring the spaces on the base of the specific needs characterizing the property of each view.

Through the point of view of a facility manager it is essential manage data, grouping it in several way depending on his objectives, such as the spaces management and the related facilities, the scheduled maintenance, etc. For this reason, the use of a graphical database such as a BIM model allows the professional to manipulate data in the better way, ensuring a high quality of results.

One of the key factors due to the integration between BIM and FM should be that many of the typical FM data (spaces, areas, equipments, architectural detail, etc.) can be obtained directly from the BIM without the need to be refilled in an FM system. BIM has to be organized to support, exploit and appreciate this information providing to facility managers:

- a sort of manual able to unify the basic information;
- an accurate model (architectural, structural and system) rich of information related to the elements that are part of the building appropriately selected, described, represented, and if necessary simplified;
- a valid support for analysis, especially those related to the energy and sustainability fields, but also to structural field;
- an instrument for the planning of different scenarios or for the environments safety control. [28]

Considering the UniKL building, at the beginning a general study for the spaces optimization was investigated in term of square meter. The results were charted using Excel, and underline that the major part of square meter belongs to the *Corridor*, followed by the *Classroom* and the *Lecturer rooms.* The chart below is related to 16th until 26th floor of UniKL building.

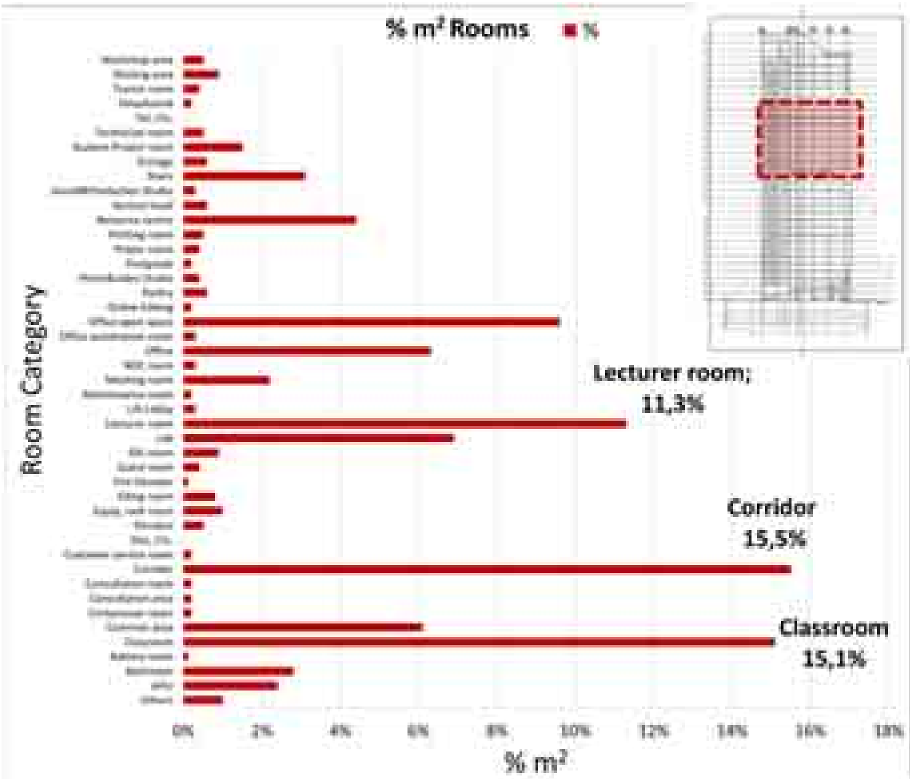

Figure 61 Chart of the percentage of m² grouped for Room category

Regardless of the results obtained, it is evident that the goodness of this method is highlighted by the fact that for this calculation were considered 262 spaces grouped into 45 Room's categories.

Considering the spaces in a more specific way, they can be organized following the international standard Building Owners and Managers Association (BOMA). (ANSI/BOMA Requirement, document 265.1-1996: Standard Method for Measuring Floor Area in Office Building, updated in 2010) [29].

Below different charts describe how the same spaces can be grouped in different ways on the base of the parameters explained previously.

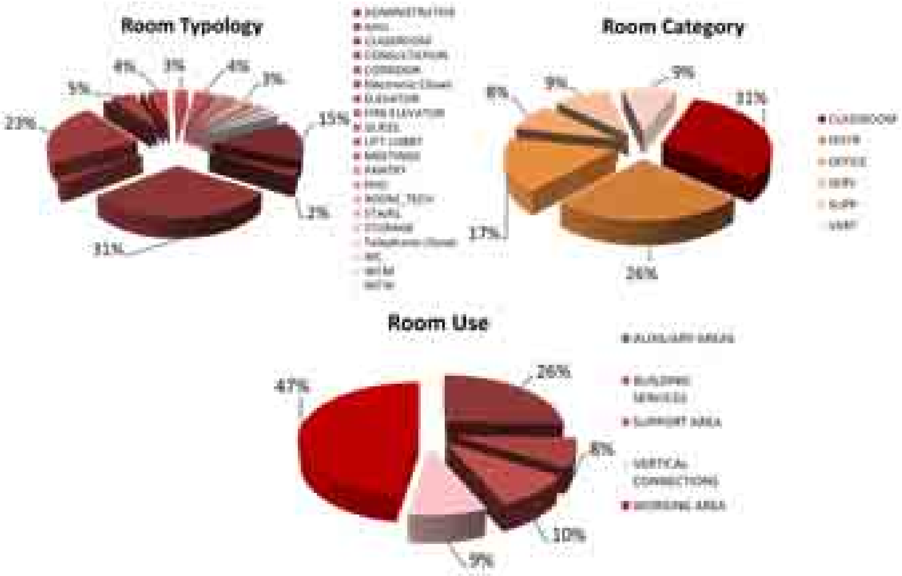

Figure 62 Pie Charts about UniKL spaces

Thanks to the organization of the spaces that are grouped by, Working areas, Support areas, Auxiliary areas, Building services, Vertical connections and External areas, the Efficiency Index was calculated. It represents a first indicator to describe the best exploitation of a rented area and is generated by the percentage ratio between the Net Usable Area (NUA) and the Net Lettable Area (NLA). In this case the Efficiency Index resulted 63% which reveals the possibility of improving the space management of the UniKL city campus.

Moreover, the BIM model was tested as a validation tool to check the minimum dimension of bathrooms using *Conditional Instruction*, filling the field about the malaysian law requirements [30]. The validation consisted on the use of the *Conditional Instruction* tool that can automate the comparison between the data of the model and the requirements.

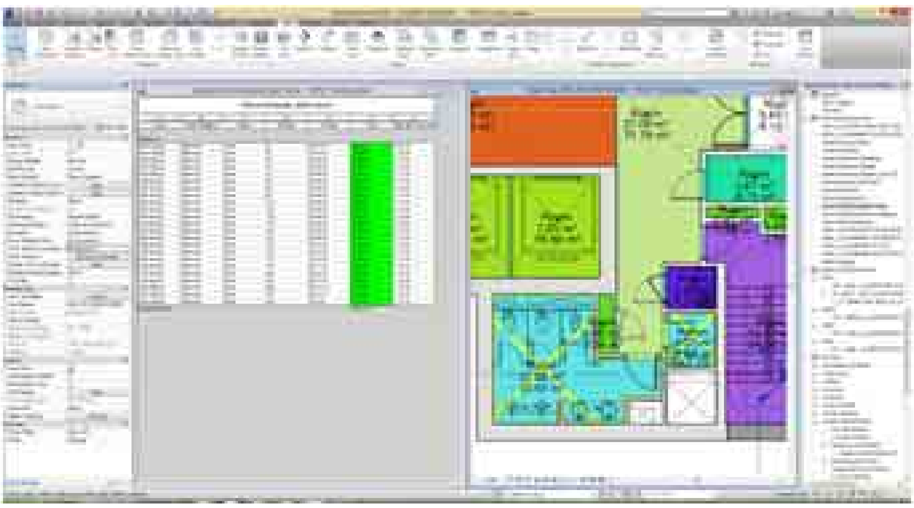

Figure 63 Conditional instruction for the control of the rooms

If the rule is respected the field has the property to became green coloured as visible in the figure above. In this way should be easy for the professional to identify Rooms that respect the law requirements. Currently, this condition is available only in the schedule's view, and to simplify the visualization in the plant view *Filters* on the Rooms were created In term of architectural details the model was enriched with details views. This quality permitted to discover the capability of the model to reach a very high levels of precision in terms of detail representation and of alphanumeric data management. This kind of development corresponds to the AIA LOD 400, where each model element is graphically represented within the model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the model element [12].

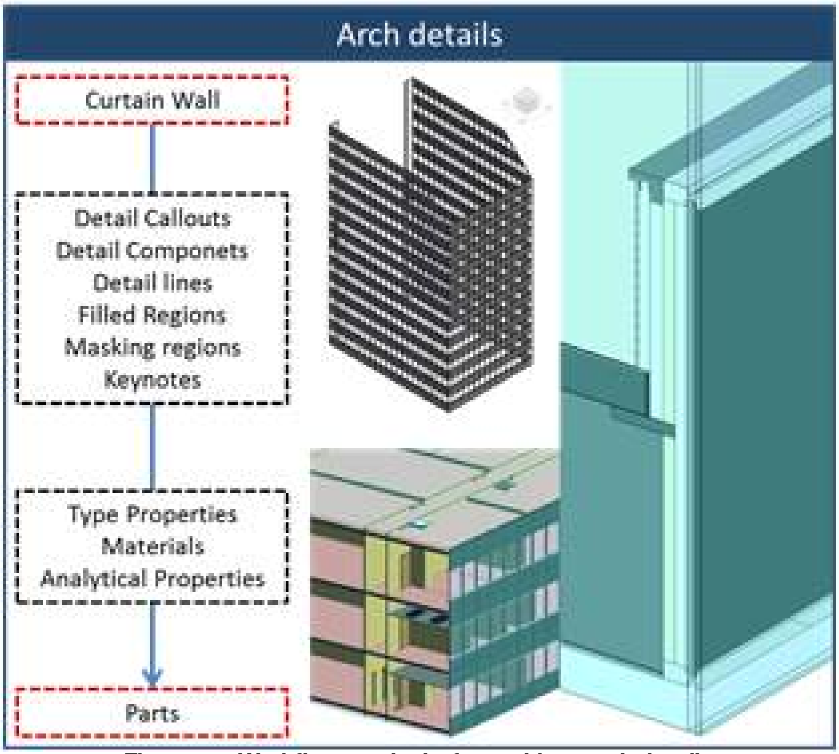

Figure 64 Workflow analysis for architectural details

In this way it was possible to query the model/database to discover the take-off quantity of materials discovering for example the quantity of Insulation.

Creating detail drawings using Revit Architecture involves a combination of live views generated from the building model and overlaid two-dimensional embellishments and notes. This was possible using *Callout* view. Unlike the other Revit Architecture views, all drafting components appear only in the view (Callout) to which they are added. For a professional who uses Revit without focusing on detailing, it seems that to create a detail is like creating a simple section view in the appropriate area of the model and opening the resulting view should see an automatically generated detail direct from the BIM model. The reality is that it is a rare instance when all of the specific components required by a successful construction detail can be effectively modelled in all aspects and thus “built into” the overall building model. In most cases, the effort required to model the small scale components shown in the typical construction detail would prove impractical and would generate a very large and unwieldy model. Therefore, while theoretically a fully embellished and detailed building model capable of generating all large scale views and details is seen by some as the ultimate goal, currently the means to do so do not justify the end. To keep the size of our models reasonable and to avoid spending additional and often unnecessary effort modeling every bolt screw and piece of flashing, the strategy to detailing in Revit is instead a hybrid approach. The professional will be able to start the process with a cut from the model. This live view of the model portrayed at the scale of the detail, gives him a starting point upon which to add detail components and other view specific elements and annotations. By separating a detail into both live model elements and view-specific embellishments, it achieves the best of both worlds: he has an underlay that remains live and changes automatically with the overall building model and he has all of the additional data required to convey design intent occurring only on the specific detail view, thus saving on overhead and unnecessary modeling effort [31].

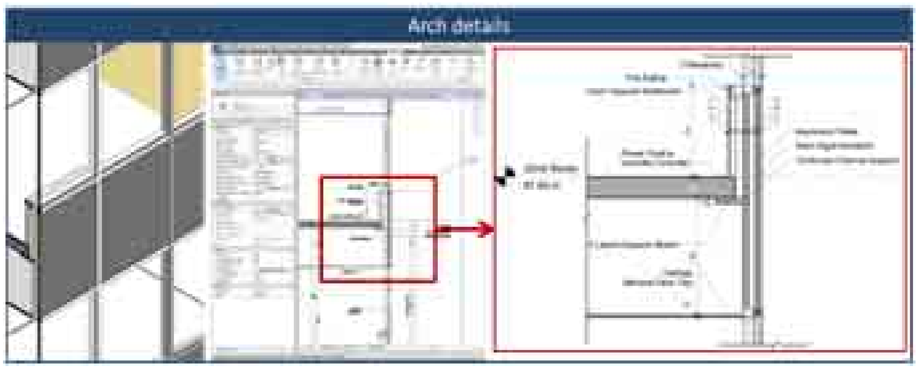

Figure 65 A Callout view for the architectural detail

As an example, the detail of the connector of curtain wall and the floor was modelled creating a *Callout* view, adding detail elements (Figure 65). To understand the correspondance of the name of the view with the name of the sheet was created a sheet with parameter text in order to automate the naming of the sheet’s process. As said above, each component is enriched with the thermal properties. Each layer of the stratigraphy was implemented, associating the appropriate material with the relative thermal properties, such as the thermal insulation as visible in the figure below. Once finished the modelling step the Simulation test step started. A daylighting analysis was investigated using the Revit plug- in «Lighting Analysis for Revit-LEED», as visible in the figure below.

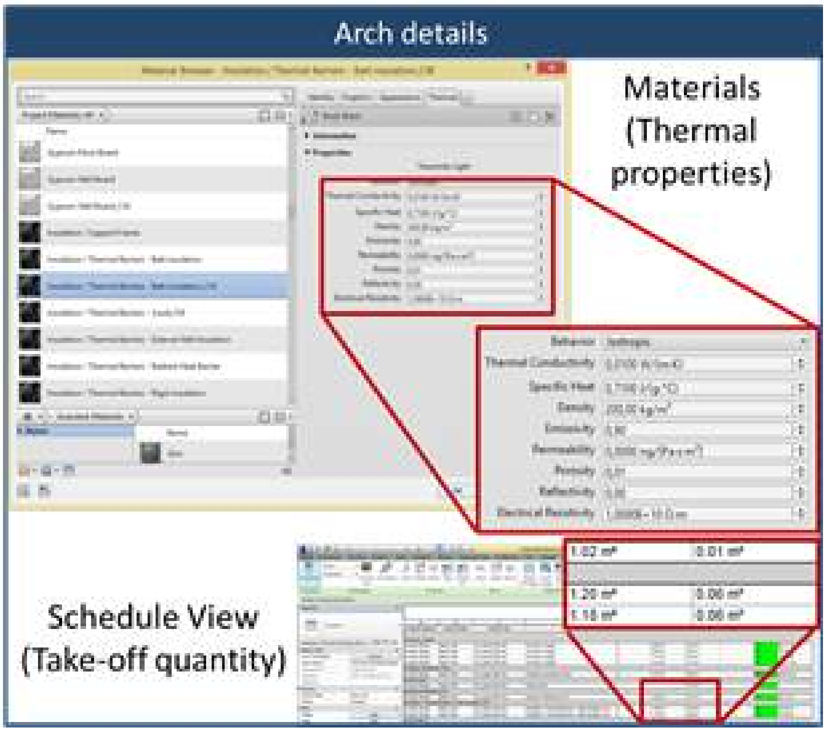

Figure 66 Thermal properties settings and take-off quantities analysis

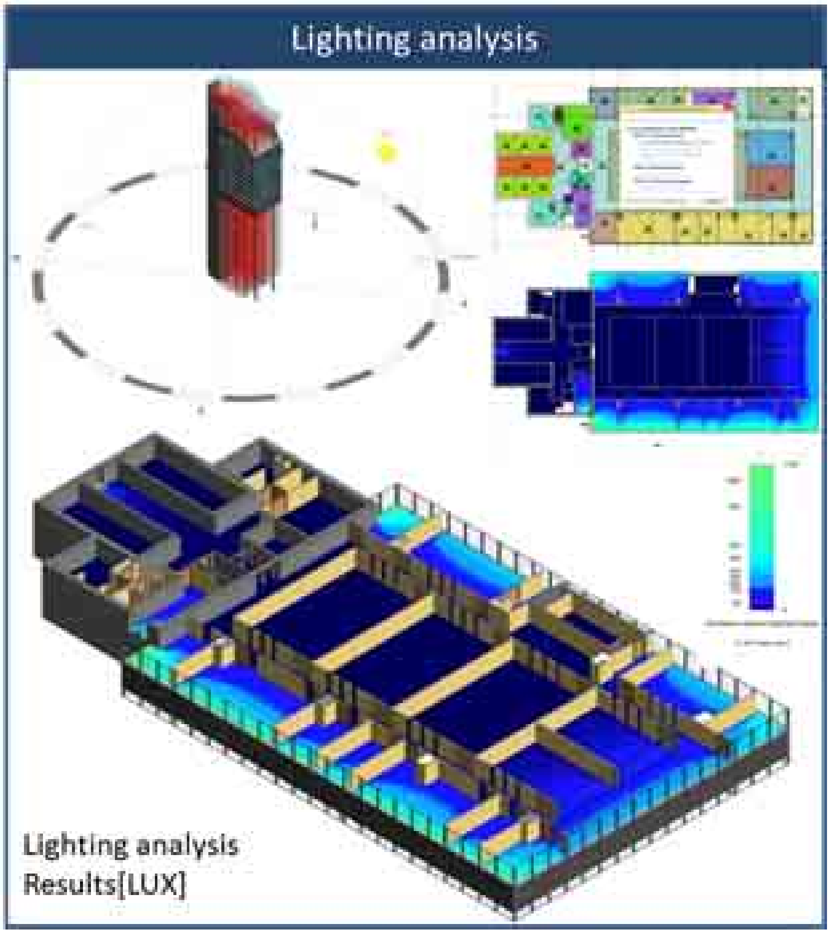

Figure 67 Lighting analysis using Revit Plug in

For this test the location of the Building was set. Also for this test the Room tool was necessary. From the test is visible the LEED Evaluation and also the LUX values in the plan view and in the 3D view. In this way, the professional, who needs to maintain the building, should be facilitated to discover how can optimize spaces in order to use natural light instead of artificial light, refurbishing the building in a green building. Then, Data Visualization step was investigated using AR. As UniKL is a university, the visualization of the model has been thought also starting from the point of view of the students. For this work was tested the AR with marker through ARmedia software and markerless technology using Aurasma software.

Figure 68 AR visualization with ARmedia and Aurasma

In the first case the 3D model has been explored using clipping planes that allow the students to discover the university, such as visualizing the building through section plane. ARmedia was used as plug-in of Autodesk 3D Studio Max. In this case the BIM model was exported from Revit in FBX format to avoid data loss during the interoperable process. Unluckily, it was necessary to import again the Points Cloud because this format does not support this kind of data. Then, the model was associated to a marker in order to be visualized with the AR.

Using Aurasma, the plan of each floor was used as trigger image in order to overlap the image of the floor plans with more information about the Room category. The Aurasma's channel is public, in fact to display added information coming from AR is enough to be follower to Politecnico of Torino Channel, called PoliToAR. The use of this tool is allowed without internet connection. The added information was extracted from the BIM model.

Using AR the UniKL university could advertise itself better by offering the opportunity to interested parties to navigate the model even remotely just by using this technology. Obviously this technology needs to be investigated more because at present the use of AR software has highlighted some critical issues related to the type of file to be used in different platforms.

As said in the introduction, malaysian AEC industry is growing rapidly and for this reason the government would like to update his data management system, providing BIM standards developed by PR1MA to the professionals for the development of new buildings around the country

PR1MA Corporation was formed under the PR1MA Act 739 2012 to promote greater home ownership especially among the middle-income earners by providing more affordable residential properties in major cities and sub-urbans nationwide. It is one of the government's initiatives implemented to help the urban and sub-urban citizens manage their costs of living. PR1MA Act 739 2012 is an Act to provide for and regulate matters relating to the development and construction of housing accommodation, infrastructure and facilities under the PR1MA programme, to address the need for sustainable housing and community living towards creating socio-economic housing development model.

In this terms, PR1MA is working on the creation of a requirements applied to all high-rise developments for all business models .

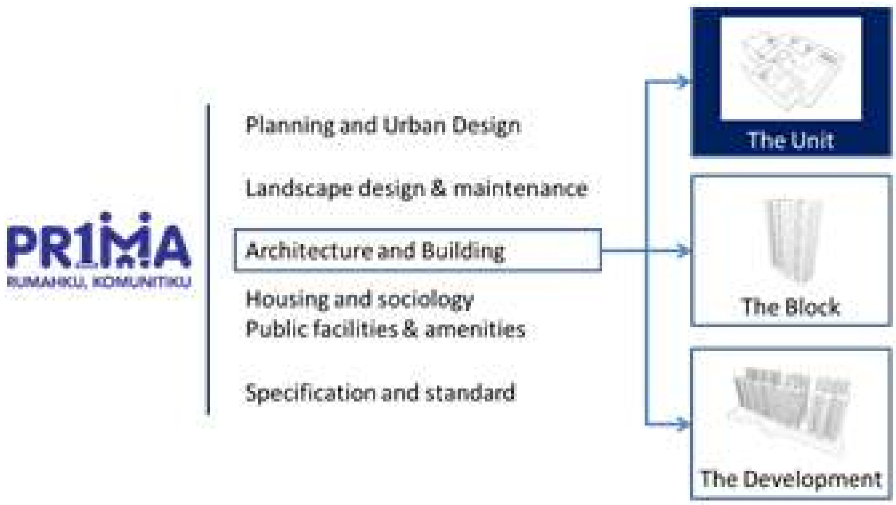

Figure 69 PR1MA Framework

It focuses on *High Rise Minimal standards* for the definition of parameters of PR1MA Home. An emphasis on modularity and efficiency is placed whilst optimizing spatial comfort to ensure that future residents get the best value and quality out of their home. Each high rise is broken up into 3 Components which is the *Unit*, the *Block* and the *Development* which is defined by scale, principles and levels of interaction.

This work investigate the *Unit* component fixing the size of each room typology as visible in the figure below.

Figure 70 Unity layout strategy: Fixed

So, one of PR1MA's goal is to create a tool, such as a BIM template, that contains each the minimum requirements for an apartment in term of square meters. This is due to the fact that the layout directly impacts on the quality of residential amenity, such as access to daylight and natural ventilation, and the assurance of acoustic and visual privacy.

Providing several rules that regulate the rooms' dimension it should be possible:

• To ensure that apartment layouts provide high standards of residential amenity;

• To maximize the environmental performance of apartments;

• To accommodate a variety of household activities and occupant needs;

• To optimize cost through procuring materials & items that match the PR1MA Unit sizes.

In this terms, a BIM template was developed, creating a *Key schedule* that collects the fixed dimensions of the selected rooms. Then, a BIM model was created following a sample of unit plans provided by PR1MA inserting also the *Rooms*. At this point, the *Room* size is compared with the fixed ones established in the *Key schedule.* If the area respects the rule established in the schedule the conditional fields will be highlighted in red as visible below.

Figure 71 BIM model of a PR1MA unit example with the use of a Key schedule

So, the definition of a template with the requirements of PR1MA will avoid to re-set each time the visualization, querying and interface rules, that can generate waste of time and inefficiencies due to the repetition of some operations that should become a standard to follow for all the models.

In these terms, the concept behind a template is the need to create a standard able to goal the requests of the customer, while meeting the project requirements. This implies a consideration on what you want to achieve from the model that is to be made before starting the modeling phase.

6.3.1 List of relative papers published

- **Del Giudice M.**, Giovannitti S., Osello A., Aris A., Bachmann R. T., Smart data management with BIM and AR in Malaysia. In: XXXVII International Conference of Professor of Disciplines of Representation UID 17 – 18 – 19 September 2015– Turin, Italy – ISBN 978-88-492-3124-3.

- Osello A., **Del Giudice M.**, Bachmann R. T., BIM: a new methotodology for the refurbishment of the architectural heritage. In: 2nd UniKL Postgraduate Symposium 2014, Kuala Lumpur.

7. Results

Through this study the added value and the importance of BIM has been highlighted. Following this methodology can give a great contribute to develop a smart building optimizing the data management, focusing on the data sharing among all the users involved in a building project.

To find out the step that required more resources in term of effort and processing time in the workflow explained above, a score from 0 to 5 was assigned to each step considering the three topics of this study, as visible in five radar charts below. The color coding for topic helps to visually correlate and contrast the three topics over the various aspects.

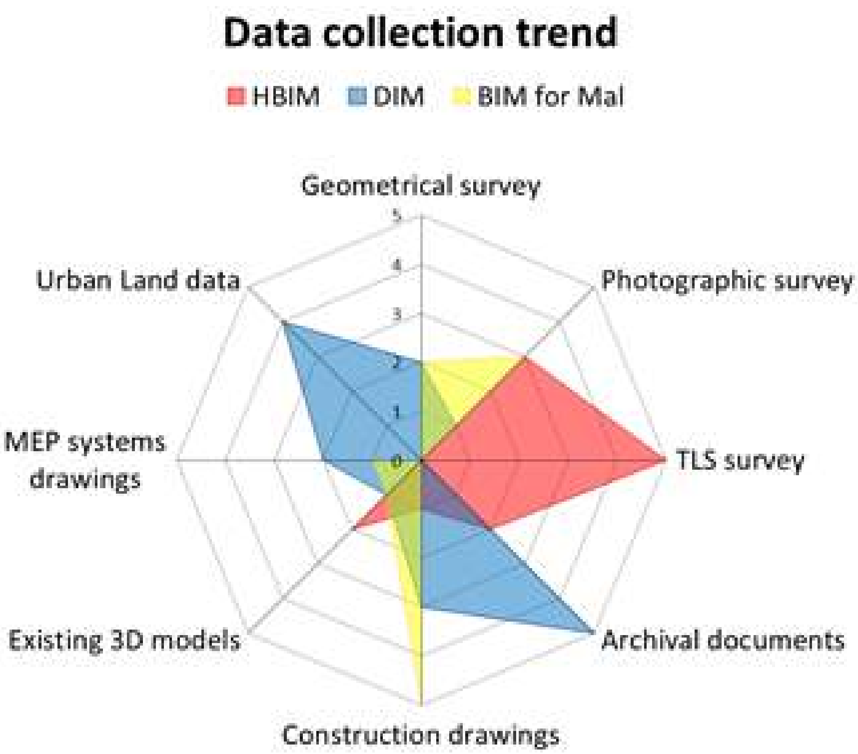

Figure 72 Data collection trend

This radar chart analyzes the Data collection step for the three topics that are ranked each on eight parameters. The HBIM is focused on the TLS survey while the DIM topic gains more points on the Archival documents and Urban Land data spokes.

The last topic that is labelled with "BIM for Mal" represents the use of BIM for the Malaysian architectural heritage. In this case the data collection step is more focused on the Construction drawings and on the photographic survey

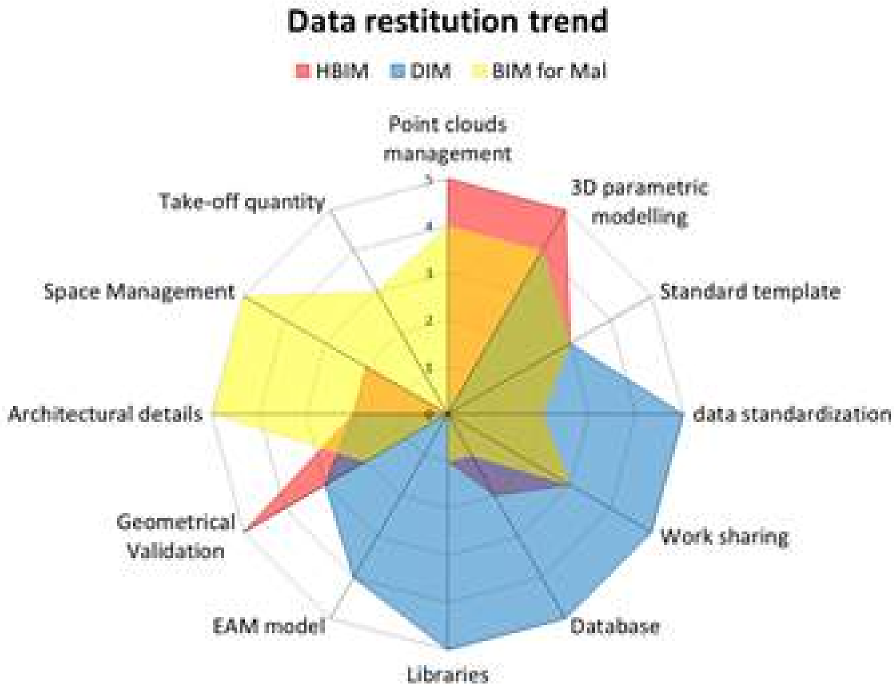

Figure 73 Data restitution trend

This chart is characterized by twelve spokes. It is visible how the "DIM" topic reaches the highest score for the 30% of the spokes, followed by "HBIM" topic that focuses on the Point clouds management, the 3D parametric modelling and on the Geometrical validation. Instead the "BIM for MaI" concentrates mainly on the Space management and architectural details spokes, where it reaches the highest score. DIM topic is mainly focused on the data management for the optimization of the process, whereas the other two topics deepened the parts related to BIM model as a single repository.

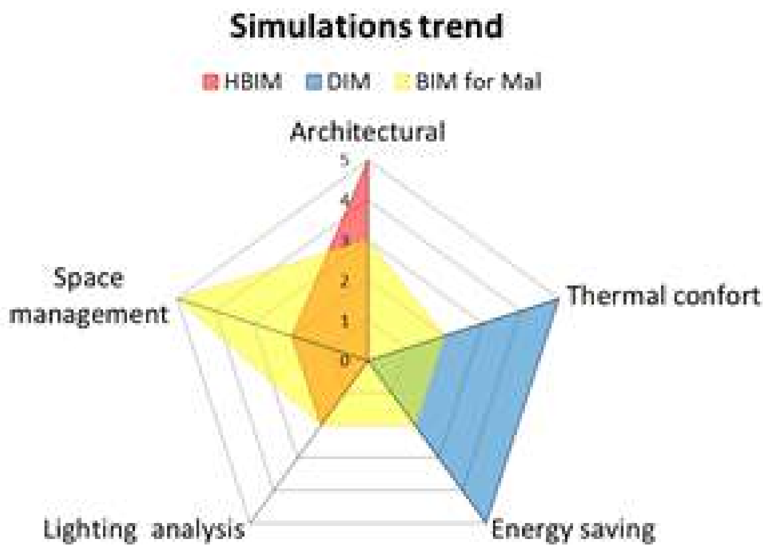

Figure 74 Simulations trend

Considering the simulation trend, is visible that “DIM” topic reaches the highest score on thermal comfort and energy saving simulations with considering the other arguments. However, the BIM for Mal” has investigated all five topics, mainly focusing on the space management that was once of the objective of the topic. The Architectural argument is particularly examined by the “HBIM” topic that is characterized by the historical buildings where the heritage preservation value is higher than the other topic.

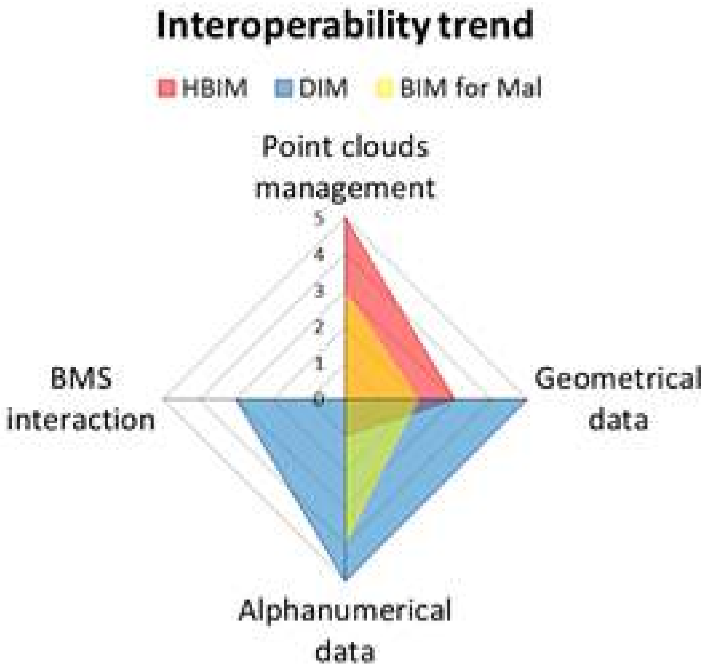

Figure 75 Interoperability trend

From the interoperability radar chart it is visible how some aspects are more general and they are present also in the other charts. The reason is that this arguments is present along the workflow and each step is influenced by the good or bad results of the interoperable process. From this point of view is visible that DIM topic characterizes this chart reaching around the 50% of the total score of this step. In fact, the DIMMER project is mainly focused on the connection between different datasets, using different kinds of interoperable ways.

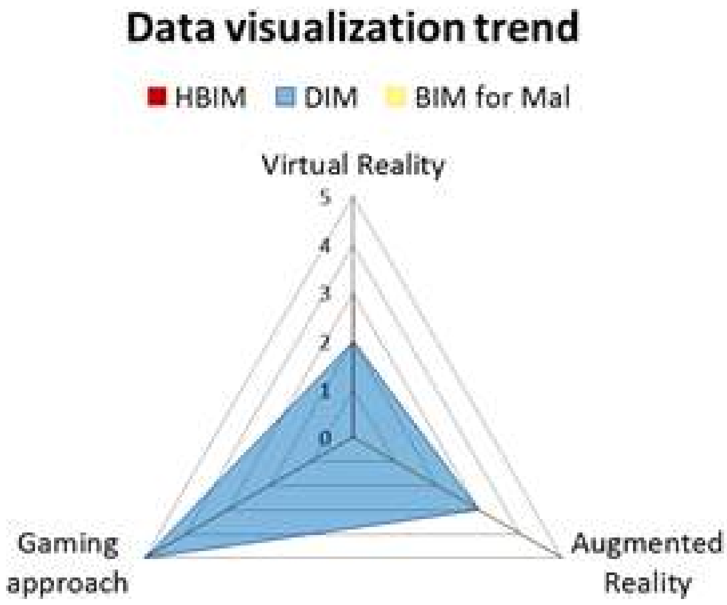

Figure 76 Data visualization trend

Data visualization step is characterized by the VR, AR and the gamification approach. From this chart is visible that only the "DIM" topic investigates all the three arguments reaching the highest score for the Gamification approach. This arguments aim at stimulate young generation to avoid energy waste, becoming them active part in the energy saving process. So for this aspect both VR & AR are used for the generation of games, while in "HBIM" topic and "BIM for Mal" topic use VR and AR for professional uses.

Then, data were charted again to have a global view in term of building process creating a bar chart.

It illustrates the employed effort on each building process step, subdivided in sub steps that are the same used for the comparison of the three topics visible in the previously radar charts.

Observing the Figure 77, it is possible to affirm that the highest score of effort is reached by the 3D parametric modelling sub-step, followed by the work sharing sub step, and by the geometrical and alphanumerical sub steps.

It is clear how the Data restitution step and the interoperability step are considered the two main important steps, considering the objective of each topic.

the phase with the lowest score is the MEP systems drawing that reaches three points. Obviously this value is due to the fact that for the topic taken into account the collection of documents concerning the system of each case study was not so important for the goal of each project. However, this result should not be misleading and should not be overlooked due to the importance of the system for the development of efficient buildings concerning the data management.

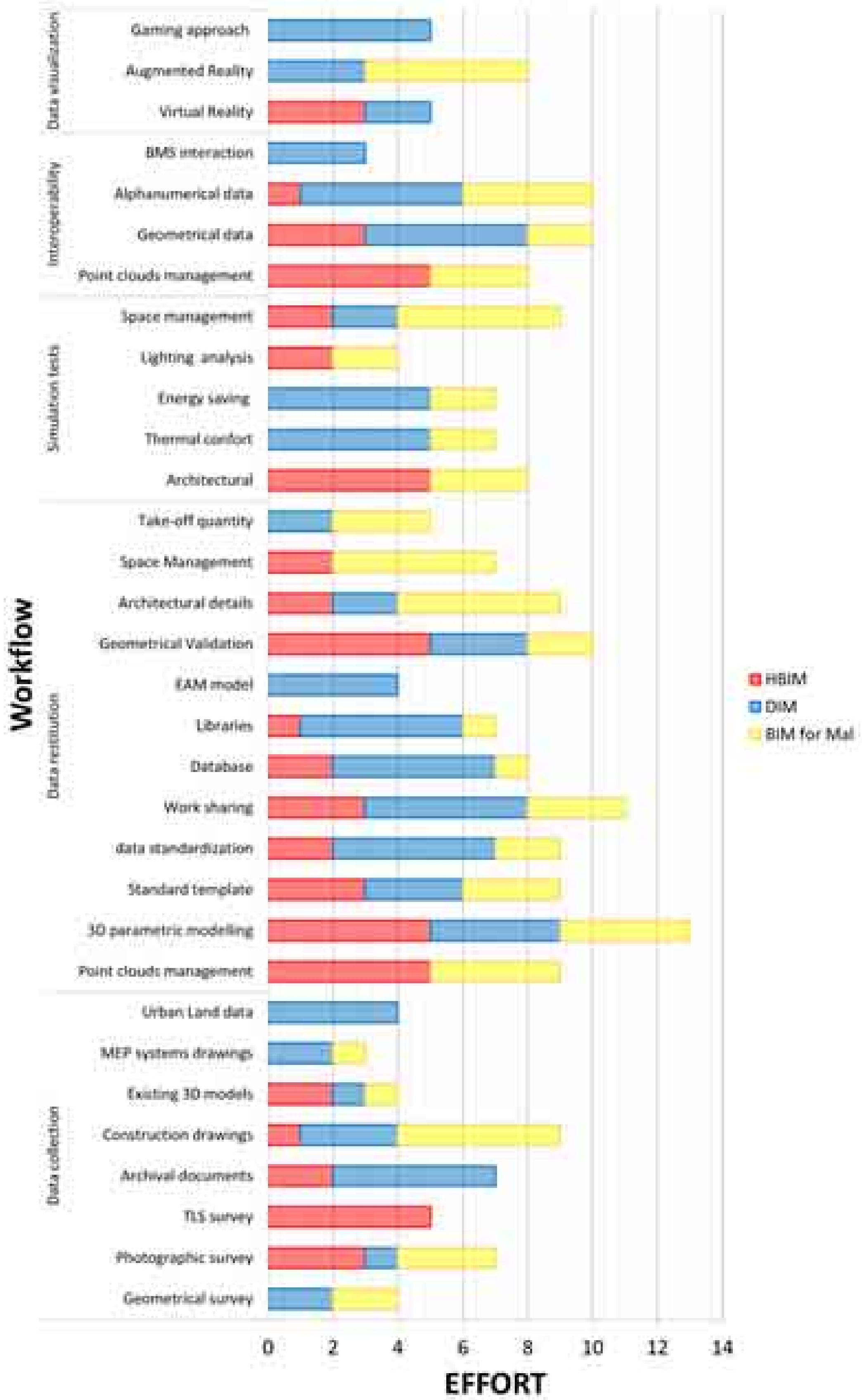

Figure 77 Effort trend related to each step of the workflow

From the previous results it is evident how data management and control are considered real catalysts for coordination in a project, providing an opportunity to finally address the issue of collaboration in the industry, which is identified as an obstacle in the traditional approach in the building industry.

Considering different kind of input data 3D parametric models were developed depending on their purpose, such as building renovation, energy efficiency, space management.

Certainly, the creation of a 3D parametric model implied that data are managed according to the use of individual users that are involved in the building process. This means that each 3D model can be developed with different Levels of Detail/Development (LOD) basing on the goal of the data source.

Along this thesis the importance of LODs was taken into account related to the kind of information filled in a BIM model. Basing on the objectives of each project, this research highlights how a BIM model can be developed in a different way to facilitate the querying data for the simulations tests.

The three topics were compared considering each step in order to highlights the main differences basing on the different objectives of each arguments. Moreover, through these topics highlighting the strengths and weaknesses of BIM was possible. In this terms, the importance to set a BIM template before the modelling step was underlined, managing information in order to be collected and extracted for different purposes and by specific users.

Then, the value of interoperability was arisen from these tests considering that it provided the opportunity to develop a framework for collaboration, involving all parties of the building industry. Additionally, the use of innovative technology such as VR & AR made possible the communication of the projects results to the people who became active part in the transforming process of a smart city

Moreover, basing on the results obtained in terms of the 3D parametric model and in terms of process, the proper level of maturity of BIM was determined for each topic.

The development of BIM model was not restricted to the level 1, characterized by the development of a simple 3D models, but it was focused on data sharing between different users through the use of different standard exchange formats, testing the worksharing in a team project, reaching the Level 2 of maturity. Moreover through the DIMMER project Level 3 of BIM maturity was achieved. Through a common platform that is the DIMMER Middleware different data sources such as BIM, GIS and SIM; Sensors and Energy Measurements (Device

Connectors) are related and integrated in order to collect and query different data, creating a dataflow that involves heterogeneous data coming from different domains. Each data source is considered a web service that is managed by a collaborative model server (the DIMMER Middleware) that can be queried using JavaScript Object Notation (JSON) language suitable for the data exchange between client-server applications. So, in the DIMMER project it possible to affirm that iBIM was developed. Obviously, at present, this level of BIM maturity, shows its potentialities, but needs to be improved with other several tests in order to optimized the dataflow between the stakeholders involved in the building process

8. Conclusions

In the last years the need to share information between people is growing, and it is facilitated by the IT. In these terms, the AEC industry is moving toward the sharing of information for the optimization of the building process that is characterized by the multidisciplinarity of the users involved in a project. So, through the use of BIM methodology the value of interdisciplinarity was possible due to the development and implementation of a relational database linked with other data sources that generate an integrated system able to optimize data management for the creation of a smart city. In these terms the main objectives of this research can be synthetized in the list below:

- Validation of the potential of a BIM both as an innovative methodology and as a relational database customized for different objectives;
- 3D parametric modelling aimed at several purposes such as energy saving and space management;
- Analysis of the interoperability value between different applications and different users involved in the building process;
- Development of the BIM data visualization with V & AR.

the obtained results attest that data management is considered one of the most important steps for the refurbishment of an existing building and for this reason it needs to be improved. Through BIM methodology, the building process will speed up, optimizing time and costs usage. All data concerning the building will be managed in smart way through the use of only one platform where each data source will be shared in an easier way exploited with web server avoiding data missed.

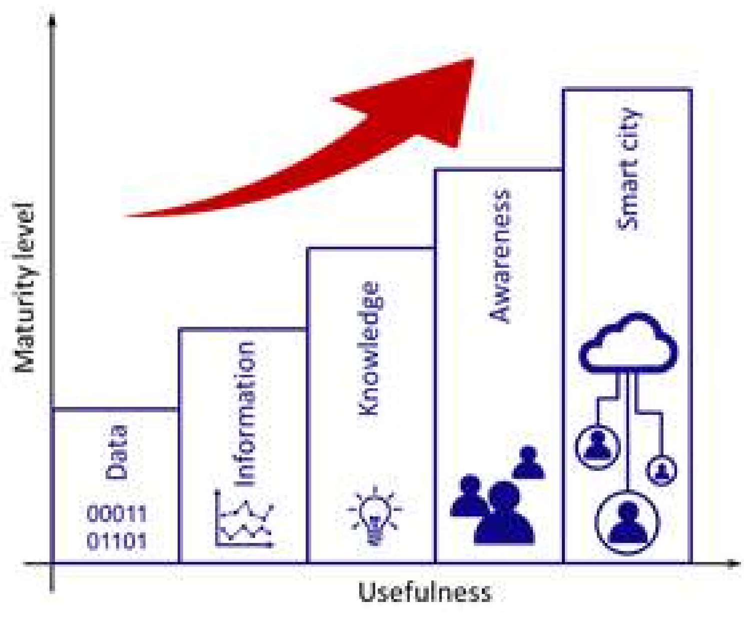

Figure 78 Intelligence hierarchy chart

It essential to understand that the 3D parametric modelling has to be considered as a vehicle to manage data in a consistent and optimal way. As visible in figure 74 it is possible to describe a sort of intelligence hierarchy based on maturity levels. Starting from data level, it works as a repository of useful but unarranged and unstructured information in a raw format. It is necessary to interpreted and store in the right context of intelligence these data in order to generate information that can be used by different users to create knowledge. It can be required in various forms by different parts of the organizations that exploit it to optimize data processing, findings new strategy for the future.

Once created knowledge it is necessary to spread it among people to make them aware of their surroundings, making them an active part in society changing their life style. So, through the people awareness data becomes *smart* data, allowing the development of a smart city.

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Appendix A

List of Publications

A.1 International journals

- Osello A., Dalmasso D., **Del Giudice M.**, Erba D., Ugliotti F.M., Patti E., Davardoust S., *Information interoperability and interdisciplinarity: the BIM approach from SEEMPubS project to DIMMER project*, In: Territorio Italia, Agenzia delle Entrate, ISSN 2240-7707. 2013.

- Brundu F. G., Patti E., Osello A., Del Giudice M., Rapetti N., Krylovskiy A., Jahn M., Verda V., Guelpa E., Acquaviva A., *IoT software infrastructure for Energy Management and Simulation in Smart Cities*, In IEEE Transactions on Industrial Informatics. *Under review*

A.2 Book Chapters

- Osello A., **Del Giudice M.**, Rapetti N., District Information Models. *The DIMMER project: BIM tools for the urban scale*. Under review

- Anna Osello; Andrea Acquaviva; Daniele Dalmasso; David Erba; **Matteo Del Giudice**; Enrico Macii; Edoardo Patti, *BIM and Interoperability for Cultural Heritage through ICT*. In: Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modeling, and Representation / Stefano Brusaporci. IGI Global, pp. 281-298. ISBN 1466683791

- **Del Giudice M.,** *L'impostazione di un modello BIM per un edificio esistente*. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 40-49. ISBN 978-88-579-0478-8.

- **Del Giudice M.,** *La gestione delle nuvole di punti con il BIM*. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 76-83. ISBN 978-88-579-0478-8.

- **Del Giudice M.**, *Il GIS per la gestione dei dati alla scala urbana/edilizia*. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 258-267. ISBN 978-88-579-0478-8.

- **Del Giudice M.**, *L'utilizzo della AR per la responsabilizzazione degli utenti con un approccio al gioco*. In: Building Information Modelling, Geographic Information System, Augmented Reality per il Facility Management / Osello A. Dario Flaccovio Editore, Palermo, pp. 286-291. ISBN 978-88-579-0478-8.

- **Del Giudice M.**, Boido C, *Caso studio 12. L'impostazione di un database per l'interpretazione critica dei dati.* In: Osello A., Il futuro del disegno con il

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A.3 Proceedings of International Conferences

- **Del Giudice M.**, Osello A., *The enhancement of architectural heritage through HBIM and interoperability*. In: XXXVIII International Conference of Professor of Disciplines of Representation UID – Florence 2016. Abstract submitted

- Osello A., Uffredi V., **Del Giudice M.**, Rapetti N., *Il BIM per il patrimonio edilizio storico, realizzazione di un database per la manutenzione*. In: XXXVIII International Conference of Professor of Disciplines of Representation UID – Florence 2016. Abstract submitted

- Rapetti N., **Del Giudice M.**, Osello A., *From District Information Model(DIM) to Energy Analysis Model (EAM) via Interoperability*. In ECPPM 2016. Abstract submitted

- **Del Giudice M.**, Rapetti N., Osello A, Ugliotti F. M., Acquaviva A., Patti E., Brundu F. G., *BIM and interoperability for data management and visualization at urban scale*, In MSSCE 2016. Abstract submitted

- **Del Giudice M.**, Giovannitti S., Osello A., Aris A., Bachmann R. T., *Smart data management with BIM and AR in Malaysia*. In: XXXVII International Conference of Professor of Disciplines of Representation UID 17 – 18 – 19 September 2015– Turin, Italy – ISBN 978-88-492-3124-3.

- Osello A., **Del Giudice M.**, Marcos Guinea A., N. Rapetti, A. Ronzino, F.M. Ugliotti, L.Migliarino, *Augmented Reality and gamification approach within the DIMMER project*. In: INTED 2015 Conference, Madrid, Spain.

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- Marco Zerbinatti, Isabella Bianco, Cristina Boido, **Matteo Del Giudice**, Paolo Piumatti, Pablo Ruffino, *Survey and parametric modelling for historic architectural heritage*. In XXXV International Conference of Professor of Disciplines of Representation UID – Matera, Italy. PATRIMONI E SITI UNESCO MEMORIA, MISURA E ARMONIA, 2013, pp. 993-999. – ISBN 978-88-492-2728-4
- Chiara Aghemo, Laura Blaso, Daniele Dalmasso, David Erba, **Matteo Del Giudice**, Anna Osello, Giovanni Fracastoro, Anna Pellegrino, Pablo Ruffino, *Interoperability between building information models and software for lighting analysis*. In BSA 2013, Bozen, Italy, Jan30 - 31, Feb 1 2013.
- Osello A., Acquaviva A., Pellegrino A., Candelari E., Chiesa G., Dalmasso D., **Del Giudice M.**, Erba D., Mannanova K., MD Rian I., Noussan M., Patti E., Pippione M., Serra A., Shaghayegh R., Tomasi R., *Multidisciplinary team activity using BIM and interoperability. A PhD course experience at Politecnico di Torino*. In: Le vie dei Mercanti XI Forum Internazionale di Studi, Aversa-Capri, 13-15 June, 2013. ISBN: 9788865422908.

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A.4 Proceedings of Italian National Conferences

- Isabella Bianco, Carlo Caldera, **Matteo Del Giudice**, Andrea Maria Lingua, Anna Osello, Paolo Piumatti, Pablo Angel Ruffino, Marco Zerbinatti, *A digital process for conservation to traditional stone heritage*, In PPC Conference 2014, Monza and Mantua, Italy, 5-9 May2014.

Appendix B

List of Papers

*di Anna Osello
**Daniele Dalmasso
**Matteo Del Giudice
***David Erba
***Francesca Maria Ugliotti
****Edoardo Patti
*****Sanaz Davardoust

Information interoperability and interdisciplinarity: the BIM approach from SEEMPubS project to DIMMER project

Parole chiave: BIM, Interoperability, Augmented Reality, Virtual Reality.

Abstract Design, implementation and management constitute the cornerstones of the building process and the current trend, albeit still at an embryonic state in Italy, is represented by the application of a problem-solving approach combining integrated analysis and research between interdisciplinary professionals able to integrate their know-how and experience.

The project SEEMPubS (*Smart Energy Efficient Middleware for Public Spaces*), which ended in August 2013, investigated the theoretical and operational possibility of using a network of sensors to monitor energy consumption and raise awareness of this issue among end-users in academic and working places. The project DIMMER (*District Information Modeling and Management for Energy Reduction*), that kicked off on October 01st, 2013, represents its evolution, as the research extends from buildings (building scale) to the neighborhood (urban scale), simultaneously expanding the areas of study.

Data and information to be processed and analyzed call, in this case, for a reconsideration of the activities to be carried out, through the use of innovative instruments and procedures to ensure correct information flow and optimal data management. For this purpose, we adopted the BIM methodology (Building Information Modeling) for digital representation and modeling of our case studies, facility management and analysis of interoperability between different software applications, investigating how the tools currently available on the market and the interdisciplinary collaboration between professionals from different areas may constitute the standard for tomorrow's communication

INTRODUCTION

The need for specific aggregations of data and information has been increasingly pressing for a number of years. In the Web 2.0 era, the amount of data and information available has steeply increased, facilitating their access but also creating confusion, encouraged by redundancy and lack of a monitoring and verification system.

Designing, building and facility management all involve considerable amounts of data and information shared and exchanged; moreover, during the lifecycle of a building or a neighborhood, in addition to specific information on construction, we must consider also data and information derived from interactions with other areas, such as transportation, rents, utilities, security, entertainment, etc.

Computer science can help us to properly manage all these interdisciplinary actions and activities,

*Associate Professor at the Department of Structural, Geotechnical and Building Engineering of the Polytechnic University of Turin
**PhD at the Department of Structural, Geotechnical and Building Engineering of the Polytechnic University of Turin
***Research Fellow at the Department of Structural, Geotechnical and Building Engineering of the Polytechnic University of Turin
****Research Fellow at the Department of Automated and Computer Engineering of the Polytechnic University of Turin
*****External collaborator at the Polytechnic University of Turin

by providing the professionals involved with effective and innovative tools to manage and monitor the flows of information.

The project SEEMPubS allowed experimenting practical interdisciplinary collaboration between professionals working in different areas, through the involvement of different scientific disciplines.

As described in detail in the following chapter, a number of experimental activities were carried out to examine how the professionals involved could benefit from practical collaboration. Construction was related to the energy sector in order to integrate building modeling with lighting and thermal analysis. Likewise, construction was linked to facility management and IT (developing a tablet app to support facility maintenance).

The project SEEMPubS enabled (as DIMMER will) to practically apply the above theories to a number of case studies. Through the use of software available on the market or apps specifically created by our research group, we investigated possible future developments for data and information management in several areas, such as energy consumption, facility maintenance, installations, etc. both at building and neighborhood level.

THE PROJECT SEEMPUBS

Smart Energy Efficient Middleware for Public Spaces (SEEMPubS)[1] is a STREP project (*Small or medium-scale focused research project*) with a duration of 36 months (started on September 01st, 2010 and ended on August 31st, 2013), funded with 2.9 million Euros by the European Commission within the Seventh Framework Programme[2]. The project was aimed at reducing energy consumption and carbon dioxide emissions in existing buildings (including historical buildings), by monitoring physical variables (temperature, humidity, lighting, presence of people, CO_2 emissions, etc.) of the environments chosen as case studies through the use of ICT (Information and Communication Technology) and without carrying out any construction work.

Monitoring was performed by an integrated network of sensors and the *middleware*[3] software LinkSmart for the management of *embedded*[4] systems. The middleware software acted as a "translator" for the various languages used by the sensors installed to communicate with each other, manufactured by different producers, thus allowing for uniform data monitoring, collection and analysis.

A number of premises of the Polytechnic University of Turin were chosen to implement and demonstrate the project; specifically, 6 pairs of rooms were identified, with one room working as testing facility and the other one, similar in size and type, as reference room.

Contrasting pairs of rooms were needed in order to clearly show the benefits obtained through monitoring as well as to verify energy savings achieved in the long-term.

The rooms selected are located in the Castello del Valentino, the headquarters of Corso Duca degli

1 http://seempubs.polito.it/

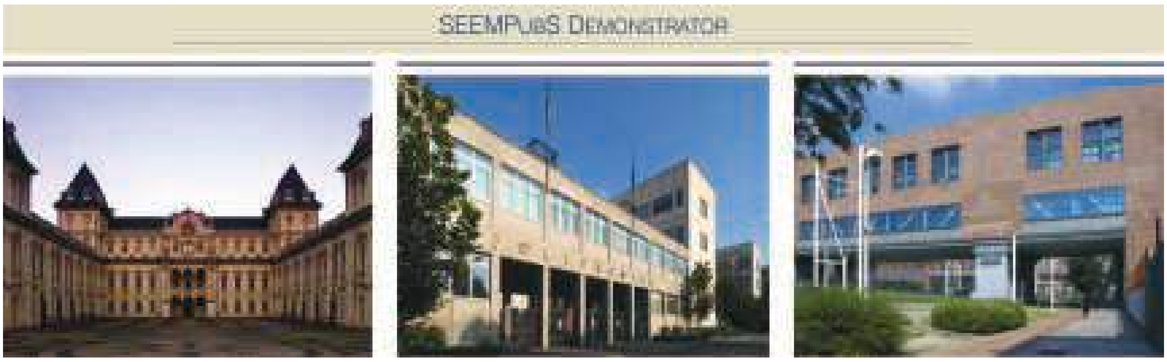
2 The EU Framework Programme is the main instrument used by the European Union to fund research in Europe during a fixed period of time (5 years). The Programme is designed to provide funds to universities, research institutions and SMEs that participate in a call and are selected (http://cordis.europa.eu/home_it.html). The Seventh Framework Programme is due to expire this year (2007-2013).

3 A *middleware* represents a set of computer programs or apps whose objective is to enable communication and management of data in distributed applications. For instance, sensors for energy monitoring communicate with each other using their own computer languages, often created or implemented by different manufacturers. Consequently, the *middleware* works as a "translator", thus allowing the sensors to communicate with each other.

4 An *embedded* system is an electronic system for data processing provided with a microprocessor, developed to perform specific operations or activities. Home automation sensors such as thermostats or anti-intrusion system control panels are classic examples of *embedded* systems, as they are developed to manage and monitor specific operations.

Abruzzi and the Polytechnic Citadel. These premises were strategically chosen as the buildings all have different construction characteristics - related to the period they were built in - and, consequently, specific energy issues.
Different types of sensors were installed according to the characteristics of the above premises. For the Castello del Valentino, built in the first half of the seventeenth century and featuring frescoes, stucco and high-quality materials, we could not carry out any construction work to reduce energy consumption; therefore, we installed *wireless* sensors. In the other two premises, two modern buildings, *wired*[5] sensors were installed instead.

Picture 1 The premises chosen to demonstrate the project SEEMPubS

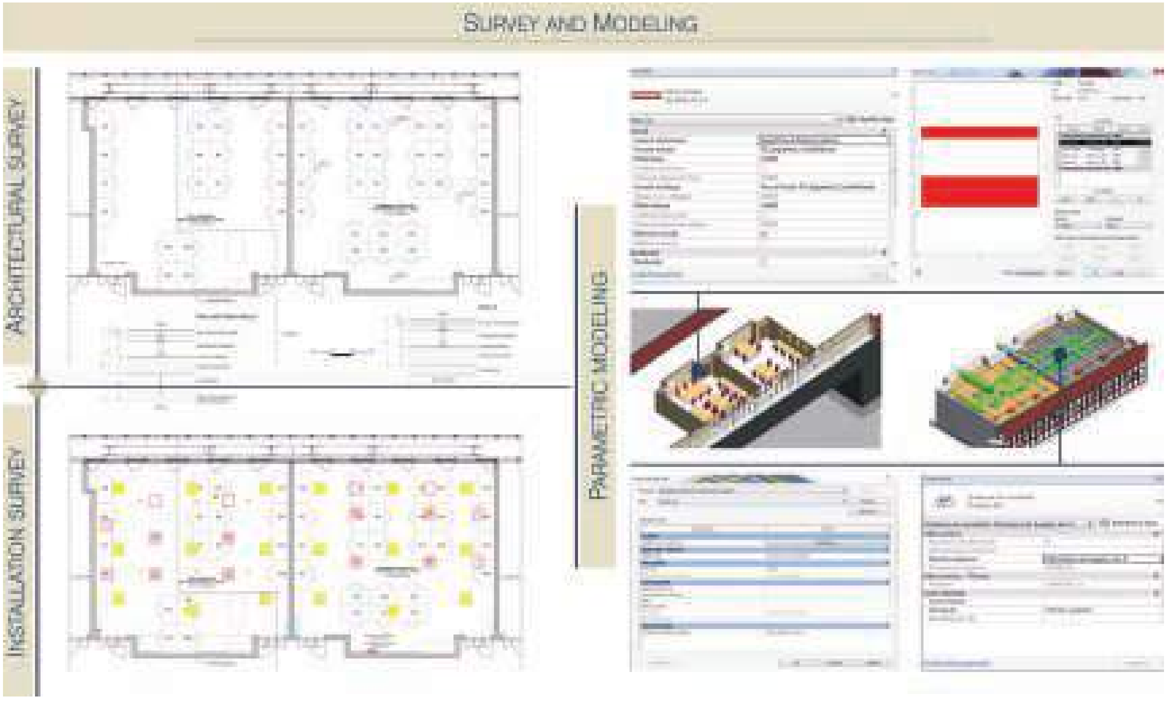


Following the selection of the physical spaces to demonstrate the project, the initial phase of the project consisted in modeling the premises with BIM parametric applications. Thus, three-dimensional models of the premises were obtained, which were then used for energy simulations and the development of an Android app for maintenance management.
The starting idea was to apply the paradigm of the BIM methodology, according to which any object or artifact only needs to be modeled once and then it can be used to support other activities through appropriate data export or import.
During the preparatory phase for modeling, we carried out an in-depth survey of the rooms, a key starting point to collect and implement information; in particular, we measured the dimensions of the rooms and checked the positioning of the installations, including any other additional equipment, such as computers. Modeling was created using the software Revit Architecture 2011 and the results obtained can be classified as a *bim* model instead of proper BIM modeling.
There is a substantial difference characterizing the whole methodology here. BIM (Building Information Modeling) is intended as a **parametric information model**, that is a model containing not only graphic information but also other kinds of information in its internal database, including data on thermal characteristics of materials, costs, technical specifications or others. This information can be integrated and shared by a variety of professionals (interoperability) in their respective areas of expertise. On the other hand, a *bim* (building information model*)* model simply represents a three-dimensional geometrical model devoid of any other information; a *bim* model, therefore, is nothing but a three-dimensional model, which differs from a classic 3D CAD model as it can be implemented with additional information and, therefore, become a BIM model.
This first three-dimensional model was needed to start energy and lighting simulations and that is

5 A *wired* system is an electronic system requiring a wire for data transmission. *Wireless* systems do not need wires instead.

why it can be classified as a *bim* model; as our research continued and extended into new areas, we also had the opportunity to implement three-dimensional models of the premises tested and, therefore, develop a more advanced and complex BIM model, integrated by alphanumeric information.

Picture 2 Graphic rendering of a plan (CAD) and BIM parametric modeling.
The images show the pairs of rooms named DAUIN Labs



Parametric models, therefore, provided the graphic/information support for a number of complementary research activities to the project SEEMPubS, in which we were able to test interoperability between different software apps and between databases.

The research covered the following topics:
- Use of the bim model for lighting simulations
- Use of the BIM model for facility management
- Use of the bim model for the development of an Android app

Bim for lighting simulations
Within the preliminary analysis on the possibility of improving energy efficiency, a number of lighting simulations were carried out to assess availability of natural sunlight in the environments tested in order to establish the best technology to monitor and adjust artificial lighting according to the amount of natural sunlight available. As simulations usually require the creation of 3D models for calculations purposes, our lighting experts were able to develop this model independently according to their requirements. Following the afore-mentioned interdisciplinary cooperation between professionals from different areas, we decided to integrate modeling and simulation activities, trying to optimize the latter.
Below are the procedures adopted to transfer the three-dimensional model from the design environment to the apps for the simulations.

Application

As previously mentioned, the premises chosen for our project were modeled using BIM parametric modeling (Revit Architecture 2011).

In order to perform a correct simulation, it was essential to provide the model with a high level of detail, especially for the geometry of the rooms. Such characterization was achieved through the internal logic of the parametric application, which provides for the hierarchical creation of the model by using the types of generic families available and parameterizing the elements needed from time to time. Each constitutive element of the rooms (walls, ceilings, doors and windows, etc.) was modeled according to their surface materials. This strategy proved highly effective since lighting simulations are strictly related to the surface characteristics (color, roughness, etc.) of the materials that come into direct contact with the light.

A detailed modeling type was chosen also for the environment outside the rooms tested, in order to ensure correct simulation.

Once such operations were completed, we transferred the model from the parametric application to the software used for the lighting characterization of the elements, Ecotect Analysis[6]. Three different export files formats were tested (.IFC, .gbXML and .FBX) in order to identify which one would provide the best results. The first two formats did not achieve the expected results, in particular .IFC was affected by a number of import errors of some essential elements needed for the simulation, such as the uprights of doors and windows; moreover, we observed discrepancies between the elements imported and the original model. Files exporting, and subsequent importing, via the .gbXML format also revealed a number of critical aspects, the most significant being the transformation of all solids into surfaces. Correct file exportation was achieved instead with the .FBX format. Here, the model is exported from Revit Architecture in .FBX format, and then imported into another app acting as a "bridge" and thus facilitating the data transfer; this app was identified in 3dsMax. By performing additional file exporting in .3ds format, we were finally able to import the three-dimensional model into Ecotect Analysis.

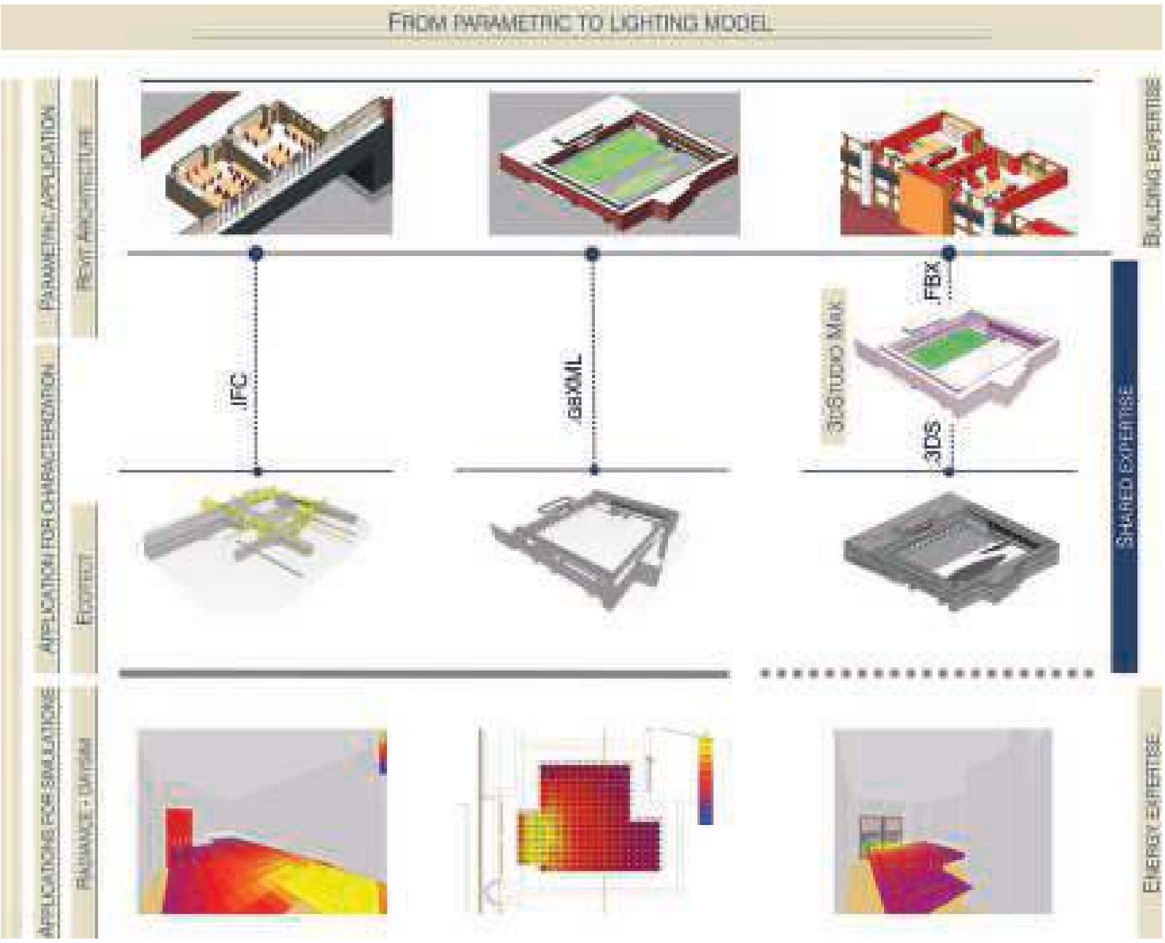
This long and complicated procedure (not entirely logic in terms of software interoperability) allowed preserving the original model in its entirety, without incurring into any data or geometry losses.

In Ecotect Analysis, the model was integrated by adding information on the lighting characteristics of the rooms, including the characterization of different surfaces, then exported once again to the apps for lighting simulations, Radiance and Daysim.

The use of the above "bridge" app was an example of effective collaboration between different engineering areas, following the afore-mentioned interdisciplinary approach; this operation highlighted, once again, the positive results that can be achieved by sharing and integrating information from different areas of expertise.

6 http://www.autodesk.it/adsk/servlet/pc/index?id=15078641&siteID=457036

Picture 3 Representation of the export/import procedure of the three-dimensional model from the parametric application to the apps for lighting simulation



BIM for facility management

Facility management plays a fundamental role in the construction process, due both to its duration - a percentage higher than 70% of the buildings' lifecycle - and the consistent number of activities, operations and professionals involved. In addition to this, facility management represents a key area especially in times of economic crisis, as it can help achieve significant savings in terms of cost and time.

In 2010, the Polytechnic University of Turin, started purchasing and using a CAFM (Computer Aided Facility Management) app called ArchibusFM[7]. Structurally, this software consists of an alphanumeric database containing information and data entered by authorized users, and a graphic interface, represented by CAD plans. The software integrates alphanumeric data entries and graphic interface to ensure constant facility management in real time. This application is being currently used to manage facilities as well as cleaning and maintenance services on demand.

While the above app was being used by several offices and department of the Polytechnic University of Turin, we carried out a parallel research aimed at replacing its CAD graphic interface with the BIM model.

7 http://www.archibus.com/

Our objective was to investigate how the parametric modeling apps used by the University could be implemented for facility management. The issue here revolves around the necessity of having common interpretable software for graphic representation which provides data accuracy and updating at the same time.

Application

The Polytechnic University of Turin currently uses Archibus Version 18.2, which for the first time allows for the possibility of using Revit 2009 for facility management through a specific *overlay*, that is an upgrade of the original version.

For modeling purposes and with the aim of supporting the management activities carried out by the University, we were able to achieve a satisfactory level of detail for the parameterization of the building components. Our objective, in fact, was to create a model that could support facility management while analyzing limitations and opportunities for improvement; consequentially, our priority was obtaining a model displaying correct spatial arrangement rather than one containing other kinds of information.

From an operational point of view, facility management should be carried out since the designing of a building and, consequently, a parametric model (*as-built*[8]) containing all information needed should be made available upon completion of construction. However, we decided to develop a specific model for research purposes. The overlay provided by Revit 2009 consists of an *add-on*, that is a number of additional commands compared to the standard version. The Revit overlay for Archibus, in fact, shows a number of additional buttons in the commands menu that allow for an exchange of information between the alphanumeric database and the three-dimensional model.

Once the model is implemented, another essential step is needed to ensure correct facility management; this operation consists of placing the object “room” within the rooms constituting the model. The object “room” is a specific request by Revit, as it is used to compute a number of information related to room surface, perimeter, name, type or others.

Each room physically modeled within Revit can be associated to an object “room” that will acquire and visualize the afore-mentioned information. So far, we have worked exclusively inside the Revit environment by exploiting the potential offered by this application, hence the main potential users in this case would be professionals, such as architects or civil engineers, who need to design buildings and obtain a digital representation of their relevant data. The next operations allow instead also other professionals, such as management engineers or professionals, to interact with data and information contained in the model.

Once the model is populated with the objects “room”, we can use the commands provided by the overlay to connect data and information in the Revit model with the Archibus database.

It is then possible to update information on the rooms, such as surface, category and type, building location, personnel and equipment associated to them, by operating both on Revit and Archibus.

However, the procedure tested raised a number of issues, first of all the impossibility to change some parameters contained in the overlay, which resulted in an error in the count of areas; as this is the first version of the overlay and is designed only for the American market, we could not change the units of measure from square feet to square meters, and, consequently, all areas shown in the database were incorrect. The second main issue was that, although it was possible to link graphic and alphanumeric elements, we could not observe a bi-directional flow of information. In fact, while

8 An *as-built* represents the entire design updated according to the actual execution of a building. An *as-built*, therefore, is the closest representation of a building to reality.

the Archibus database can be directly accessed by sending a query to the Revit graphic model, you cannot do the opposite; in fact, while navigating inside CAFM, the graphic model cannot be displayed. Although the test did not achieve the expected results, we investigated the possibility offered by the interaction of the two apps, which target professionals working in different areas, yet feature intrinsically connected and parallel procedures. The path we tested is potentially feasible, provided that the afore-mentioned issues are solved.
Seeking a remedy to the above problems, we tried an alternative way, which does not involve the use of Archibus; instead, we only used Revit in *stand alone* mode.
This strategy relied on a specific command offered by Revit and called "shared parameter". A shared parameter is a specific parameter which can be totally customized by users who create it. It is mainly used to elaborate all those characteristics not offered by the standard application.
With regard to facility management, we then entered the shared parameters for the characteristics associated to the rooms, such as their type or the buildings they are located into. As information needs to be continuously updated, which is key for correct facility management, this task should be carried out by different professionals in their areas of expertise.
For this purpose, we decided to provide all users involved in the updating process with an easy-to-use and common format; through Revit Dblink, we were able to export the whole internal database of the parametric model to an Excel file. By interacting with this file, each user can thus enter any updates and then re-import the Excel file into the model, so that the latter is always updated.
Compared to the previous path, here we could observe perfect bi-directional flows of information while maintaining a strong control over updates and users. Both procedures involve the collaboration between professionals operating in different areas and are aimed at facilitating data exchange and integration.

Picture 4 Representation of the procedures tested on integration between BIM and Facility Management

Bim for the development of an Android app

All buildings, whether modern or historical, are characterized by a number of complex and different issues related to the time of their construction and the technology adopted; moreover, all buildings must undergo maintenance interventions that further highlight their criticalities.

Within the project SEEMPubS, we developed an Android app for building maintenance based on virtual and augmented reality.

While the technical description of the application is not within the scope of this study, we will illustrate the steps and operations we carried out to use the 3D model in the app for tablets.

Application

The first task was to create the three-dimensional and parametric model of the building with BIM modeling tools; after the architectural and structural parts, we modeled all installations by entering information on mechanical parts, electricity system and HVAC (Heating, Ventilation and Air Conditioning), so that the model could be used not just for analysis and simulations but also, and mostly, to be displayed on the tablet. The model was integrated also by introducing models of the sensors installed under the project or those already installed. The sensors are used for monitoring temperature, humidity, CO_2 concentration, human presence, etc. These operations were carried out through Autodesk Revit and in accordance with the *as-built* (if applicable) and our investigations/findings.

Once the parametric modeling was done, the model was exported to 3dsMax 2013, using both .FBX[9] (FilmBoX) and .DWG[10] (DraWinG) file exchange formats, in order to export as much information as possible from the original model. The .FBX format allows exporting the model geometry, while .DWG helps solve a number of issues related to the complexity of the geometries modeled; in fact, this format allows users to choose what kind of solids to export; moreover, thanks to the use of ACIS[11] geometries, we were able to considerably reduce the numbers of polygons constituting the surfaces of the model.

Using the .DWG format, we exported then the geometries of the building and the installations, while the models of the sensors were exported with .FBX.

The different files exported with Revit 2013 were then assembled in 3dsMax 2013 to create the original model. Also imports followed two different methods: firstly, we linked the 3dsMax environment to the files through the command Manage Links; the second instead consisted in importing directly from the original file. Using the first procedure, you can choose the recognition method of the elements imported (type of material, type of element, identifier, etc.); with the second procedure, file 'weights' can be reduced.

The next step was to export the model from 3dsMax to two different formats, .OBJ[12] (OBJect), for geometries, and .MLT for materials. The last operation consisted in importing the model and its information to the Bonzai Engine[13], which is used to export the model to .JMF format[14] (Java MultiFile). The latter is the format used by the Android app for display and browsing.

9 http://www.autodesk.com/products/fbx/overview

10 http://usa.autodesk.com/adsk/servlet/pc/index?id=6703438&siteID=123112

11 http://en.wikipedia.org/wiki/ACIS

12 http://people.sc.fsu.edu/~jburkardt/data/obj/obj.html

13 http://bonzaiengine.com/index.php

14 http://dotwhat.net/jmf/7232

Finally, in order to make these models in .JMF format available for browsing on the tablet, they were uploaded, through a BIM Manager application specifically created by the research group, to the online storage BIM Server. Online storage ensures usability and accessibility to the model at any time and from any tablet. Model navigability is provided by virtual and augmented reality.

Virtual reality allows accessing the model at any time, even when users are not in proximity of the room to query, since the application directs to the virtual model provided by the storage and then, browsing through it, users can send queries.

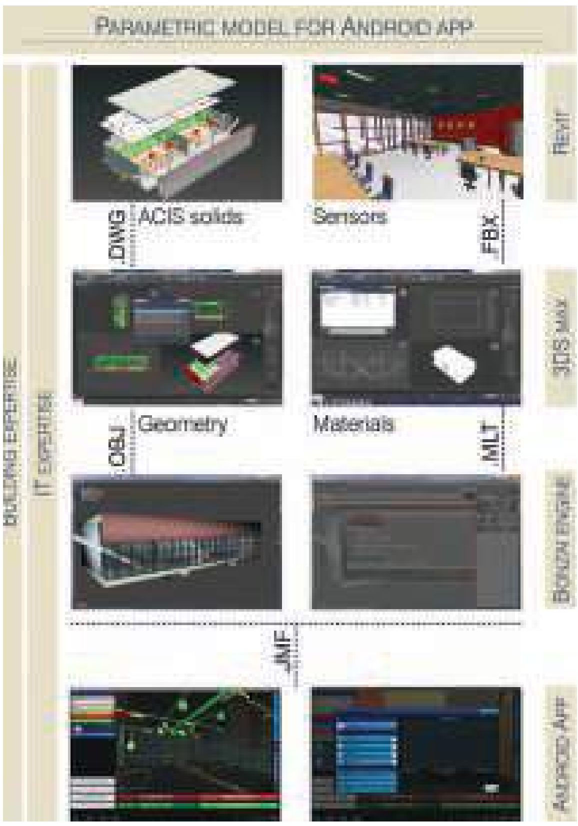
To query the model, you just click on an item, for instance a sensor, and visualize the information recorded by the device, then processed by the middleware and a dedicated Web Portal in real time. For example, you can click on a sensor monitoring temperature and visualize the trend in the short and long term.

The other feature developed in the application was the transparency of the building elements modeled, so that all of them can be read correctly (architectural elements, furnishings, installations, etc.). This function is extremely useful whenever users need to visualize installations covered by internal partitions.

Augmented reality, instead, is helpful any time users are in the proximity of the room they intend to query. The procedure here provides for the scansion of a specific QR code which refers to the online storage and thus allows visualizing information on the environment at issue.

Information and data visualized by the Android app come from a variety of sources and are taken from specific databases created in real time. In particular, information on monitoring performed by the sensors is taken from dedicated databases, while reference data on the premises are taken from the Archibus database used by the University for facility management.

Picture 5 Representation of exporting procedures of the parametric model for the Android app



THE PROJECT DIMMER

The project DIMMER (District Information Modeling and Management for Energy Reduction) represents the natural evolution of the project SEEMPubS, its objective being to extend the ideas and analysis tested on buildings to a neighborhood level.

It involves the participation of public authorities, research bodies and partners from Italy, Germany, England and Sweden.

The project moves from the basic concept that today ICT technology is essential to improve energy efficiency of any urban community. Technology for energy monitoring has been developed in conjunction with specific campaigns to raise awareness of energy-related issues among end-users, as we have seen in the project SEEMPubS. And yet, we can observe that such technology innovations are still scarcely used both by households (housing unit level) and plant operators (neighborhood/city level).

ICT technology can be extremely useful by providing and facilitating access to information on buildings and their environmental and energy characteristics in real time. Likewise, on a wider urban scale, it can provide access to information on heating/air-con systems, power supply network, etc. Opportunities offered by ICT are exemplified by the middleware software, an interface able to detect different languages used by sensors to communicate with each other, usually produced by different manufacturers, and translate them into a common language thanks to a centralized decision-making system.

Our project envisages a combination of ICT technology and Building Information Modeling as the ideal platform to create a digital organization leading to the development of the District Information Modeling (DIM).

The basic concept behind DIM, introduced by this project for the first time, is to implement the BIM philosophy and extend it to a neighborhood level. This approach will allow examining several issues shared by any neighborhood, which go beyond the typical engineering and scientific elements of buildings, as they are influenced by social aspects involving a plurality of users. The project's ultimate goal is to create a web-oriented interface able to collect data and information on the single buildings and the neighborhood as a whole, including data and information on their energy requirements.

This project offers multiple advantages to professionals operating in different areas; for instance, energy carrier suppliers could use the digital platform to identify potential new customers, while facility managers could access aggregated information to obtain an overview on specific issues.

The most advanced use of the platform is on public buildings, where users can, for instance, provide feedback on the services offered or the comfort of the premises.

The tool developed to access the platform is essentially a web portal. Nevertheless, to facilitate interacting with it, users are encouraged to access it also through augmented reality, such as QR Codes. QR Codes are placed in the proximity of the buildings whose data and information are to be disseminated, so that users can visualize them on their tablets or smartphones.

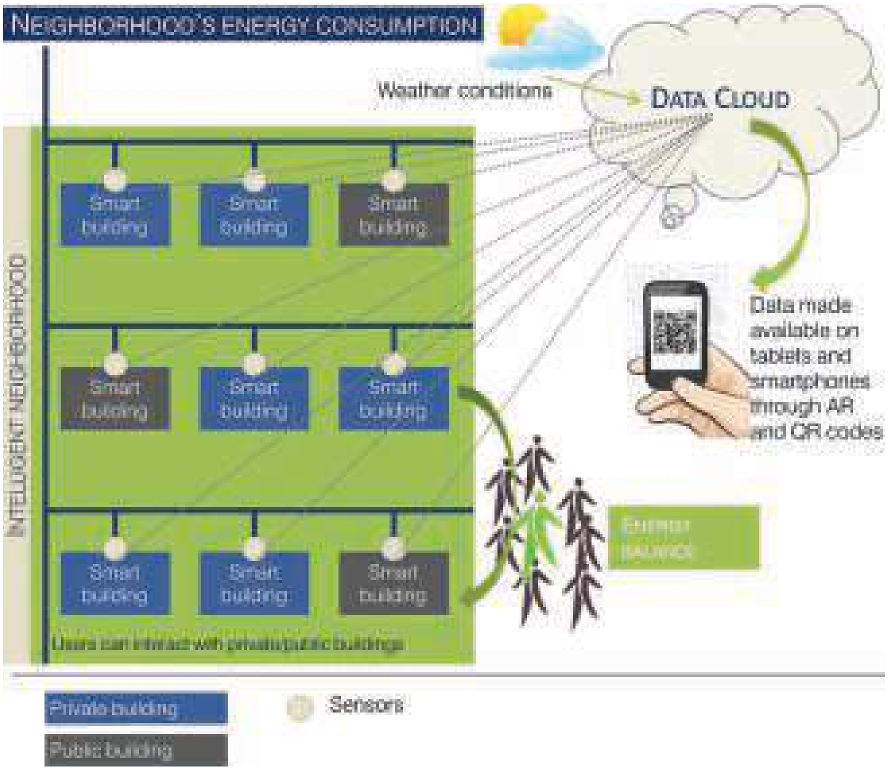
From an operational point of view, the project provides for the creation of a graphic model of the neighborhood through BIM parametric applications, whose database will contain data and information on architecture, structure and installations of the buildings, both public and private buildings, that will be chosen for testing.

The parametric model will constitute the starting point for developing the information platform, which will collect also other types of information on the neighborhood, such as utility networks, flows of people or rents.

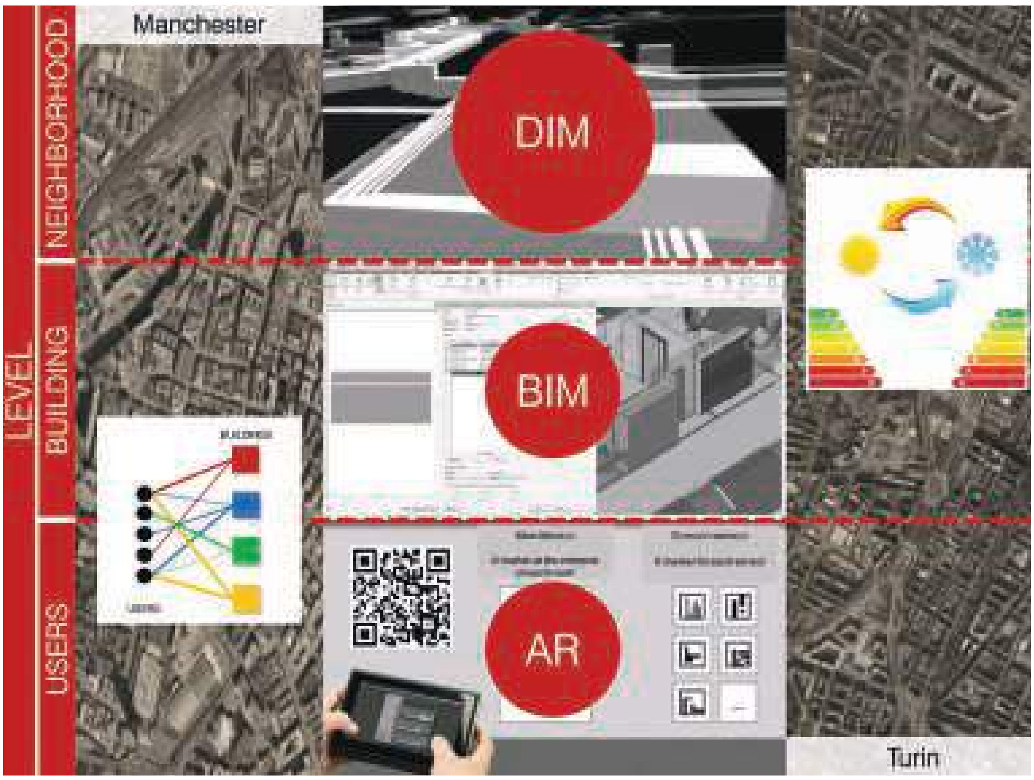
The middleware software and the network of sensors installed will perform data monitoring, collection, analysis, elaboration and dissemination.

The final objective is to create a parametric digital model to manage all information on a given neighborhood, including visualization of energy consumption trends and feedback from end-users, who could benefit from information on energy-saving opportunities.

Picture 6 Diagram of the *concept* behind the project DIMMER



Picture 7 Diagram of interaction levels involved in the project DIMMER



CONCLUSIONS

Both project SEEMPubS and its natural extension DIMMER intend to raise awareness of energy-related issues, by involving users through a differentiated use of ICT technology. As such technology is now deemed essential in all areas, these projects aim at showing the benefits of exploiting its potential to reduce energy consumption. Both projects are based on significant use of the BIM methodology, not just to digitally represent existing buildings but also for simulations and facility management.

BIM tools, in fact, offer a great support to integrate information and optimize the management process. Yet, there is still a number of issues to be solved, such as those mentioned in the previous paragraphs. In particular, the analysis of the formats used by different apps to exchange information is key to define common, interpretable and safe processes.[15]

A full and effective collaboration between professionals from different areas must be supported by perfectly functioning tools, technology and formats to exchange data and information, in order to avoid slowing down and jeopardizing analysis and simulation activities. One of the main issues here, in fact, is related to the transfer of information between different areas of expertise. Our case studies involved a considerable number of professionals and skills; the availability of a single information model undoubtedly offers advantages which were unthinkable until a few years ago. Critical aspects emerged though when transferring the graphic model to the different apps. Despite the use of different formats, such as IFC or gbXML, the expected results were only achieved through alternative methods, with a consequent waste of time and energy. Use of common data exchange formats (IFC and gbXML) is not straightforward and requires advanced IT skills to export a graphic model correctly. As we observed when transferring the model from design to lighting simulation environment, the optimal path identified cannot be classified as standard, representing instead a specific procedure to obtain a model containing all data and information entered in the designing phase. In short, the use of common data exchange formats showed a number of functional impairments, instead of being easy to use and immediately applicable.

Despite the above criticalities, our project successfully demonstrated that different skills and interdisciplinary cooperation can help achieve correct, updated and functional data exchange. This is highlighted also by the results of the project SEEMPubS, which should be consulted for more details[16]. In particular, the use of a single BIM model, specifically created for our case studies, was effective to carry out lighting simulations, as it allowed installing the network of sensors in the most appropriate way. At the same time, the BIM model provided the graphic/information support, along with the facility management application, needed to develop the afore-mentioned tablet app.

The analysis conducted so far represents the starting point for the project DIMMER, (due to start October 2013), where our study will be extended from buildings to a neighborhood level.

15 In the book *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, published in 2008, Eastman offers a series of tables showing a number of data exchange formats between different apps. However, the formats proposed did not always work correctly on the totality of data exchanged. This is due to many reasons, mostly the fact that the complexity of the model and the app updates, now on an annual-basis, often lead to the necessity of testing data exchanged, including, as in our case, new formats.

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Sitography

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Site of the software 3dMAX, URL: <http://www.autodesk.co.uk/adsk/servlet/pc/index?siteID=452932&id=14596087> [access date 25/09/2013]
Site of the application DBLink, URL: <http://wikihelp.autodesk.com/Revit/enu/2013/Help/00005-More_Inf0/0001-Subscrip1 /0096-Autodesk96> [access date 25/09/2013]
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IoT software infrastructure for Energy Management and Simulation in Smart Cities

Omitted for double blind review

Abstract—**This paper presents an IoT software infrastructure which enables energy management policy deployment and simulation in a city district. Such platform is a smart digital repository of various kinds of information about the buildings and the thermal grid. It leverages upon Web technologies and standards to integrate heterogeneous IoT devices and other district level data. The paper draws a real world case study, showing how the platform enables new district-level energy management policies exploiting fine-grained monitoring allowed by distributed sensors in the thermal grid and inside the buildings. Through the proposed platform, it becomes possible to assess in (near-)real-time the energy request profile of each building and correlate with environmental sensors and other information sources. Thus, this platform fulfills an unmet need in a smart city energy management, enabling the integration and correlation of IoT technologies, and the simulation of new energy policies in a district-level scenario.**

Index Terms—**Internet-of-Things, middleware, energy saving, energy flow simulation, Smart City, distributed software infrastructure**

I. Introduction

GLOBAL urban population reached more than 54% of the total global population [1]. For this reason, in an energy-intensive world, savings achieved by energy optimization of buildings is a key aspect. Furthermore, when dealing with thermal and electrical energy, grid aspects involving several buildings in a district must be taken into account. For instance, energy peaks smoothing requires the implementation of district-wide policies based on the knowledge of energy demands of all buildings in a district, as well as the grid model [2].

In this scenario, the new concept of Internet-of-Things (IoT) [3] emerged recently as a viable solution to "upgrade" our cities, by introducing "intelligence" in the buildings and in the environment. Indeed, the idea of IoT is the pervasive presence of "Things" (sensors, actuators, mobile phones, etc.) around us, which cooperate as a system of systems to achieve common goals [4].

With the introduction of district-wide resource management, new challenges have to be faced by IoT technologies and platforms. First, it is required to embed intelligence both at the building and grid level. Second, there is need for integration of new data sources and repositories, such as Building Information Models (BIMs) [5], grid models and Geographical Information Systems (GISs) [6]. The final purpose is to devise optimization policies capable of accounting for building and grid characteristics and evaluate their impact on user comfort.

For instance, considering the thermal grid, intelligent heat exchangers or heat pumps can provide information about building thermal energy demand. This information, correlated with the position of buildings in the grid (through GIS) and their construction characteristics (through BIM), can be used to optimize energy consumption in a district. From the other side, to assess the impact of policies on building habitants, intelligence inside houses can be deployed in the form of environmental sensors (e.g. temperature, humidity, luminance) to provide a measure of comfort level.

In this scenario, where not only buildings but also grid components are becoming connected things, an unprecedented amount of data is to be integrated. IoT platforms are instrumental both to calibrate energy policies such as energy peak smoothing and to tailor the customer experience, thus coupling district and user needs. The requirement for an IoT platform, in this context, is not only to enable real-time data measurement and historical data collection, but also to integrate other information such as grid model, BIM and GIS. By integrating building and grid models, it is also possible to perform building energy simulations to tune energy management policy impact on single houses or rooms. These simulations can be later compared with actual comfort measures given by indoor sensors. Moreover, such simulations are mandatory to evaluate policy impact in buildings where environmental sensors are not or cannot be deployed.

In the last decade, several frameworks have been proposed to exploit IoT technologies at building and house level [7] [8] [9]. Moreover, more complex distributed software infrastructures and middleware [10] [11] [12] are required to manage proprietary data exchange formats and protocols, which are mostly incompatible between them. A viable solution is thus a shared infrastructure based on a middleware, which needs to scale up rapidly and reliably and provide a uniform interface to all deployed technologies.

The following work presents a distributed IoT platform able to collect, process and analyze energy consumption data and structural features of systems and buildings of a district. In particular, data from Building Information Models [5] (BIMs), System Information Models [13] (SIMs) and Geographical Information Systems [6] (GISs) are interrelated and enriched with historical and (near-)real-time data from heterogeneous IoT devices deployed across the district to monitor and manage the energy distribution systems (both power and heating). Further, this infrastructure was developed by making use of Web Service technologies to provide uniform interfaces to data. Therefore, it acts as a shared repository of district information, in which different stakeholders, playing in a smart city scenario, collaborate and provide novel district services to share such information and exploit it to district level energy management and simulations.

This paper presents a real-world case study where the proposed platform has been deployed and evaluated in a city district, with several IoT devices connected to monitor and manage the heating distribution network. The proposed infrastructure is instrumental to store, correlate and provide: i) Historical and (near-)real-time data coming from IoT devices deployed across the district; ii) Geo-referenced information together with topological and parametric models for energy distribution networks and buildings. Finally, thanks to the proposed infrastructure, peak smoothing policies of the district heating network have been simulated and evaluated. These policies perform energy request re-scheduling to reduce district level energy peaks. Individual energy demands of buildings are re-scheduled to reduce the peak while keeping a defined level of comfort (i.e. internal temperature) for building habitants. The IoT platform exploits data from sensors installed in heat exchangers (i.e. the connected "things"), as well as network and building models allow to evaluate building impact on energy peaks. On the other side, user comfort is measured with building sensors. Also, the integration of building models in the infrastructure allows to compare building sensor data with results of building energy simulations. In general, this IoT platform enables a fine-grained monitoring of the energy distribution network across the city, also in (near-)real-time. Hence, more detailed information about energy request profiles are available, and more efficient control strategies may be implemented.

This article is organized as follows. Section II reviews relevant background literature. Section III introduces the proposed IoT software infrastructure for energy management and simulation. Section IV draws the real-world case study. Section V introduces the energetic policies, which may be exploited thanks to the proposed solution, and discusses the experimental results. Finally, Section VI provides the concluding remarks.

II. Related Work

Recently, different ICT solutions have been proposed to cope with the need of energy consumption optimization in Smart City domains. In the following the most relevant in this field are presented.

In a Smart Grid context, Kim et al. [14] presented a data-centric middleware to allow decentralized monitoring and control, exploiting a publish/subscribe model [15], which is appropriate for delivering information but is not yet sufficient to have data access that is independent of this model. Indeed, the request/response communication approach is also needed to provide novel services that can easily retrieve data without having to wait for new events.

In [16], a distributed software infrastructure for general purpose services in power systems is presented. The software architecture enables the interoperability across heterogeneous devices by creating a secure peer-to-per network.

Differently from these solutions, the IoT platform presented in this paper aims at creating a virtual model of a city district for providing Smart City services. Hence, considering data coming from IoT devices deployed across the energy distribution networks is not yet enough. Indeed, such data have to be integrated and correlated together with information, often geo-referenced, about buildings.

In the Smart City scenario, several middleware solutions have been proposed to integrate heterogeneous data sources. The ReActOR system, presented in [17], is characterized by a tiny footprint and can be deployed as a service. It is composed by three layers: a facade layer (Web Service), a core layer, and an extensions layer (providing support for different technologies). It enforces user authorization, and each user is mapped to set of devices that he or she can manage, control, and sense. Finally, ReActOR provides only identifiers for the different agents in the system, hiding user and device data. This middleware is limited to hardware devices and it does not support the integration of different data sources, such as Database Management Systems. Cândido et al. [18] presents an evolvable and customizable infrastructure, focused on interoperability, modularity, uncomplicated management and adaptation, and composed by a set of different components. Each component exposes its services to the network using open web standards, enabling the composition of interoperable modules. However, these approach is limited to industrial automation scenarios.

SemsorGrid4Env [19] provides a service-oriented architecture that eases the design of open large-scale semantic-based sensor network applications for environmental management. Further, it enables the rapid development of thin applications (e.g. mashups) and it allows the integration of real-time data with historical data from other heterogeneous data-sources. This solution is tailored to environmental management and cannot be applied seamlessly to city district setting.

For what concerns the interoperability across various application domains, different research projects and initiatives contributed to the definition of models and guidelines. For instance, the IoT-A project [20] provides an IoT reference model, allowing the description of an IoT solution by using shared building blocks, a reference architecture and general advices to IoT architects. On the other hand, the OneM2M alliance [21] aims to develop detailed technical specifications, to address the need for a common M2M Service Layer, using existing IoT and Web standards. However, it does not cover many aspects of IoT platforms, such as scalability, availability and deployment. FI-WARE [22], another research project, is devoted to design a service infrastructure for the Future Internet vision. Such infrastructure would be composed by

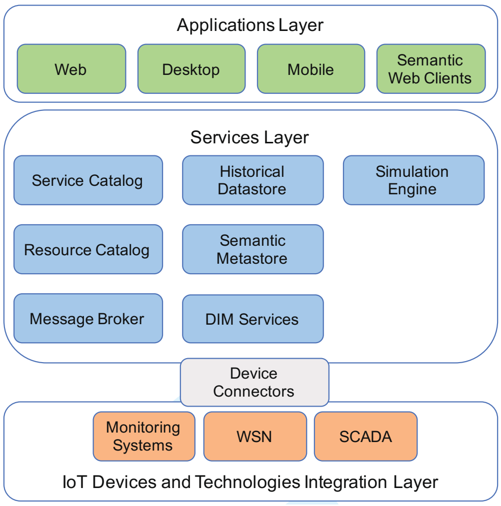

Figure 1. Architectural schema for the proposed IoT software infrastructure for Energy Management and Simulation

reusable components, which could be selected and complemented with additional specific components.

The novel contribution of the following work is the design and development of a distributed IoT platform, based on open standards of the Web, which creates a virtual parametric district model that can be queried as a whole by client applications. It is in charge of providing a standard access to heterogeneous IoT devices deployed across the city. Indeed, out IoT platform creates a uniform interface by using REST [23] Web Services and MQTT [24] APIs, Furthermore, it integrates different and heterogeneous technologies (e.g. Building Information Models, System Information Models and Geographical Information Systems), which are developed and maintained by several independent stakeholders, in several different locations, and by means of different standards and formats. Such stored information is correlated and enriched with historical and (near-) real-time data, collected by heterogeneous IoT devices deployed across the district. The information provided by the presented platform is then exploited as a shared open repository, where different actors can provide new services for the IoT-enabled management of energy consumption of a city. Such services can be used for energy simulations on alternative control policies for the energy distribution network.

III. IoT Software Infrastructure

Building a distributed IoT platform to create a virtual parametric district model for energy management and simulation is a challenging task. Indeed, such platform needs to transparently integrate hundreds of heterogeneous data sources and IoT devices, that may be exploited to monitor and manage energy consumption. Furthermore, it has to be scalable and reliable. For this reason, a suitable model is needed to step back and see the districts at a lower level of detail or to focus on specific entities (e.g. buildings, IoT devices). The proposed infrastructure implements a request/response communication paradigm based on REST [23] and a publish/subscribe approach based on MQTT [24] to cope with (near-)real-time requirements.

This IoT software infrastructure is based on the LinkSmart® OpenSource Middleware [25], adopting and extending it to address the requirements of a Smart City context. The tasks of the platform include: i) modeling of real-world IoT devices and ICT systems, ii) providing their search and discovery by applications, and iii) exposing their data via common application protocols. To implement these tasks, the platform defines several abstraction models and APIs implemented by a number of integration components and services described in this section. Figure 1 shows the architectural schema of the proposed software infrastructure. It consists of three layers: i) *IoT Devices and Technologies Integration layer*, ii) *Services layer* and iii) *Applications layer*. The rest of this section describes each layer in more detail.

A. IoT Devices and Technologies Integration Layer

The proposed IoT platform leverages upon ICT infrastructure made of heterogeneous devices and technologies, which exploit different communication protocols and standards. The *IoT Devices and Integration Layer* (bottom layer in Figure 1) takes advantage of Device Connectors to enable the interoperability among heterogeneous devices.

Device Connectors are integration components that use a common abstraction model to describe real-world IoT Devices and ICT systems integrating them in the middleware. The Device Connector is a middleware-based software component that acts as a bridge between the middleware network and the underlying technologies, devices, or subsystems. It exposes standard APIs for discovering and querying ICT data sources for each integrated system allowing seamless data access by the applications and other services. Instead of implementing system-specific and proprietary APIs of the integrated systems, the middleware clients use the same API to access data from all integrated systems.

B. Services Layer

The *Services Layer* is the core of the proposed IoT software infrastructure. It provides components specifically designed for accessing and managing information, coming from heterogeneous IoT devices and technologies, by exploiting a Web Service approach. It is also in charge of creating a virtual District Information Model correlating data from different data-sources. Finally, it offers features for simulating control policies aiming at optimizing energy consumption (e.g. electric, heating). The main components of this layer are described in the following.

1) Service Catalog: It describes the available services in the network, by exposing a JSON-based RESTful API. It is the entry point for applications, used to discover available services in the network. It contains entries of services such as the Resource Catalog and the MQTT Broker.

2) Resource Catalog: It provides a registry of IoT devices and resources which are available through the infrastructure. It also exposes a JSON-based RESTful API to: i) Device Connectors, which register their devices and resources, and ii) Applications, which discover such devices and their access protocols.

3) Message Broker: It provides asynchronous communication for the different components of the infrastructure, by means of the MQTT *[24]* communication

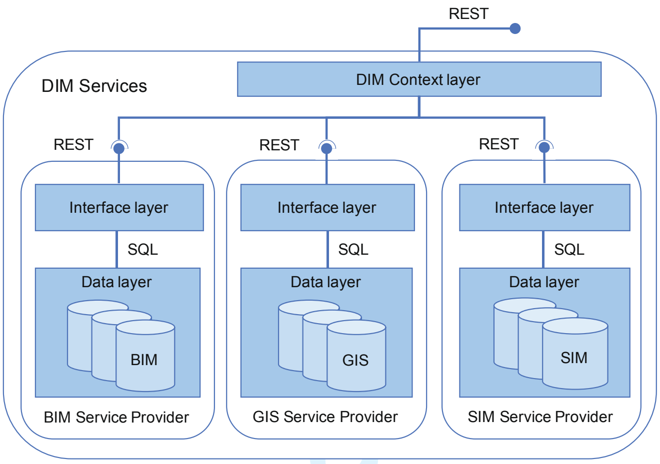

Figure 2. DIM Services schema

protocol. Such protocol is implemented following the publish/subscribe *[15]* paradigm, which allows the development of loosely-coupled event-based systems. Each device or component in the platform can i) publish information, and ii) subscribe to specific event notifications. This approach increases the infrastructure scalability, by removing the dependencies between interacting entities.

4) Historical Datastore: Querying historical data is one of the basic features of the platform required by IoT applications and services. Considering the heterogeneity of the data sources in a typical Smart City platform, it is essential to provide a unified API for accessing historical sensor data in such systems. The platform defines a Historical Datastore API that is implemented in a standalone service, as well as for each integrated ICT system that already provides a database with historical data and an API to access it. Hence, the standalone service implementation can be used for integration of new ICT or already existing data sources. In addition, it provides an optional aggregation functionality that can be used to down-sample high-frequency sensor measurements and calculate basic aggregates on them.

The integrated system-specific implementations of the Historical Datastore API allow to provide a unified API for accessing historical sensor data across all integrated systems without data duplication. Integrating historical data from a large ICT system can be indeed problematic to manage due to both its large volume, as well as the storage and access policies. By providing system-specific implementations of the Historical Datastore API, both of these issues can be tackled by forwarding data requests to the integrated system and enforcing access policies between the middleware and the data owners.

5) Semantic Metastore: Semantic interoperability is another important feature of the platform, which enables the use of Semantic Web technologies to annotate and interlink integrated data sources and query them using the semantic attributes. In addition to that, such annotations can also be used for describing higher-level services and applications, as well as to model real-world entities they operate with that are not directly managed by the platform.

This feature is implemented by the Semantic Metastore service, which builds on the off-the-shelf Semantic Web technologies such as Apache Jena [26] to provide higher-level, developer-friendly APIs for populating and querying the semantic knowledge base.

6) DIM Services: A District Information Model (DIM) is composed by different entities. In particular, it is possible to define three specific data sources, which are represented using relational databases, and can be integrated to get a comprehensive view of a district:

- ***Building Information Models*** (BIMs [5]) are parametric 3-Dimensional models, where each model describes a building - both structurally and semantically (e.g. by defining materials and costs [27]). BIM supports decisions for the whole building lifecycle;
- ***Geographical Information Systems*** (GISs [6]) map the geographical location and topology of district entities, such as district buildings or energy distribution networks: GIS provides data management and modelling for advanced cartography;
- ***System Information Models*** (SIMs [13]) describe size and structure of energy distribution networks. SIM is built to provide information for both visualization and simulation by exploiting parametric and topological data.

Despite the fact that all these data-sources could be represented using a relational database, no commonly agreed method is available to integrate and correlate them from the district point-of-view.

Because of such fragmentation, a single database for all heterogeneous data-sources cannot be deployed, because i) Database Management System (DBMS) technologies are mostly incompatible one another, and ii) the same value may have conflicting semantics between different databases.

Instead, the following subsystem is heavily based on RESTful Web Services and distributed deployment. The use of RESTful Web Services provides a uniform interface to each component of the system. In particular, the same response format is returned, independently from the actual queried data source. This also means that, if a component technology (e.g. a DBMS) changes, the client application receives the same response as a result of the same query. A bird's-eye view of the DIM Services subsystem is shown in Figure 2.

The subsystem is built in a micro-service fashion [28], i.e. it consists of a suite of small, autonomous, lightweight services. From a logical point-of-view, each component in DIM services consists of two independent sub-layers: i) *Data layer* and ii) *Interface layer*. In the following, the structure of the BIM Service Provider is presented, which is easily extended to GIS and SIM Service Providers.

The Data layer is a set of several databases, where each database represents a building in the district. The databases are managed by using a relational DBMS, which is able to store the internal representation of the BIM models (which have been created with proprietary software Autodesk Revit [29]).

The Interface layer provides a RESTful Web Service interface to the underlying databases. It interacts with the Data layer by using SQL queries and preparing JSON results. Furthermore, it also provides building resources, such as proprietary (Revit files) and public BIM standards (IFC and gbXML).

As depicted in Figure 2, within the District Information Model other kinds of data sources are needed, to complement the BIM information. In particular, GIS and SIM have been identified. Both these data-sources need a Web Service interface, to be integrated into DIM Web Services by means of DIM context layer. Both the GIS and the SIM Service provider return JSON results through the REST API.

On top of each Service provider, there is the DIM Context layer, which is the main interface to district information. It creates a virtual parametric model of the district that can be queried as a whole by client applications. It acts as a translator from the district context (district-based queries) to a specific data-source context (e.g. building-based queries). Conversely, it also integrates back responses from the different Service Providers to a single response.

Moreover, the DIM Context layer is independent from each Service Provider Interface layer, and it behaves as a proxy to the latter. By using inter-provider queries, it is able to compose complex queries, which may span different information domains (e.g. building and geographical information). For instance, by querying both the BIM and the GIS Service Providers, it gives the capability of retrieving information about buildings composed by a specific number of storeys.

7) Simulation engine: It is a specific component of the proposed IoT software infrastructure used to integrate control policies and to perform energy simulations in a district environment. It consists of a Web Service enabled interface, which provides a standard entry-point to the district simulator. In addition, the Simulation engine provides features to develop control policies, able to retrieve information from all the other platform components exploiting both publish/subscribe and request/response communication approaches (MQTT and REST respectively). Hence, such simulations can take into account both District Information Models and historical or (near-) real-time information coming from the heterogeneous IoT devices to optimize the energy consumption.

It is worth noting that the Simulation engine module is able to perform simulations for the different energy flows in the district (e.g. electrical and heating). Section V provides a more in-depth description of control policies for the district heating network.

C. *Applications Layer*

The *Applications Layer* (the highest layer in Figure 1) provides a set of APIs and tools to develop applications to manage and post-process data coming from the underlying layers of the proposed IoT infrastructure. Such applications may be web-based (e.g. online dashboard for visual management of the district using cartographic maps), mobile (e.g. mobile app for facility managers), desktop and semantic web-clients. At this level, the interoperability among different IoT devices and technologies is enabled thanks to the Web Services approach.

IV. Case Study

This IoT platform has been developed to provide smart city services for energy management in a smart city context. As main case study, this platform has been deployed and tested in a real district. In such district, the heating distribution network (DH) provides thermal energy to about 50% of private and public buildings. Furthermore, Wireless Sensor Networks (WSN) have been deployed to collect indoor data about air temperature and relative humidity on seven representative buildings.

The heating network in the city under investigation is one of the largest in Europe, being composed by about 580 km of double pipeline, with more than 5700 buildings connected (over 55% of the town). The thermal request is highly variable during the day and during the heating season. In particularly daily request presents a morning peak of about 1300-1400 MW while the afternoon request ranges from about 850 MW in typical winter days to about 400 MW in typical middle season days. Such request is fulfilled mainly through three efficient cogeneration systems, able to produce a total thermal power of about 740 MW, while the exceeding request is covered using thermal storage units and auxiliary boilers.

Currently, in the selected district, a large number of IoT devices (about 4000) are deployed for monitoring and managing the DH. They collect data (e.g. instantaneous power, cumulative energy consumption, water flows and temperatures) every five minutes. Data is then sent to remote Historical Datastore unit by means of embedded gateways, which monitor the heat exchanger of each building. Each gateway is accompanied by a GPRS modem and executes the following tasks: i) scheduling of data collection, ii) management of IoT sensors, iii) communication via GPRS, and iv) data transfer to remote *Historical Datastore*. The *Historical Datastore* for DH consists of four dispatchers, to improve reliability and scalability. Each measurement is sent to a different dispatcher, which forwards it to a database.

Differently, a significant part of the infrastructure consists of heterogeneous data sources, e.g. Building Information Models. Such models have been prepared for selected buildings and, the corresponding SIM, for the district heating network.

This paper assesses how this infrastructure is beneficial: i) to optimize the energy demand, ii) to manage a large number of IoT devices, and iii) to exploit of parametric models for energy simulations. In particular, BIMs allow fine-grained energy simulations, down to the room level, and are useful to plan retrofitting of existing buildings.

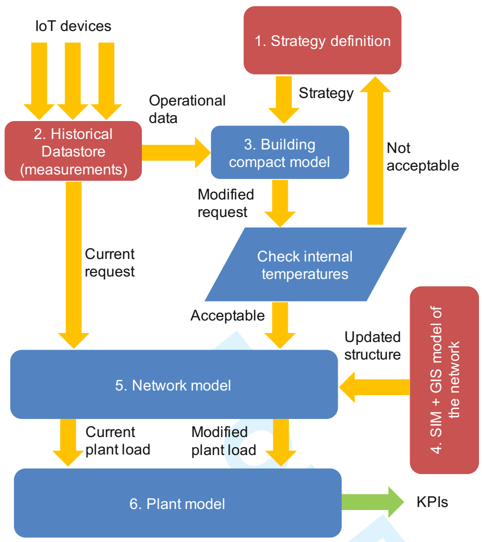

Figure 3. Procedure for the analysis of alternative thermal request profiles

The most popular construction types in the selected district are load-bearing masonry (mostly used until the '50s) and reinforced concrete. Many cases present a mixed solution between the two technologies. For this reason, seven representative buildings have been considered and WSN sensors for indoor air temperature and relative humidity have been deployed on them. They exploit the Device Connector component to be integrated into the proposed software infrastructure. In particular, such sensors communicate in (near-)real-time using the MQTT protocol [15] [24] and send collected data to a Historical Datastore.

For this case study, a Primary School in the selected district has been chosen. This primary school was originally built in 1902 and almost totally rebuilt at the end of the World War II. The building structure is a three storey load-based masonry with a heavy massive envelope. The main heating supply is based on radiators. Such rooms have been selected considering the orientation Three representative rooms have been selected to better describe the air temperatures trends of the case study and the building shape: the first room (S) is oriented to South, the second room (E) to East and the third room (N) to North-West. Further, the room N is also located in the highest floor of the North-West corner of the primary school.

V. Energy Optimization Results

A. Methods and Policies

In order to reduce the primary energy consumption to supply heating to the buildings connected with the district heating network, the use of cogeneration should be maximized. This can be achieved through thermal storage [30] but further improvements can be achieved through optimization of the thermal request profiles of the buildings. Such action is particularly important considering that the district heating network is in continuous evolution, with increasing number of buildings connected to the network. Instead, the built of new storage units has to face the issues related with land occupation and also the investment costs. The availability of the IoT infrastructure previously described allows the

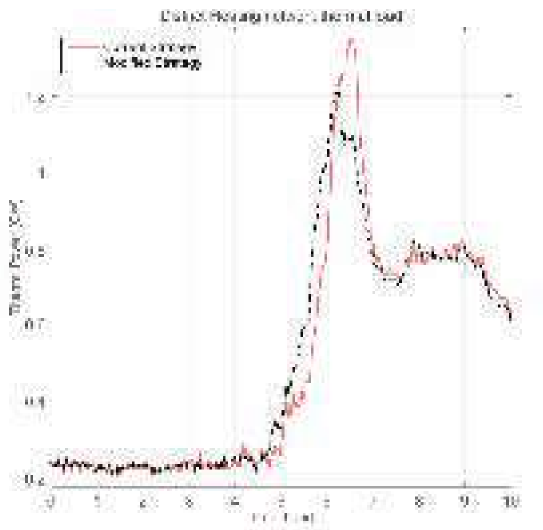

Figure 4. Thermal loads in a typical winter day obtained by using the current request profiles and the modified request profiles

implementation of an innovative approach for the analysis of alternative thermal request profiles, which are able to produce similar effects than thermal storage units. In particular, by means of the Simulation Engine presented in Section III.B, it is possible to run thermal request simulations following the approach described in Figure 3.

In **Block 1** (Strategy Definition), an alternative thermal request profile for a specific building is defined. In **Block 2** (Historical Datastore - measurements) the measurements, collected by the IoT-enabled heat exchangers in the buildings, are retrieved from the Historical Datastore of the infrastructure. Subsequently, the algorithm computes the daily thermal consumption associated with the current request profile, as well as: i) the evaluation of the status of the heat exchanger, ii) the values of parameters characterizing the heat losses and the dynamic behavior of the building [31]. The latter quantities are calculated every day, taking advantage of almost steady state behavior reached in the afternoon and transient evolution when the heating system is switched off or attenuated. **Block 3** (Building compact model) assesses the feasibility of the proposed strategy for the building, as it compares the expected average internal temperatures resulting from the proposed rescheduling with the original scheduling. The acceptability of the internal temperature is imposed as a constraint for the new scheduling, which can be adjusted in the case it is not acceptable.

Block 4 (SIM + GIS model of the network) represents an additional input for this tool. It retrieves from the DIM Services component of the infrastructure the SIM model of the network with geo-referenced information (GIS) of the various sub-networks. This model defines the physical structure of sub-networks, and it is updated every year to properly consider possible expansions of the district heating to new areas or possible connection of additional buildings. **Block 5** (Network model) performs the thermo-fluid dynamic simulation of the district heating network in order to transform the thermal request of the users into thermal load for the plants. The physical model of the network is fully described in [32].

Finally, **Block 6** (Plant model) performs calculation of the KPIs referred to energy and environmental impacts resulting from comparison of the current request profiles and the new profiles. Main KPIs are the reductions in primary energy consumption and CO_2 emission. In order to proceed with the simulation at building level, the thermal request simulation produces set points and heat scheduling for each heat exchanger. Such control policy is feasible thanks to the fine-grained monitoring provided by the proposed platform, and by the IoT devices deployed in the buildings. Detailed information about energy consumption of buildings served by the heating network are available, also in (near-)real-time. Indeed, thanks to this pervasive IoT platform, it is possible to quantify the energy request profile of each building and not only the cumulative heating request profile at the energy power plant.

To evaluate the impact of the new district heating control policy, simulations were also performed at building level. These simulations take as input the BIM for the building developed with Autodesk Revit 2015. Taking into account the building typology, the BIM is compiled with each building feature. By means of the DIM Services component of the infrastructure, the BIM model is then imported into the IES Virtual Environment by using the gbXML standard format. The Building Simulation Engine is compiled setting the room occupancy and using heating set points and schedules provided by the district thermal request simulation.

Subsequently, the Building Simulation Engine estimates thermal parameters such as the indoor temperature and thermal comfort for the building. Furthermore, for buildings under analysis, temperatures are then compared with the real measurements operated in selected rooms, where IoT sensors have been deployed. Every 15 minutes, these devices send monitoring information through the Message Broker to the Historical Datastore. In particular, this paper presents the results of simulations performed for the selected building on working days, when the primary school is occupied by users.

B. Experimental Results

In order to evaluate possible benefits that can be achieved though proper change of the thermal request profiles of the buildings, two scenarios corresponding with a typical winter day for the city under investigation are considered. Figure 4 reports the thermal loads of the plants: in the reference scenario (solid line), the current request profile of the buildings is considered. In a second scenario (dashed line), the request profiles of 50% of the buildings is modified by anticipating or postponing the time the heating system is switched on. The alteration is within a period smaller than 30 minutes, but the request profile curve of each building is unmodified.

Figure 4 shows that peak request is reduced of more than 120 MW and, more important, about 0.14 GWh of heat is moved from the periods exceeding the total capacity of the cogenerators to periods characterized by a total load smaller than the capacity of cogenerators. This means that this amount of heat can be produced using the cogenerators instead of

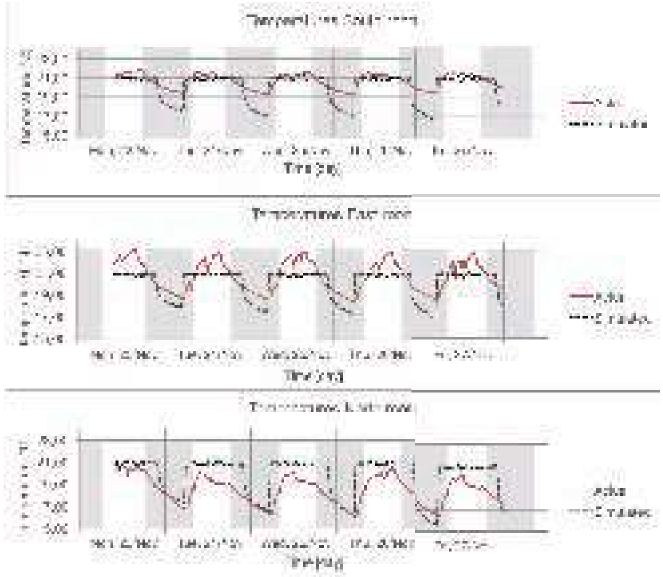

Figure 5. Simulated and actual temperature trends for selected rooms

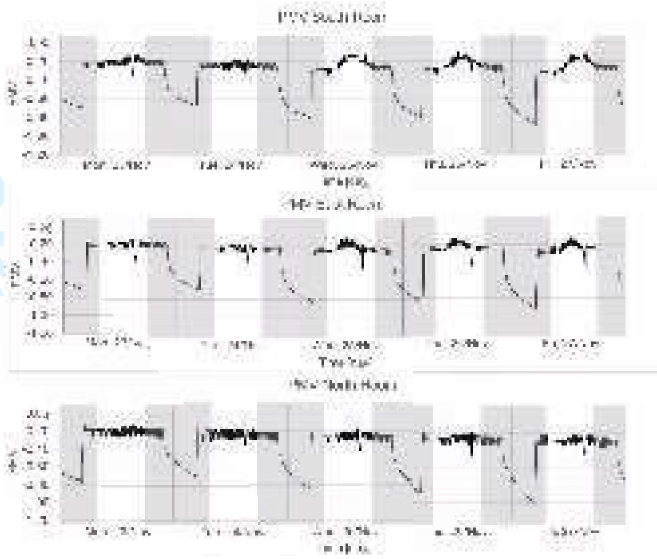

Figure 6. PMV methodology for proposed schedule for selected rooms

auxiliary boilers. A corresponding reduction of 3% in the primary energy consumption is achieved. It is worth highlighting the fact that application of a strategy, aiming at optimizing the shape of the thermal request profiles of the buildings, would result in an even larger reduction in the primary energy consumption.

TABLE I
ENERGY SCHEDULES FOR SELECTED BUILDING

	Start	Pause	Restart	Stop
Current	5:30 am	---	---	10:00 pm
Proposed	5:00 am	3:00 pm	3:30 pm	10:00 pm

Then, the building model is applied to the evaluation of the acceptability of the changes in the thermal profiles in the various buildings. This means that when the thermal request profile of a building is modified, internal temperatures are checked so that the new comfort conditions are acceptable for the end-users. The current and the proposed (anticipated) schedules for the primary school are shown in TABLE I. At building level, the comfort has been estimated using the temperature trends and by exploiting the Predicted Mean Vote methodology (PMV) [33], which is a measure of thermal comfort of the building. PMV has been estimated for i) the current energy distribution schedule and for ii) the schedule proposed as output from the district model.

First, simulated and measured temperatures from IoT devices have been compared to assess whether the model was able to simulate correctly a real world building. Indeed, the use of IoT devices, which can be exploited through the infrastructure, allows an unprecedented fine-grained measurement of indoor conditions that can be used to validate simulation models.

TABLE II
DIFFERENCE BETWEEN SIMULATED AND MEASURED TEMPERATURE (CURRENT SCHEDULE)

ΔT sim. - meas.		Room S	Room E	Room N
Max	[°C]	1.74	2.70	4.76
Min	[°C]	-2.87	-2.35	-1.05
Average	[°C]	-0.60	-0.64	1.30
St. Dev.	[°C]	0.96	1.06	1.17

Figure 5 depicts the actual and simulated (with the current schedule) temperature trends for the three selected rooms (S, E and N). The trends are estimated only for the primary school working days (Monday to Friday). Vertical white bands highlight the primary school's working hours (8 am - 5 pm), while vertical grey bands identify the hours when the building is not occupied by users. A brief description of temperatures is also provided in TABLE II. The best case is room S, which is oriented to the south and therefore is constantly exposed to the solar radiation during the day. In this case, the average difference between the actual and simulated temperature trends is 0.6 °C with a standard deviation of 0.96 °C. Differently, room E and room N cannot fully benefit of solar exposure during the day. Room E has a more variant trend during the day, due to its discontinuous exposition to solar radiation (average difference 0.64 °C, standard deviation 1.06 °C). The worst case is room N, which is located in the north-west corner of the highest floor of the primary school (average difference 1.30 °C, standard deviation 1.17 °C). As depicted in Figure 5, the building simulation is only a sub-optimal approximation of the actual building behavior. In particular, actual indoor air temperature may be affected by unforeseeable factors (e.g. the number of open windows), which can be instead detected with appropriate IoT devices.

Finally, to better assess the degree of comfort, the PMV methodology has been used to compare the current energy distribution schedules and the schedules proposed by the output of the district simulation. As shown in Figure 6 and reported in TABLE III, the PMV estimate for the proposed schedule has a variable range of comfort between -1.01 (slightly cold) and 0.10 (slightly hot), with an average of -0.37 (slightly cold), where 0 is the ideal value on a scale from -3 (cold) to 3 (hot). The corresponding PMV estimate for the current schedule has a variable range of comfort between -0.95 (slightly cold) and 0.03 (slightly hot), with an average of -0.35 (slightly cold). It is worth noting that the PMV estimate takes into account also the hours when the school is not occupied by the users. In Figure 6, the school working hours (8 am - 5 pm) are highlighted by vertical white bands.

TABLE III
PMV CURRENT SCHEDULE VS PROPOSED SCHEDULE

		Room S	Room E	Room N
Current	**Min**	-0.95	-0.95	-0.95
	Max	-0.02	-0.09	0.03
	Avg	-0.36	-0.35	-0.35
Proposed	**Min**	-0.89	-0.94	-1.01
	Max	0.10	-0.10	-0.08
	Avg	-0.37	-0.36	-0.38

In the presented case, the building simulation supports the adoption of a new energy distribution schedule by the energy provider, that promotes energy saving (at the district level) without compromising the user comfort (which has been estimated using the building model).

VI. CONCLUSION

This work presented a novel IoT platform for city district data management and energy flow simulations. In particular, this platform is instrumental i) to integrate heterogeneous IoT devices for monitoring and management of a whole city district; ii) to share building and energy network resources, both for visualization and simulation of energy policies, at building and district level; and iii) to assess the quality of the energy model of buildings.

The presented platform is designed and developed following the micro-service paradigm, and it is able to scale up reliably. Further, the use of shared open standards of the Web makes it easy to integrate into existing systems.

Finally, this platform satisfies the need for an energy management system for a city district, which is currently unmet in state-of-art applications. As shown in the real world case study, this platform is suitable to run energy distribution policies simulations from the district level down to the building room level, with a special focus on both district energy savings and end-user comfort level. It is worth noting that such policies are feasible thanks to the fine-grained monitoring provided by the proposed IoT platform.

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Urban Data
Tecnologie e metodi per la città algoritmica

10. District Information Models. The DIMMER project: BIM tools for the urban scale

di *Anna Osello - Politecnico di Torino, Andrea Acquaviva - Politecnico di Torino, Matteo Del Giudice - Politecnico di Torino, Edoardo Patti - Politecnico di Torino, Niccolò Rapetti - Politecnico di Torino*

10.1. Introduction

To transform an existing district in a smart district in the field of energy reduction, according to Horizon 2020 program, it is necessary to understand the complex phenomena typical of a city and to know how to manage a large amount of data. For this reason, Information Communication Technology (ICT) is becoming a key factor to enhance energy optimization in cities. As a matter of fact, thanks to ICT it is possible to access real-time information about building environmental characteristics and energy consumption (at building scale) as well as about district heating/cooling and electricity grid (at district/city scale).

Despite the availability of mature technologies for monitoring energy in buildings, at the moment these technologies are not of widespread use by energy and facility managers and in private households. Nevertheless, tools like middleware and Building Information Modelling (BIM) can help to change this because of their ability to create a data infrastructure where different systems are able to interact each other. In fact, middleware enables the use of an interface able to monitor and control heterogeneous devices because these sources of information can be put together in a centralized decision system; on the other side, BIM enables digital management of building characteristics and parameters storing them in a database.

The DIMMER (District Information Modelling and Management for Energy Reduction) project (October 2013 – September 2016) represents an E-volution of the use of BIM, extending its use from buildings (building scale) to district (urban scale), simultaneously expanding the areas of study thanks an interdisciplinary use of ICT based on interoperability. The project started from the results of the SEEMPubS (Smart Energy Efficient Middleware for Public Spaces – September 2010 – August 2013) project, in which, different technologies for energy monitoring and control have been tested/developed, in conjunction with specific activities aiming to raise end-users' awareness of energy-related issues.

The basic concept behind District Information Model (DIM), introduced for the first time by the DIMMER project, is to implement the BIM philosophy and extend it to a district level, using common data at both building and district scale, involving a plurality of users, starting from both technical and social aspects. The goal is to create a web-oriented interface able to collect data and information on the single buildings and the district as a whole, including data and information on their energy requirements.

The aim of this chapter is to show a possible way to connect BIM and GIS (Geographic Information System) focusing on alphanumeric information, developing a DIM starting from data modelled at different LODs (as Level of Development) for both BIM and GIS, and using a middleware to query several kind of information for different users. For this reason, different tools are considered to visualize data about public and private buildings (such as schools, university campuses or municipal buildings as well as residential) in different ways for different users/stakeholders using Virtual and Augmented Reality (V&AR). Furthermore, within the DIMMER project, APPs like a dashboard and a benchmarking tool are under developing to visualize real-time energy consumption, in order to lead a considerable educational impact for the citizens.

10.2 Reason of a research: towards a District Information Model

Nowadays, there are several researches and industry efforts aiming at developing new technologies and platforms able to handle large amounts of data from multiple buildings in order to perform energy simulation using environmental monitoring and its digital visualization. One of the major challenges concerns the interoperability between heterogeneous devices as well as between different software.

Due to this, nowadays, the interaction between different domains is one of the major challenges required to Architecture, Engineering and Construction (AEC) industry, using correctly ICT. Of course, the integration of different dataset such as Building Information Model (BIM), Geographic Information System (GIS), System Information Model (SIM) and Building Automation

System (BAS) requires a common platform able to visualize different kind of data at different scale, focusing on both geometrical and alphanumerical information. In this context, within the DIMMER project:

- BIM is a 3D parametric model of buildings, enriched with semantic information such as measures, materials and costs;
- GIS provides geographical location of buildings, energy distribution networks and/or other elements and it is used for data automation and compilation, management, analysis and modelling of advanced cartography;
- SIM collects dynamic and static information from district energy network, such as substation heating temperature, geometrical data about pipes and connection with the systems of the buildings;
- BAS consists of a temperature and humidity sensor framework aiming to collect data, improve occupant comfort and efficient operation of building systems, reduce energy consumption and operating costs.

Obviously, parametric models created in different domains have different characteristics because they refer to different information. For example, GIS is adopted at urban scale while BIM at building scale and for both of them it is requested the ability to exploit geometric and alphanumeric information. Unfortunately, the data sharing between these two domains is not easy and interoperability plays a key role.

The DIMMER project is investigating a chance to evaluate the value of interoperability creating a new information model: the District Information Model (DIM), that can be compared with a Unified Building Model (UBM) [EMOS12].

In UBM, CityGML and IFC models are encapsulated, thus avoiding translations between the models and loss of information. All classes and related concepts has been collected from both models, concepts has been merged, new objects have been created to ensure the capturing of both indoor and outdoor objects, and finally, spatial relationships between the objects has been redefined.

According to UBM, the DIM provides heterogeneous data from different data sources (BIM, GIS, SIM and BAS). The main difference is the development of a multi-service platform able to receive data coming from both real-time monitoring and digital models, and not only by the overlap of geometric information.

10.3 Methodology

One of the main innovation introduced by the DIMMER project is the middleware able to simultaneously handle data from different heterogeneous domains, focusing on:

- Analysis of environmental condition due to geographic and morphologic characteristics at both building and urban scale.
- Interoperability between different data sources.
- Integration of real time data from building scale (BIM) to urban scale (DIM).
- Use of web-based interface to improve people's awareness on energy saving/efficiency, using virtual and augmented reality.

Potential users of the DIMMER technology have been identified (Public administrators, Energy utility professionals and Estate managers) in order to guarantee different information based on a well-defined multi-scale geometric data usage (from building scale to urban scale and vice-versa). In fact, for each user different kind of information have been identified/modelled and different visualization tools are under test/development.

At this stage of the research, district data are stored in different databases that can share information through the DIMMER Middleware, exploiting the web services provided by both BIM and GIS Service Providers. Information is extracted using different DIM Levels of Detail (DIM-LOD) based on the users' needs, as detailed below in this chapter and as summarized in Fig. 01.

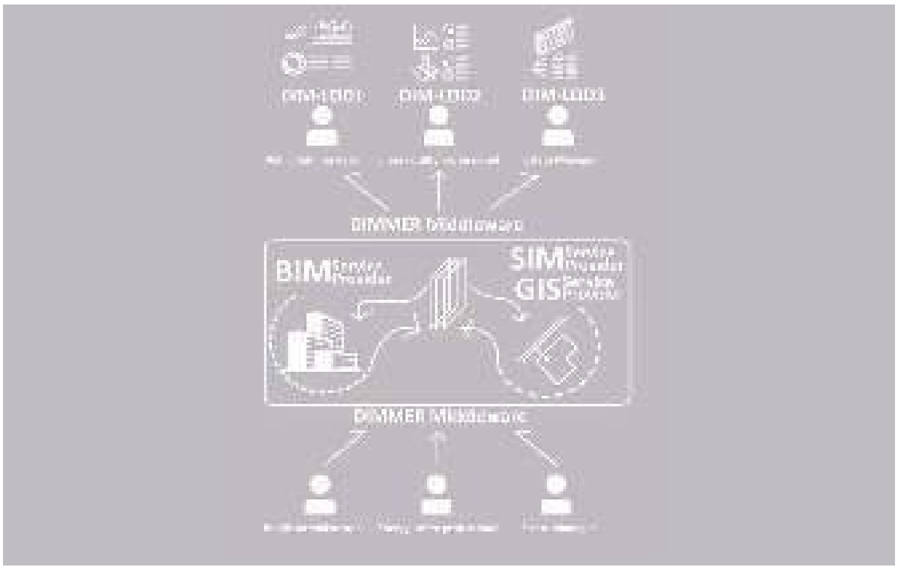

Fig. 01 - A possible usage of the DIMMER middleware by different users (for both, data input and output).

10.3.1 District knowledge: working with representative and replicable case studies

In order to guarantee the replicability of the results, for the DIMMER project two demonstrators were selected in Turin (Italy) and in Manchester (UK). In this paper the attention is focused on the Italian one (named "Politecnico district" because is the area around the main campus of Politecnico), composed by public and private buildings mainly connected to district heating.

In terms of energy resources, the selected area in Turin features a low emission thanks the presence of the district heating. From the electricity grid point of view, although small renewable plants are present, they are used only for dedicated building electricity production, with little impact on the electricity grid balancing.

Concerning building types, the selected district in Turin includes heterogeneous buildings in terms of dimension, construction period (end of 1800 to 2013), orientation, usage (offices, laboratories, private houses, etc.) and users (students, private owners, workers, etc.) as shown in Fig. 02 below.

To better explain this, a DIMMER Matrix has been created to highlight the heterogeneity of the representative case studies selected.

Fig. 02 – The selected buildings for the demonstrator in Turin.

At present the matrix is composed by four areas, and each part is organized in several fields coming from different data sourceqs: BIM, GIS, SIM and Measurement of energy using sensors (MEA). In this way, heterogeneous data coming from building scale to urban scale (and vice versa) are collected, starting from the fact that usually these data are stored in different ways on each country (see Fig. 03 below).

Going in deep, the field Case Type is a link to another matrix that describes the building typology of each case study. In this way, it is possible to visualize each component of the building envelope, related to the selected building typology. Each component is described with the name, the U-value, etc., starting from the data available from the IEE Project TABULA, where residential building typologies have been developed for 13 European countries. The U-value in the matrix is reported following the TABULA U-value, matching each case study with the reference values.

Fig. 03 – The DIMMER matrix of the selected case studies in Turin and in Manchester.

Adding to this data, specific information of each case study are available in a DIMMER Schedule, where it is possible to find geometrical data such as S/V value and physics/thermal information about the different components of the buildings. In this way it is possible to synthetize all the selected information about the buildings. Starting from the identification of the building components, such as roof type, external wall, transparent shell, window type, etc., it is possible to suppose the stratigraphy of each components and consequently to obtain the U-value necessary to proceed with the energy simulation of the buildings using specific software (that for the DIMMER project is Energy Plus).

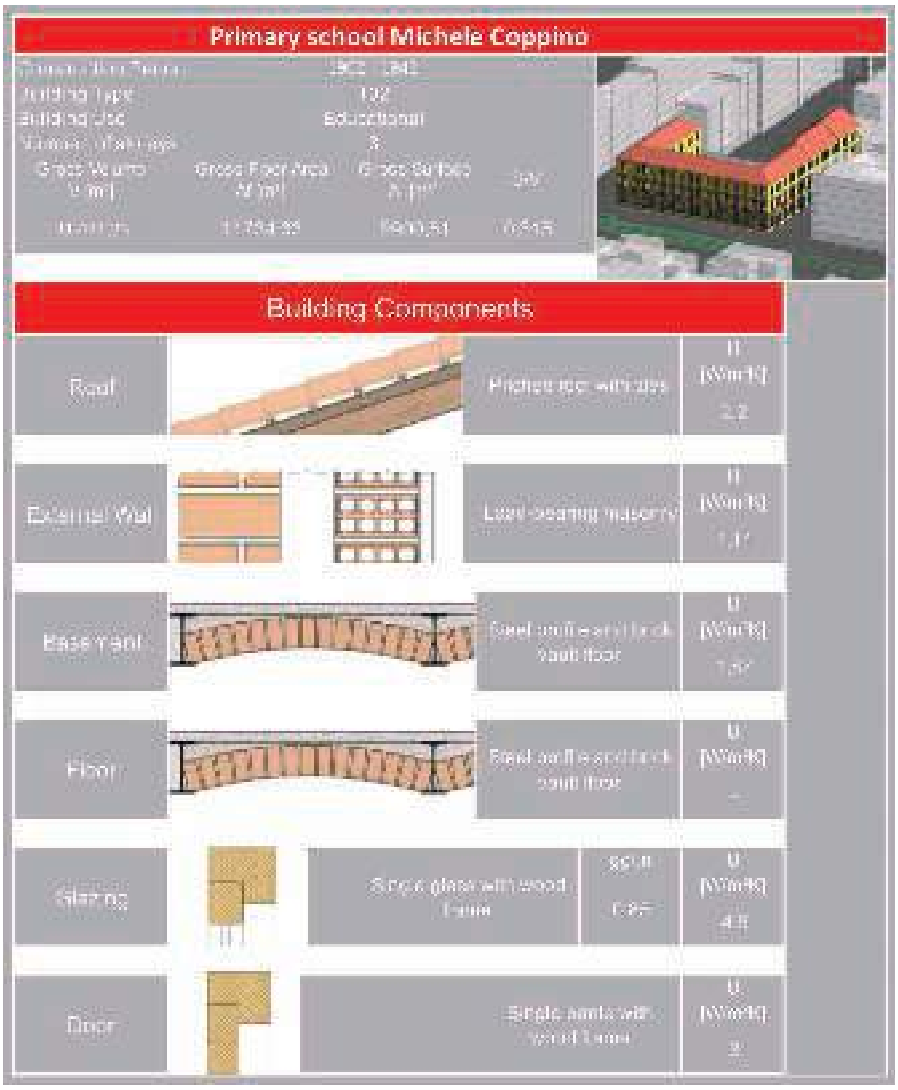

Fig. 04 – The DIMMER Schedule containing the description of the building components based on the TABULA methodology.

Each field in the DIMMER Matrix is characterized by a colour that depends on the availability (or not) of the data. This visualization highlights the heterogeneity of the information collected and underlines the difficulty that characterize the work with existing buildings. Based on preliminary results of the project, the graph below (see Fig. 05) shows that 59% of data are reliable or assumed while the 41% of data is not available (assuming no costs for technical analysis).

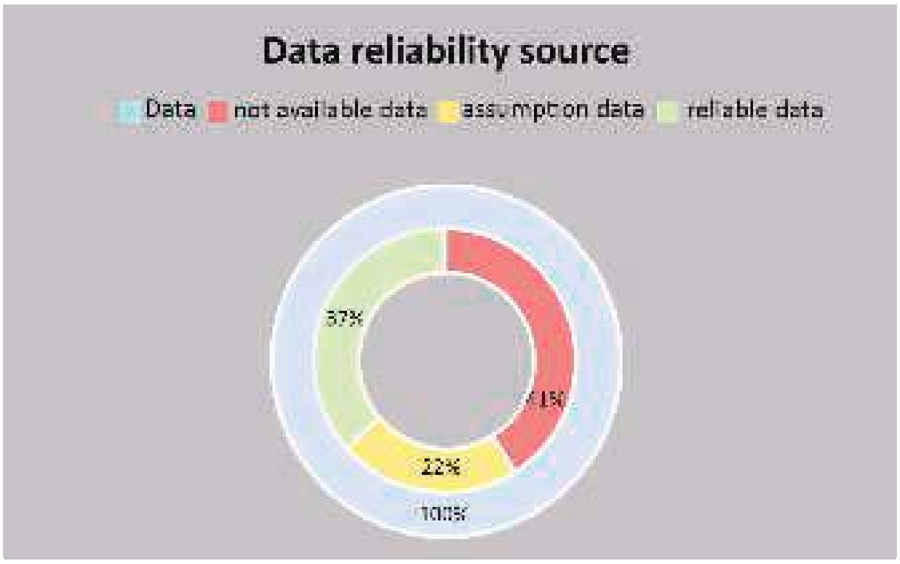

Fig. 05 – The data reliability source within the DIMMER case studies.

From an operational point of view, linking the buildings and the district heating characteristics, the project provides a graphic model of the district through BIM parametric applications, whose database are able to contain data and information about architecture, structure and HVAC (Heating, Ventilation and Air Conditioning) systems of the selected buildings. The direct applicability of the DIMMER strategy on the buildings depends on the shape of their thermal request for all the selected buildings as shown in Fig. 06 below.

Category	Buildings	Normal occupancy time	Thermal System Schedules
Residential	T15 - University student accomodation Renato Einaudi	0.00-24.00	5.00-21.30
	T06 - Building Pigafetta 32	0.00-24.00	6.30-22.00
	T07 - Building Mediterraneo 130	0.00-24.00	6.30-21.00
Educational	T01 - Politecnico di Torino	7.30-22.00	5.30-21.30
	T12 - Primary school Michele Coppino	0.00-24.00	6.30-22.30
	T03 - Kindergarten Paolo [illegible]	0.00-24.00	0.00-6.30 11.30-18
Administrative/Officies	T1[illegible] - Turin Municipality Smart City Directorate	7.00-20.00	4.30-21.00

Fig. 06 – The shape of the thermal request for the selected buildings in Turin.

In the case where the time of utilization of the heating system was not compatible with the application of peak shifting, an indirect application of the DIMMER strategy is possible through the installation of a local thermal storage systems. In this case, it is worth stressing that the direct applicability depends on the time delay, caused by the water velocity in the district heating network, between thermal request of the buildings and thermal load of the plants.

It is also worth considering that time shifting is applied with the aim of guaranteeing that internal temperature set-points are reached at the same time or before the base case (i.e. scenario without time shifting). Therefore heating schedule should not be considered as a constraint to keep, but one of the criteria to be considered while examining the suitability of a building for the application of the DIMMER strategy.

10.3.2 The DIMMER platform/framework

Following the Smart City view, the DIMMER platform was developed where one of the key elements is the decentralized data management approach of microservices. The services use their own views or concept of the Internet of Things (IoT) devices as well as storage backends to store their meta-data (decentralized data storage), building a hierarchical abstraction model. The core of DIMMER platform is the Middleware, that integrates heterogeneous IoT devices and ICT system in the platform. The tasks of the middleware include the following: (i) providing modeling abstractions of real-world IoT devices and sensor systems, (ii) enabling search and discovery of these devices and their resources by applications and services, (iii) providing unified APIs and protocols for historical and (near) real-time sensor data access.

The microservice architecture is necessary to ease the management and simulation of energy consumption at urban district level exploiting middleware technologies to integrate heterogeneous data-sources. It aims at providing a common and open digital repository for energy-related information of the district itself. To achieve this, the LinkSmart middleware has been extended with specific modules for addressing the requirements to manage and correlate information coming from the whole district. As shown in Fig. 07, it is a three-layered architecture consisting of (i) Data-sources integration layer, (ii) Services layer and (iii) Application layer.

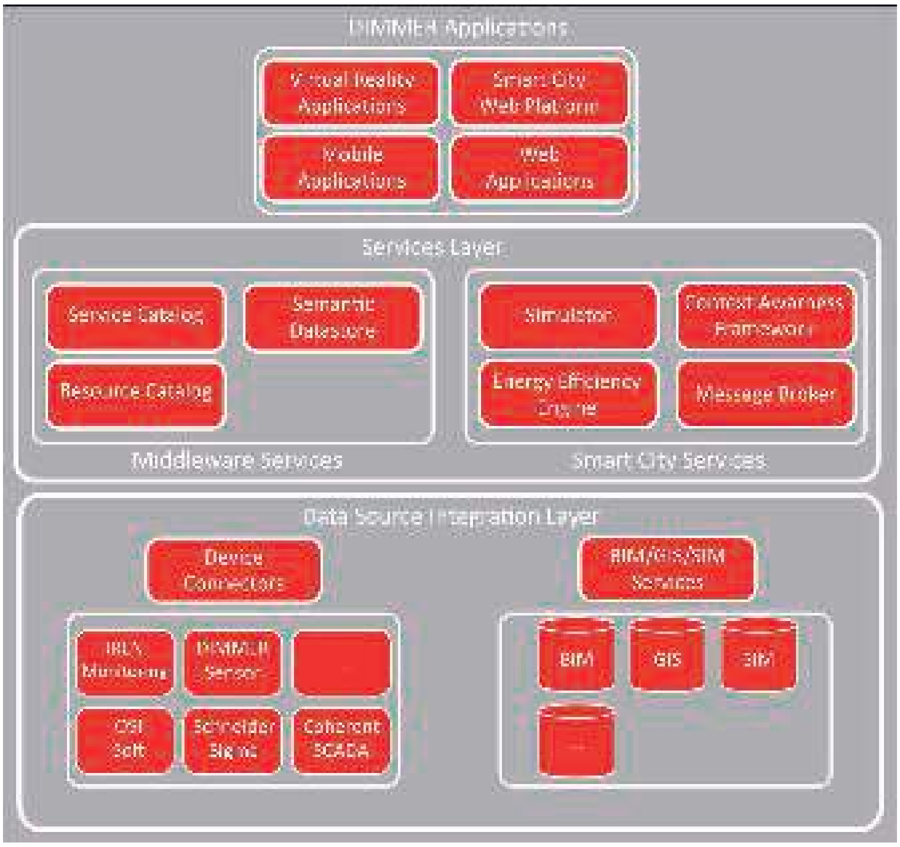

Fig. 07 – The three-layered architecture of the DIMMER Middleware.

The Data-sources integration layer, the lower layer, is in charge of integrating heterogeneous technologies, both hardware and software, by abstracting their features into Web Services. Hence, it acts as a bridge between the middleware network and the underlying technology, translating whatever kind of language the low-level technology speaks into Web Services. In this layer, we integrated different standards for devices to monitor and manage buildings and energy distribution networks, such as Spirit and SCADA. In addition, we also integrated data-sources that provide geo-referenced information (GIS) and parametric models of buildings and energy distribution networks (BIM and SIM respectively) exploiting the concept of LinkSmart Service Provider .

The Services layer is the core of the proposed infrastructure. It provides features in forms of Web Services to manage all the entities in the district for developing Smart Environment applications. Its main features are:

- Secure and Scalable Communication. The proposed middleware offers a peer-to-peer approach to share resources and enable the interoperability across the peers playing in a district scenario. In addition, it implements the publish/subscribe approach for giving to the whole infrastructure an asynchronous communication, which increases the scalability. Indeed, this paradigm removes the inter-dependencies between producer and consumer of the information allowing the development of system-independent applications. It is worth noting that only trusted peers can communicate with each other and the information flow is encrypted.
- Semantic Knowledge. The Services Layer includes a specific module for providing a semantic description of the entities in the district enriched with additional attributes and relations to other entities exploiting ontologies and semantic web technologies.
- Historical Data Management. This module collects data coming from pervasive devices deployed across the district and provides them to other middleware components or applications.
- Simulation engine. It exploits data from other middleware components and from the Data-source integration layer for simulating energy optimization policies at district level. In addition, it implements features to estimate the energy production of renewables that might be deployed in the district. Finally, the Application layer provides a set of tools, API and Web Services to develop applications for post-processing energy-related information of the district and increasing user-awareness exploiting for instances virtual and augmented reality or web platforms and dashboards.

10.3.3 Data communication based on interoperability

As described above, the DIMMER Platform provides an easy way to access different kind of data, fostering different scenarios and demonstrators. At the moment the Platform integrates mainly two different types of data sources related to (i) Building Information Models, Geographic Information Systems, and System Information Models; (ii) Sensors and Energy Measurements (Device Connectors).

This means that the interoperability that characterize the DIMMER Platform, consists in creating a dataflow that involves heterogeneous data coming from different domains, as shown in Fig. 08 below.

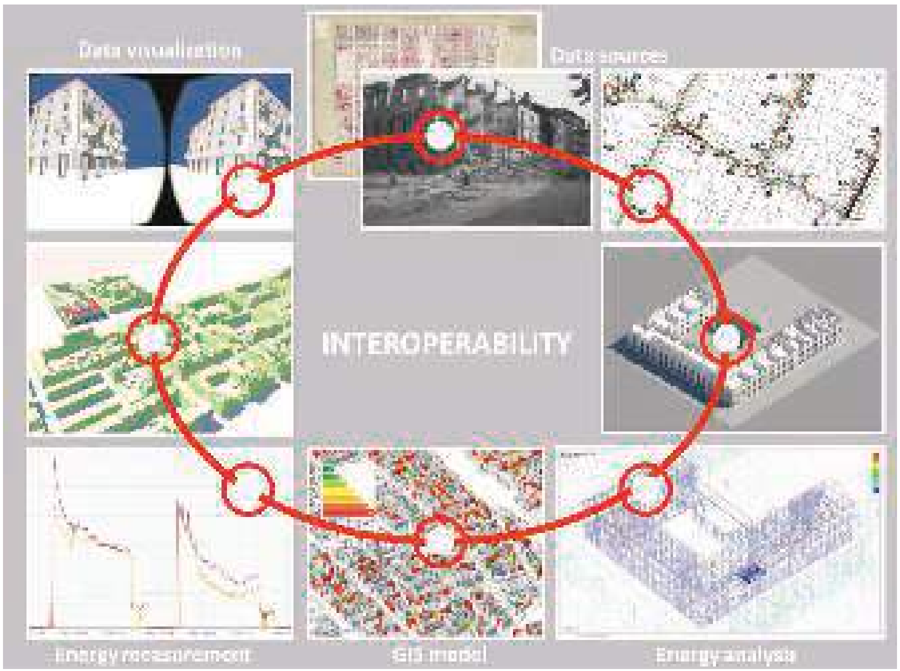

Fig. 08 – The DIMMER data flow based on interoperability between different domains.

This approach aims at providing a high degree of flexibility and replicability of the methodology as well as of the technology. This is because currently, commercial software simulate only specific parts, and interoperability between different tools often is limited. In fact, the use of different software that have to communicate each other reproduces the typical workflow in the building industry and can be considered one of the main objectives of DIMMER, aiming at innovate this process following the work sharing idea. Based on the different domains identified, software and tools used in the project differ from urban scale to building scale, to better fit the needs of the specific users, as visible in Fig. 09 below and data at urban scale become input for the analysis at building scale and vice versa.

DOMAIN	TOOLS/ DATA MODELS/ FORMAT/ SERVICES/ STANDARDS	S.E.F. | data sharing
Urban/ district (GIS)	ArcGIS	.shp | .geotiff | .dbf | .xml | .dwf | .dxf | .dwg | .gml | .kml | [illegible] | .csv | .ifc
	QGIS	.shp | .geotiff | .dbf | .xml | .dwf | .dxf | .dwg | .gml | .kml | .csv | .csv | WMS/WMTS Client | WFS Client | WFS and WFS-T Client
	[illegible]	
	DFM	.json | .gml
Building domain (BIM)	Revit 2016	.dwg | .ifc | .dxf | .gbXML | .idf | .doe | .sat | [illegible]
Energy Analysis Model (EAM)	Environment	.gbXML | .dxf
	Design Builder	.idf | .gbXML | .txt
Building Automation System (BAS)	Siemens CoDeSys [illegible] DCS/SCADA Schneider Sigma OSI Soft PI EnOcean STM Sensors IPSN Heat Network Monitoring System	OPC [illegible] Modbus DNP3 BACnet SNMP EnOcean Equipment Profiles Other proprietary binary formats
End users awareness	HTML, CSS, Javascript, JQuery, Web services, SQL Server	.jpg | .png | .xml | .csv | .xls
Visualisation and Simulation (DIM)	Infraworks	[illegible] | .shp | .xml
	Unity3d	Static Models: .FBX, .DAE, .3DS, .DXF, .OBJ, .MAX, .MB, .MA, .BLEND, .JAS, .C4D, .LXO, .XSI, .SKP, WINGS, Carrara, Lightwave Dynamic data: Link to data source objects/ APIs via the DIMMER middleware. This will require bespoke development, as defined in the usage scenarios / use-cases.

Fig. 09 – Software and tools used in the DIMMER project.

10.3.4 DIM data

Through the definition of DIM data, heterogeneous data are visualized coming from different data sources. The aim is obtaining a 3D city model composed by different domains such as architectural, structural, electrical, HVAC and so on, at both building and district level. DIM model selects information stored in several service providers, thus it is possible to visualize the data in different ways for different users. This is essential because a city can be considered a complex system, composed by a dense network of relationship, where several stakeholders are engaged.

The approach adopted is shown in Fig. 10 below: the 3D city model is described through different scale where information can be managed with different kind of data e.g. BIM, DIM, SIM. Adding to this, each level can be split into different parts related to the discipline e.g. Urban, Architectural, Structural, Utilities, Real Estate. The added value of this representation is the easiness to visualize different kind of information establishing a data hierarchy based on both the discipline and the level of detail.

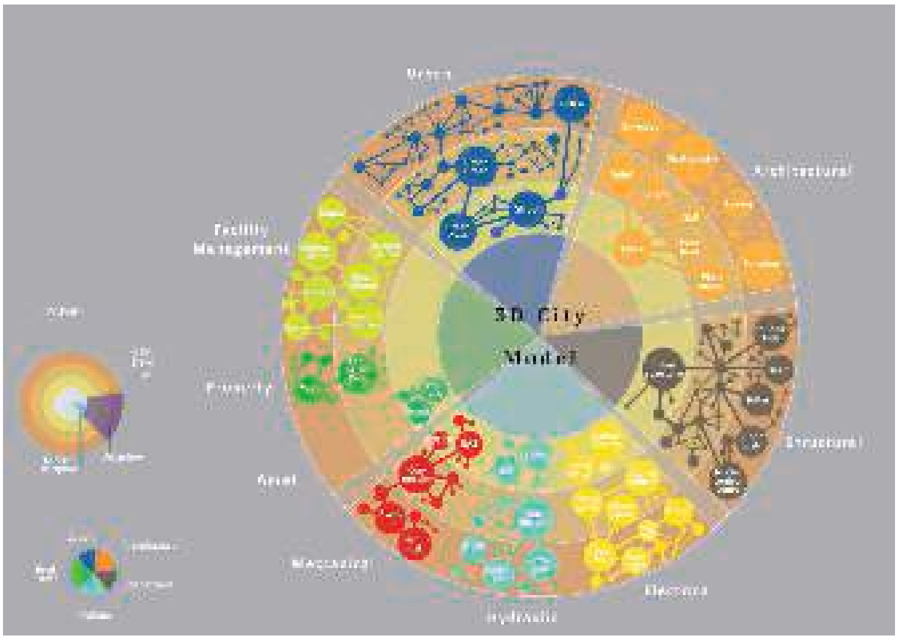

Fig. 10 – The 3D city model able to consider the different domains.

Based on this concept, the 3D city model can be synthetized as a proper City Information Model (CIM) composed by a series of information that is organized in various disciplines and grouped into different developing domains such SIM, DIM and BIM that represent the reality.Concerning DIM, it can be described by the chart visible in Fig. 11 below.

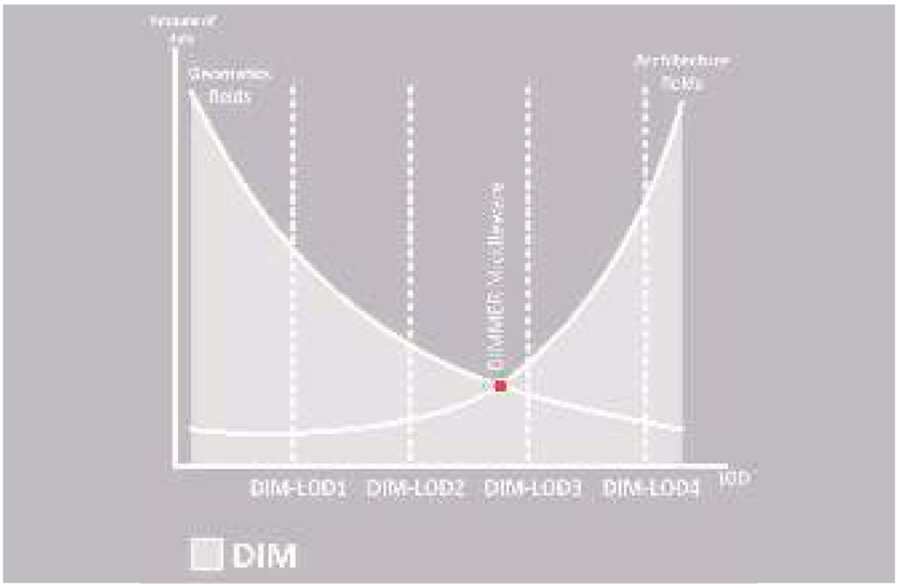

Fig. 11 – The DIM chart.

The area under Geomatics and Architecture fields ideally represents different levels of information of the district model. The junction of both curves represents the DIM concept where all the information is shared between the two systems working on the “smart interoperability” exploiting DIMMER Middleware.

In this way, different actors playing in a Smart City scenario (e.g. public administrator, energy utility professional and estate manager) can access several kinds of information that will be described ahead.

Therefore, DIM should not be regarded as a fixed 3D model but rather a dynamic model where, relating to the users, it can be reached with different data.

A DIM model is not just an overlay of the different 3D models described below, but it is mainly a common platform where many information (coming from different datasets and with different data format) are linked each other.

10.3.4.1 Building Information Modelling (BIM) data domain

BIM aims at the improvement of the building process and, as innovative methodology, is focused on the information management of all technical resources that are able/essential to represent the complexity of a building. It focuses on the data management optimization in order to get the right information to the right place at the right time.

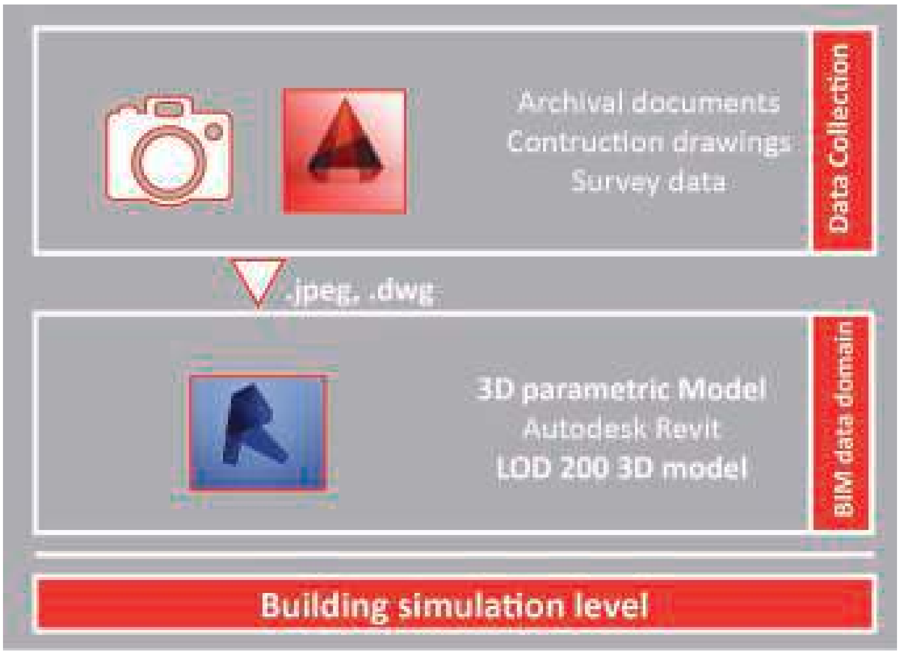

Fig. 12 – The BIM data domain.

Within the DIMMER project, BIM data domain represents all information about the building scale and it can be used to perform all the simulations needed for its design and operation like lighting and thermal analysis, without the need to remodel the geometry in any application, avoiding the data duplication and the error generation. At present, the model setup for the DIMMER project follows five step, as visible in the Fig. 13 below.

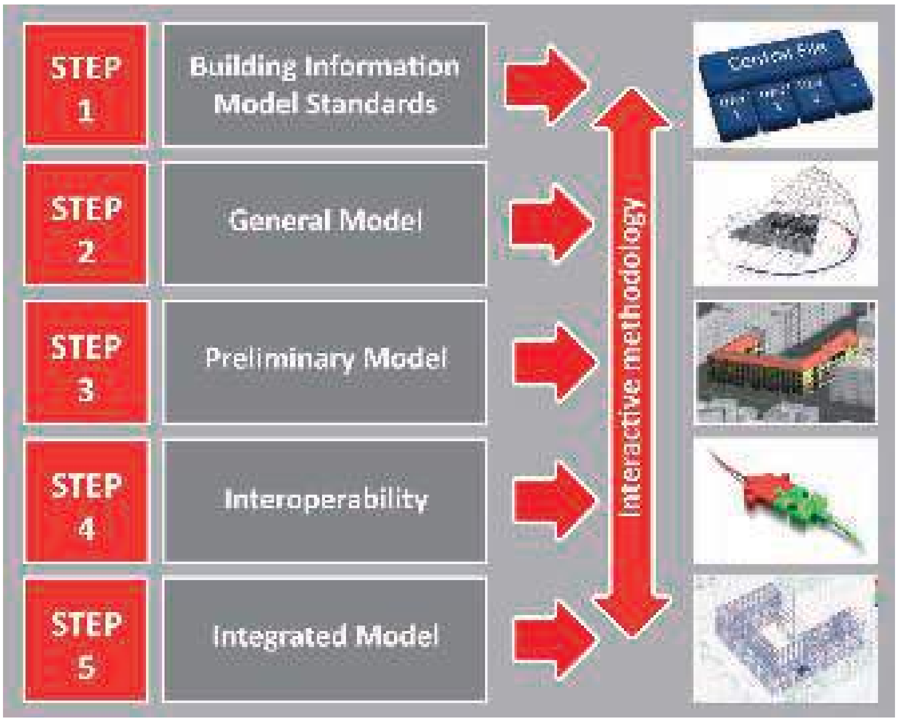

Fig. 13 – The BIM domain within the DIMMER project.

The first step is based on the BIM (as modelling, namely as process) and must be organized into different domain (architectural, mechanical, electrical, etc.) based on well-defined rules.

The second step concerns the creation of a simplified parametric model which collects geometric and alphanumeric information that can be used to analyze the main aspects of the building's performance, with a particular emphasis to energy efficient and sustainable design and management. For instance, using the sun's path, it is possible to create solar studies by placing the sun at any point along its daily path, and at any point along its analemma.

After the generation of a simplified parametric model, the third step (that is based on a speed survey) is focused on a preliminary model development, using simple objects like roof, wall, floors and opening, enriching with other information such as material and stratigraphy of wall, floor, roof, openings, etc.

The fourth step deepens interoperability which has a key role in the DIMMER project. The choice of the tools is related to the information life cycle. All domains, that work stand alone to create an iterative process, require a data flow. Although hypothetically this phase should be guarantee from standard formats exchange (e.g. IFC, .gbXML), there are still many problems due to loss of data rather than the failure to import data.

The fifth step concerns the development of a method for continual data cross-check and update in order to assure that the integrated model (architecture, structure, HVAC and lighting systems) is as accurate as possible for any use (energy performance, thermal comfort, lighting and management).

In the fifth step the integration of the model must consolidate the data flow in order to guarantee an iterative process, where the different domains exchange data in a loop, which static and dynamic data update themselves into an algorithmic process. Such as an example, if data sensors could influence on data coming from parametric model used for energy analysis, on the other hand, results coming from energy analysis could interact with parametric model in order to generate changes. This step is strictly linked with the previous one and it is continuously evolving, because knowing exactly what kind of data and among which software tools they can be exchanged. This brings about interesting considerations on the standards to be used in the integrated model in order to optimize the BIM process.

10.3.4.2 Geographic Information System (GIS) data domain

The GIS data domain in the DIMMER project is used to manage urban and district data for the collection of a large amount of information useful to permit the integration and the elaboration of various information related to "energy", that are crucial for decision making on energy issues. Furthermore, GIS data domain is essential to collect data about district heating network and energy demand, useful to analyze at district scale the energy consumption. The GIS domain allows public administrator, energy manager and other decision maker to enrich their knowledge giving the opportunity to activate energetic policies to improve energy efficiency at urban ant district scale.

Concerning the Turin pilot, the use of GIS data domain highlighted that the major of houses were built between the year 1945-1970. These buildings mostly correspond to the low energy efficiency class. Furthermore, it provides information, about gross volume, gross area, number of floor, etc. All these data are used in the BIM domain as input for the creation of the parametric model.

Fig. 14 – The GIS data about the heating consumption of the buildings for a selected block.

10.3.4.3 Energy Analysis Model (EAM) data domain

The aim of the Energy Analysis Model (EAM) domain is linked with the energy simulation needs at building and at district scale. The virtual models are approximation of real world and they are used to simulate the buildings and the district behaviour. Obviously, although they are very close to reality, gaps are always present comparing them with the real case studies. Therefore it is necessary validate the EAM model through the calibration's model using sensor data. This means that thanks to the iterative process, the validation model takes place comparing the model to actual energy behaviour in order to tune the model step by step. At present EAM model was developed through the interoperable process between Revit and Design Builder that provides advanced modelling tools enabling energy simulation starting from a 3D parametric model as shown in Fig. 15 below.

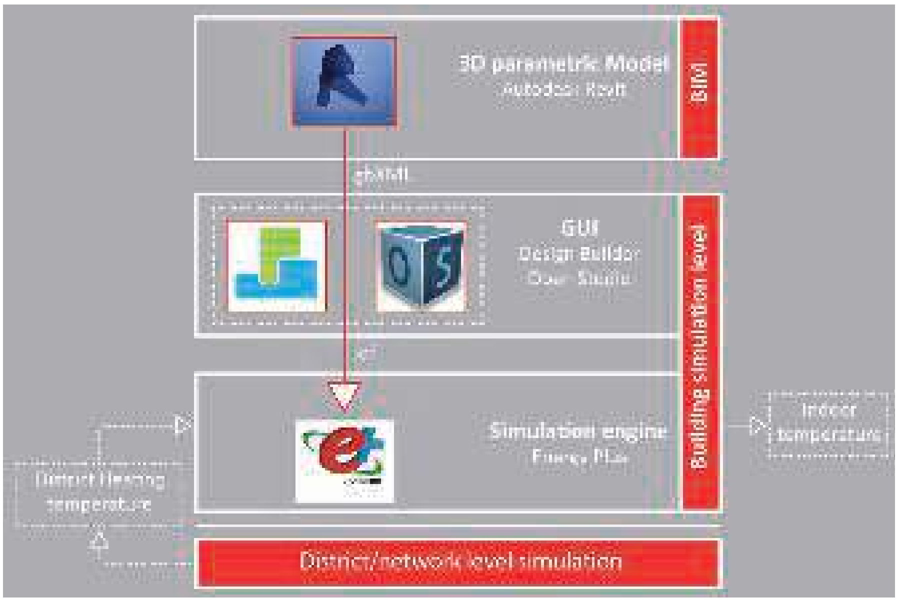

Fig. 15 – The EAM and the interoperable process between Revit and Design Builder.

The EAM domain is generated from a 3D parametric model through interoperability that can "filter" the energy model. In this way it is possible to highlight data, including for example temperature and humidity that can be taken into account and compared with real data monitored (in the different case studies) in order to achieve energy saving through the use of the DIMMER platform.

10.3.4.4 Building Automation System (BAS) data domain

The Building Automation System (BAS) domain in DIMMER is represented by static and dynamic data of commercial Building Management Systems (BMS), sensor platforms and monitoring systems deployed in the demonstrator districts, and ICT hardware developed as a part of the project.

Static data provide information about the domain model to the services and applications has been integrated with the data of District and Building domain models and available to populate representations of these models in the end-user applications.

Dynamic or operational data generated by BMS, as well as custom sensor platforms and ICT developed in the project will be integrated in DIMMER through the middleware. Depending on the technical capabilities of the integrated systems and the needs of DIMMER applications and services, several

APIs for accessing dynamic data will be provided by the middleware.

To provide a unified access to the dynamic data and APIs based on open standards, the middleware integrates different industrial and proprietary protocols employed by the integrated systems, where it is required.

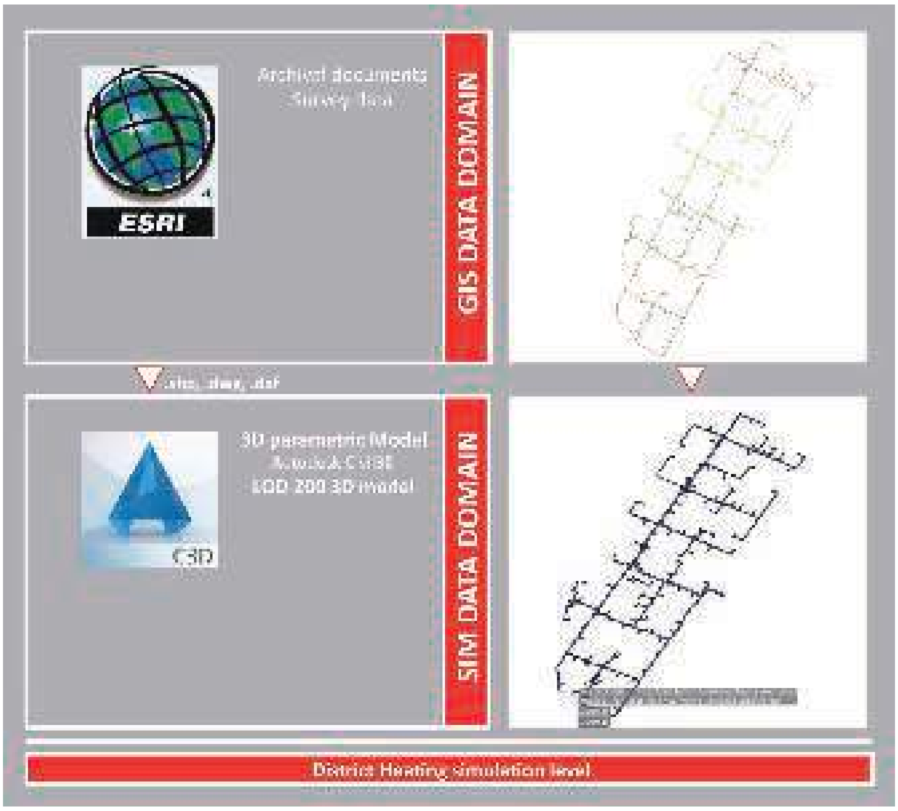

Fig. 16 – The link between GIS and SIM data.

10.3.4.5 System Information Modelling (SIM) data domain

The SIM data domain aims at calculating the primary energy savings that can be achieved by applying the DIMMER strategies to the selected districts. The model receives the thermal request profiles of the buildings as the input. The model of the district heating network is composed by:

- Thermal Substation model. This model includes the building model and the exchanger model. It allows one to check the possible effects of variations in the thermal request profiles of the buildings on the average international temperature. The proposed thermal request profile is acceptable if the internal temperature is kept at the same level as that in the initial profile.

- Network at thermal barycenter level. This model considers full fluid dynamic and thermal model of the district heating network of a thermal barycenter. This is the distribution network from the main pipeline (also called the "transport network") to the various users located in an area.
- Network model. This model considers the main pipeline. It receives the input from distribution networks as the boundary conditions and allows one to calculate the thermal load of the power plants. Thermal load is obtained on the basis of the mass flow rate in each plant and the difference between supply and return temperature. The latter is calculate by the thermal model considering mixing, heat transport, heat losses and transient effects.
- Plant model. This model considers the various thermal plants and allows one to obtain the primary energy consumption associated with heat generation. In the case of boilers, the model only accounts for their efficiencies. In the case of cogeneration plants the model is more complex, since the separate contribution of fuel consumptions due to heat and electricity is calculated.

10.3.5 The Level of Development (LOD) value

Concerning each domain, the amount and the quality of data is one of the most important things for the development of the different DIMMER datasets. Before the modeling step, referring to the American Institute of Architects (A.I.A.), particular attention has been given to the choice of the Level of Development and the Level of Detail because the meaning of two types of levels are different:

- Level of Detail is essentially how much detail is included in the model element;
- Level of Development is the degree to which the element's geometry and attached information has been thought through the degree to which project team members may rely on the information when using the model.

Summarizing, Level of Detail can be thought as input to the element, while Level of Development is reliable output (LOD Specification 2013). Adding to this, ISO PAS 1192-2:2013 proposes the definition of Levels of Model Information (LOI) that refers to the Description of non-graphical content of models at each of the stages.

For the DIMMER project, LOD means Level of Development composed by graphical and non-graphical information and for each domain they are explained below.

10.3.6 BIM LOD

BIM (as Model) has been set up at different LODs to manage all information at building scale.

Three LODs have been used, as shown in Fig. 17:

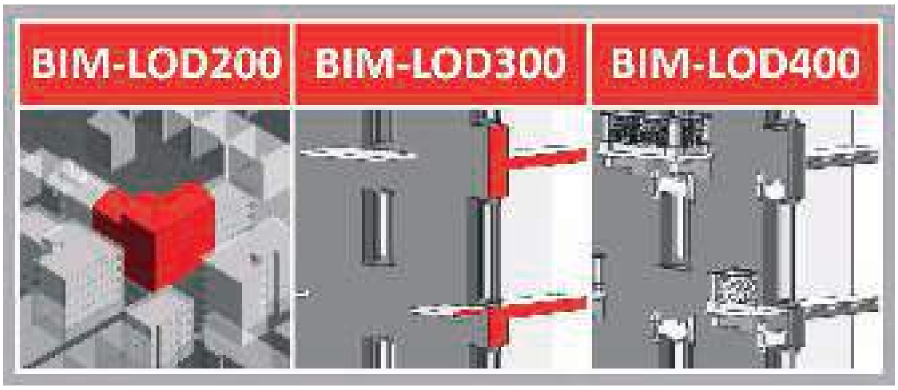

Fig. 17 – The BIM LODs.

- LOD2 is realized using masses (that can be visualized in wireframe or surface/solids), containing data needed to estimate per square meter rates and other similar metrics.
- LOD3 is realized using generic components (for both objects and systems) with detailed form and function, defining all components in terms of overall size, typical detail, performance and outline specification (if available, working on existing/historical buildings).
- LOD4 is realized using specific components (for both objects and systems) detailing assemblies accurate in terms of specification, size, form, function and location (if avail- able, working on existing/historical buildings).

LOD1 and LOD 5 are not necessary for the DIMMER project because they refer respectively to landscape and as-built documents. It is evident that such information is not always available for existing (and historical) buildings and for this reason each case study contains different information.

10.3.7 GIS and SIM LOD

Currently, in DIMMER, only the first three LODs for GIS (GIS-LOD) are under test for the purpose of the district building modeling: GIS-LOD1 is the extruded view in height of the public cadastre, GIS-LOD2 is made of a simplified geometry derived from the BIM model (if available), and GIS-LOD3 is a simplified representation where BIM materials are in place of the common photographic textures.

In addition, in DIMMER also the System Information Model (SIM) is under test in order to outline and integrate the structure of energy distribution networks with the 3D building parametric models and with measurements databases that store data collected by sensors deployed in the whole district.

At present GIS and SIM information are stored as shapefile composed by graphical and alphanumerical data.

Fig. 18 – The GIS and SIM shapefile.

10.4 Results

As shown before, during the first two years of the project, several results have been achieved on data modelling and management, integrating different domains at both building and district scale.

10.4.1 The interoperability/querying of the data using the DIMMER Middleware

The DIMMER Middleware provides a suite of data collection, pre-processing, storage, and querying services. Integrating heterogeneous ICT data sources by the means of system-specific integration components, the DIMMER Middleware offers unified APIs for querying meta-data and operational (sensor measurements) data of the integrated systems. The ICT integration is mainly implemented through two kinds of integration components: Device Connectors and Historical Datastore APIs. Device Connectors offer APIs for querying meta-data and accessing the latest values of the integrated sensors in SenML format. The Historical Datastore API exposed by the integration components enables querying of historical data from the integrated heterogeneous systems in a unified fashion.

Leveraging the Linked Data capabilities incorporated in the SenML, all sensor measurements obtained through the DIMMER Middleware carry identifiers which can be referenced and are unique to the respective data sources. These identifiers can be dereferenced using HTTP requests served by the integration components to retrieve meta-information about the corresponding data sources. Furthermore, these identifiers can be used to create higher-level abstraction models to create reference to other modeling entities managed by other services of the DIMMER Platform.

For example, these identifiers can be exploited with the DIMMER BIM Web Services. The Web Service interface to BIM models is based on REST conventions, and uses the HTTP command GET. It is used to provide a uniform interface to the different building models in the district, in this way creating a virtual district model. Such model can be queried as a whole by using the REST API.

With different REST invocations it is possible: to download several resources for a set of building models (IFC, gbXML and RVT files); to get the full JSON dump of a set of building models; to query a set of building models.

In all these different invocations, the “district” parameter is mandatory, and it is used by the Web Service to define the districts from which the buildings models data is retrieved and integrated.

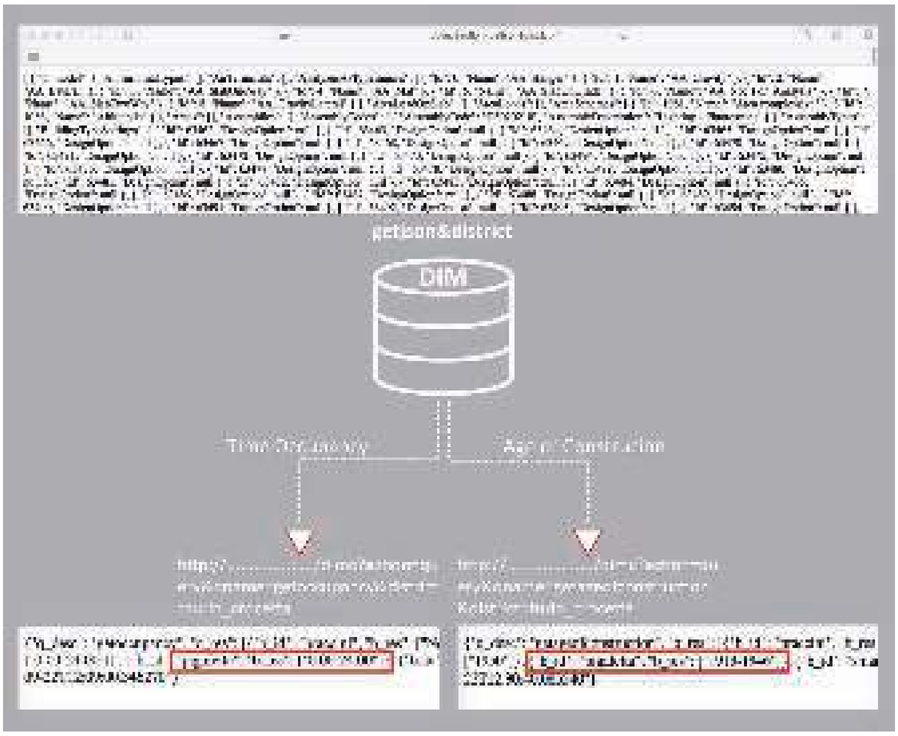

Fig. 19 – The query of the DIMMER Middleware using JSON.

10.4.2 Interoperability issues

At present the interoperable step is not error free and for this reason the 3D models need to be implemented before being processed for the energy simulation. In fact, as visible in Fig. 20 several geometrical and alphanumeric errors are produced during the interoperable process.

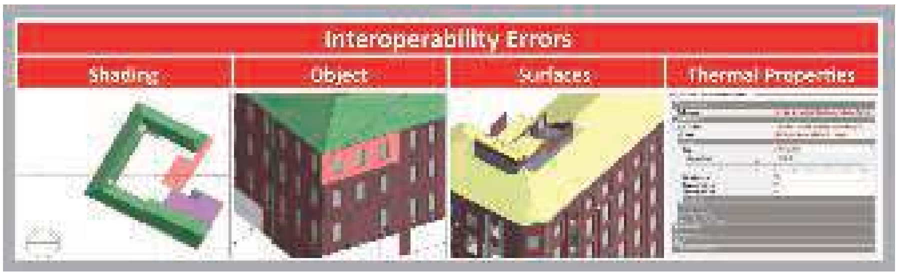

Fig. 20 – Examples of errors during the interoperable process.

10.4.3 Virtual and Augmented Reality

During the life cycle of a building it is very important that all the involved actors understand, participate, communicate, and collaborate with each other to obtain a high quality outcome of the process. The improvement of the communication between different stakeholders is one of the key factor that have to be considered in order to optimize the data flow in the construction industry.

Fortunately, during the last years, the real time visualization became more accessible, and within the DIMMER project the immersive visualization has been investigated as innovative and integrated part of the current building management process, for the improvement of the people awareness. It is based on three main components:

- The Oculus Rift, a new type of Head Mounted Display (HMD) directed at the consumer market;
- Unity 3D, a real time rendering engine supporting large building information models (BIMs);
- Autodesk Revit for the development of 3D parametric models.

In this way, starting from the BIM model, data can be exported as shown in Fig. 21, and thanks a free navigation inside the model, it is possible to present and communicate results regarding different policies and scenarios tested with the DIMMER approach.

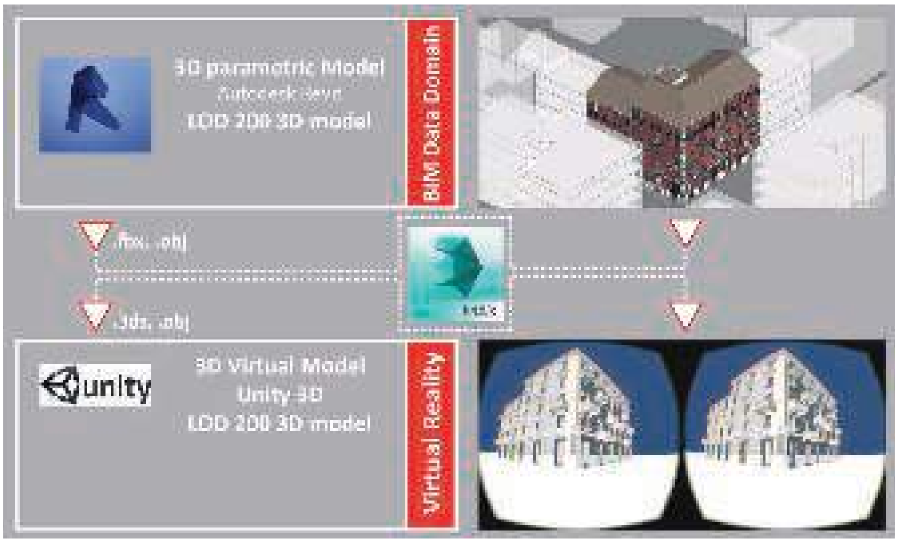

Fig. 21 – The data visualization using Oculus Rift starting from the BIM model.

10.4.4 DIM-LOD

Referring to figures above, DIM should not be regarded as a fixed 3D model but rather a dynamic model where, relating to the users, it can be reached with different data, arriving to establish different levels of detail such as the DIM LODs. Figure below represents a synthesis between the GIS and BIM LODs.

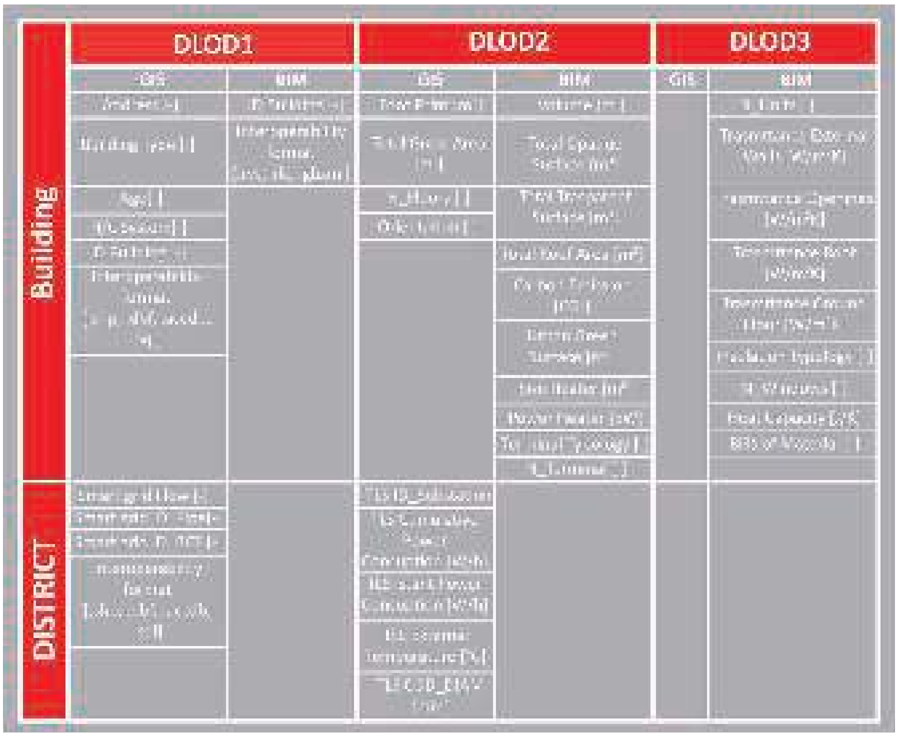

Fig. 22 – The contents of the DIM LODs as dynamic model.

At first, the district parameters were identified, taking into account the difference between the district and the building scale and considering the heterogeneous data sources. Each DIM-LOD combines several attributes in different percentages starting from DIM-LOD1 where it is possible to find more parameters from GIS than BIM, to DIM-LOD3 where data is close to BIM domain.

Of course, this table must be implemented with SIM, EAM and BAS domains.

A preliminary test of this process was then performed in order to validate these kind of LODs, taking into account the role of the estate manager importing the different BIM models into a Database Management System such as PostgreSQL and SQL Server. The import/export process is complex because a direct way to share information among several domains is currently unavailable. The tests highlighted that geometrical data was missed whereas alphanumerical information was preserved.

Following the interoperability concept, sharing information among the different domains is performed through exploiting a web-service approach. The Service Providers export the information stored exploiting RESTful Web Services.

10.5 Conclusion and future work

At present, innovative technologies allow users to visualize a city in a digital way, translating different kind of information that can be processed using several algorithms, in order to provide new solutions for the development of a smart city. These data are analyzed and processed according to the proper urban scale based on scenarios able to promote new policies, aiming energy saving.

Starting from the SEEMPubS project that investigated the theoretical and operational possibility to use a network of sensors to monitor energy consumption and to raise people awareness, the DIMMER project aims at investigate the data management based on interoperability between data at urban and building scale, integrating different domains (BIM, GIS, EAM, SIM) into the DIMMER Middleware. In this way it will be possible to define the contents of a District Information Modelling (DIM) able to allow different stakeholders to query the middleware extracting information about energy efficiency and consumption at both building and district scale. The goal is to give/receive real time data (thanks a web service interface) that can be used for different strategies to improve the buildings energy behaviour.

Future work will focus on the optimization of both interoperability between data using commercial software and data visualization using virtual and augmented reality.

10.6 Acknowledgments

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BIM and Interoperability for cultural heritage through ICT

Anna Osello; Andrea Acquaviva; Daniele Dalmasso; David Erba; Matteo Del Giudice; Enrico Macii; Edoardo Patti
Politecnico di Torino (DISEG and DAUIN), Italy

ABSTRACT

This chapter presents a methodology based on Building Information Modelling (BIM) and interoperability to convert existing buildings, even historical, into smart buildings. The chapter starts describing the main concepts of BIM and interoperability in the Architecture, Engineer and Construction (AEC) industry with special attention on integrating information from heterogeneous devices deployed in the building. Then, it details the SEEMPubS (Smart Energy Efficient Middleware for Public Buildings) middleware, which consists on three layers: (i) Integration Layer, (ii) Middleware Layer, and (iii) Application Layer. The validation of the most significant results is presented using both gamification and technical approaches involving different end-users. Finally, Apps for data management are introduced with a Community Portal and an Android Application for real-time data visualization. Future works introduce the integration of smart building into smart district context.

Key words: Building Information Model/Modelling, Distributed Systems, Facility Management, Interoperability, Middleware, Smart Building, Ubiquitous Computing

INTRODUCTION

Working on a smart building requires the use of ICT to optimize design, construction and management. BIM provides an huge amount of information in its database and, theoretically, it is able to work with all kind of data sources using interoperability. However it is essential to define standards for both data contents and format exchange. In this way BIM and interoperability can play a key role to transform existing buildings into smart buildings.

In this paper the methodology and the results obtained with the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) project are described.

The SEEMPubS project, specifically addresses reduction in energy usage and CO_2 footprint in existing public buildings and spaces without significant construction works, by an intelligent ICT-based service, monitoring and managing the energy consumption. During the project special attention has been paid to historical buildings to avoid damage by extensive retrofitting. SEEMPubS provides control of appliances to effortlessly optimise energy efficiency usage without compromising comfort or convenience and offering decision makers strategies and tools needed to plan energy saving measures. SEEMPubS makes use of the LinkSmart middleware and uses its potential to create services and applications across heterogeneous devices to develop an integrated energy monitoring and control system. The project uses its real-time energy-awareness services for all users of the public space and combines awareness services with a community portal. This enables collective, community activity motivating positive competition in saving energy, complemented by courses towards the education on energy efficiency and sustainability.

The functionality of this system has been demonstrated on existing buildings at the Politecnico di Torino Campus, characterized by different representative typologies of buildings common in European cities, above all Valentino Castle in Turin, which has been built on XVI century. The validation of the most significant SEEMPubS results allows the elaboration of an energy efficient model for existing buildings

and public spaces with a significant economic impact all over Europe. Indeed, this model could be replicated on many different existing buildings where old energy systems are already in place, avoiding expensive construction works and possible damages.
In order to optimize the data exchange among Architecture, Mechanical Electrical and Plumbing (MEP), energy simulations and Facility Management (FM), at the beginning of the project a building information model has been setup in order to contain the information that can be used in an interoperable way. Based on the results of the SEEMPubS project, it is very important to set correctly the contents of this model integrating architectural data (e.g. geometry and dimension) with energetic data (e.g. material, stratigraphy, colours and context) because interoperability between software (like Revit with Daysim and Radiance for lighting and Trnsys for heating and cooling) at present is not always perfect. This requires different formats (e.g. IFC and gbXML) and several test are often necessary.
As main result of the project, to guarantee a simplified access to all data, an APP for tablet and smartphone has been developed that leverages the SEEMPubS Middleware, which is a distributed event based Service Oriented infrastructure. It allows the end user to interact with the system in order to access heterogeneous building information available from multiple pervasive sources. It mixes structural information with fine grain energy and environmental data coming from heterogeneous devices both wireless and wired. It is worth noting that structural data information also comes from third-party software, such as Archibus FM, thanks to the Web Service approach. In addition, a Web Portal has been set up to guarantee a continuous interaction between the data, collected in near real-time, and different kind of end users (e.g. energy manager, students, staff and visitors). Moreover, a gamification approach has been used to interact with young generations in a funny way, teaching them the essential elements on energy saving.
Future work will require the extension from smart building to smart district. This is exactly the goal of the District Information Modelling and Management for Energy Reduction (DIMMER). Developing a system able to integrate BIM and 3D district level models with real-time data from sensors and user feedback, DIMMER aims to analyse and correlate buildings utilization and provide real-time feedback about energy-related behaviours.

BACKGROUND

It is known that the need to “refurbish” existing buildings, even historical, converting them into smart buildings exploiting new technologies and methodology is an essential research field because AEC industry requires innovation. In this context “smart building” describes a suite of technologies used to make more efficient the design, construction and operation of buildings. Moreover, a smart building can be considered an intelligent building, not only for the deployed technologies, but also for the methodology adopted to construct the building, from the design phase to the management phase.

BIM and interoperability in the AEC industry

Nowadays the energy saving in existing building is one of the main challenges in the AEC industry. Indeed, relating to Horizon 2020 directive, the cultural heritage refurbishing is becoming the challenge for the society in order to avoid waste in terms of energy, materials, greenfield land, etc.
BIM could be the key solution, providing the opportunity to renovate the building industry. In fact, BIM can be considered not only as a digital representation of physical and functional characteristics of a facility, but it must be considered as a set of processes applied to create, manage, derive and communicate information among stakeholders at various levels. To ensure quality and efficiency throughout the entire building lifecycle, it exploits models made by all participants of the building process, at different times and for different purposes (Osello, 2012; Eastman, 2008).
One of the cornerstones, on which BIM is based, concerns the sharing of information across different actors involved in the building process. The idea to develop a parametric model, which is enriched by each user at the same time or in different steps, allows the professional to monitor in real time the

building process analyzing the possible interferences, such as between structural parts and system parts, correcting the design project, avoiding errors with a time and cost saving.
Currently, BIM is used mostly during the design phase of new building projects, but its use is growing in the construction and operation phases. On the other hand, BIM for existing constructions still is not widely used. This is probably related to the management of the large amount of data deriving from the survey step that includes historical research, measurements done with different tools (e.g. disto, total station and laser scanner) and collection of different kind of data in different formats (e.g. printed, CAD, photo) related to the building and its context (see Figure 1). However, in the last years this methodology is under investigation in the research field because it allows professionals to develop a model as close as possible to the real world. In this way, the resulting model can be used for many different simulations, such as thermal, lighting and structural in order to develop a smart building. In this context, interoperability between software becomes crucial to share information and perform different tests.

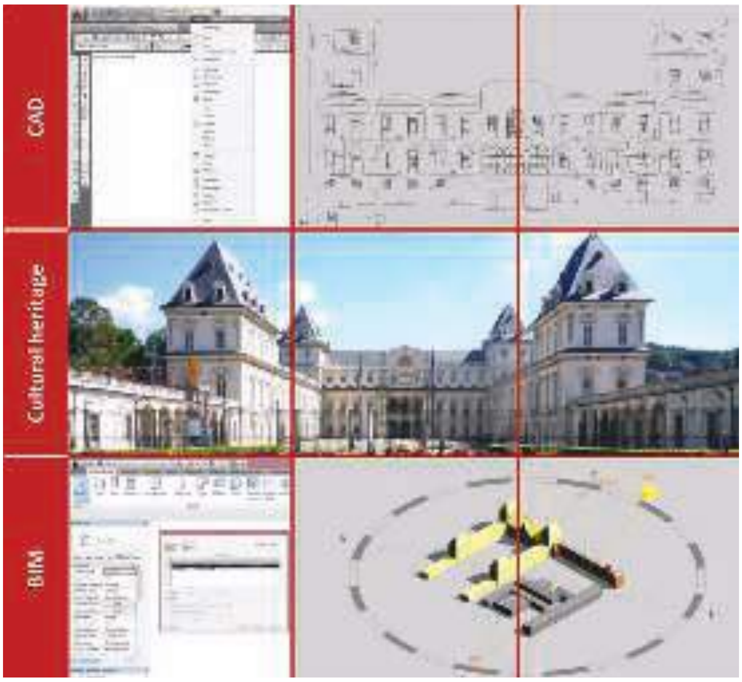

Figure 1. The Valentino Castle in Turin as example of cultural heritage from CAD to BIM for the representation of the data

Interoperability across heterogeneous devices

Nowadays, the buildings are already equipped with heterogeneous devices, both wireless and wired, to monitor and manage themselves. In this context, a key challenge concerns in achieving the true interoperability across several heterogeneous technologies. To cope with this issue, recent development of middleware and Service Oriented Architectures seems to be promising along this direction (Warmer, 2009; Karnouskos, 2010). Indeed, middleware technologies should implement the abstraction software layer required to achieve interoperability across heterogeneous devices including existing Building Management Systems (BMS).
In the domain of Home Automation, Corno et al. have developed a Dog home getaway (Bonino, 2008), which is built on the DogOnt v1.0.3 ontology model (Corno, 2009), for the interoperation between various domotic devices. The ontology is designed to explicit representation of commands, accepted by domotic devices, and notifications, generated by suitable control devices.

(Zamora-Izquierdo, 2010; Guinard, 2010; Candido, 2011) present a modular, adaptive, and open infrastructure forming a complete service-oriented architecture ecosystem that will make use of the embedded capabilities. The infrastructure components are specified, and it is presented how they can interact and they can be combined to adapt to current system specificity and requirements. Most of these solutions focus on enabling ubiquitous computing and Internet of Things (IoT) applications. However the SEEMPubS middleware targets smart energy-efficient buildings and aims to provide reusable distributed components for integrating building automation technologies with Ubiquitous Computing.

aWESoME (Stavropoulos, 2013) is a web service middleware for ambient intelligent environment. It enables the interoperability across heterogeneous devices again to provide a system that allows automation and energy savings in large buildings.

In addition to research projects, OPC Unified Architecture[1] should be noted as an example of an integration effort for typical Building Automation technologies. However, following the vision of Ubiquitous Computing, large buildings must be open to any kind of other commercial technologies.

METHODOLOGY

In the SEEMPubS project the ICT overlaps with the energy saving and BIM fields, creating an interdisciplinary research where different actors have to share different data deriving from different sources, such as air conditioning and lighting systems, sensors for environmental comfort parameter monitoring and control, wired and wireless networks, building information models for FM and analytic models for energy consumption calculations tools of data viewing (for tablets and smartphone), etc. The aim of this project is to define a methodology, replicable in different European reality, to reduce CO_2 emissions by realizing a smart ICT system for the monitoring and control energy consumptions in existing public buildings and spaces, even historical ones. Developing a parametric model for the Politecnico di Torino campus, the SEEMPubS system has been designed to provide multidisciplinary visualizations of building maintenance parameters and to share technical system information (see Figure 2).

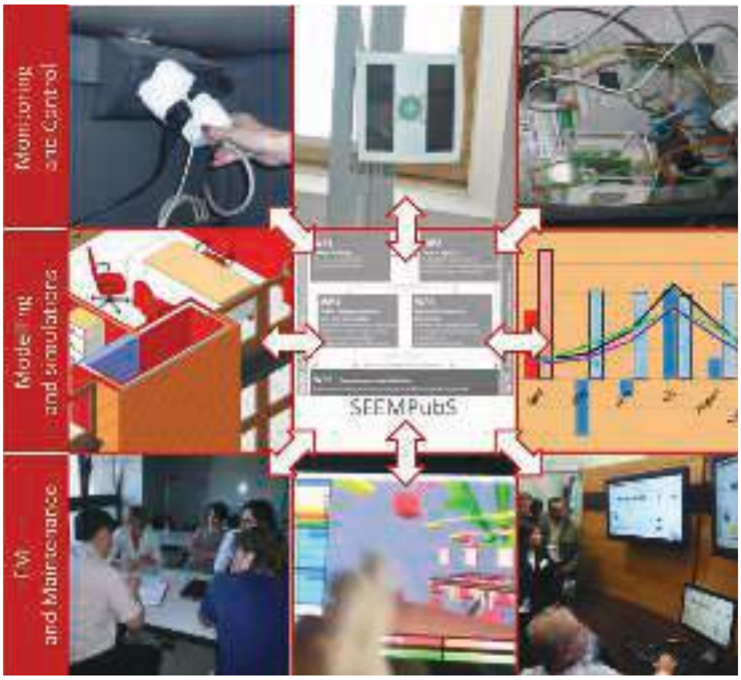

Figure 2. The SEEMPubS multidisciplinary approach, with a several format of data exchange and usage.

[1] https://www.opcfoundation.org/UA/

Obviously through the development of this complex system, the standardization roles to follow by each user become essential in order to obtain data exchange. Moreover, a hierarchical organization of the activities must be guaranteed as shown in Figure 3.

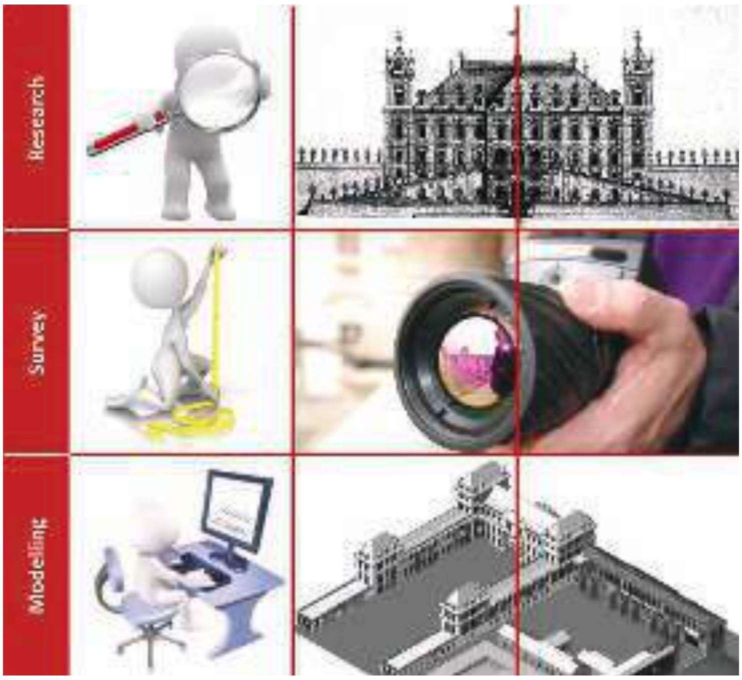

Figure 3. Hierarchical organization of the activities.

BIM and interoperability

Following the BIM approach requires the knowledge of the meaning of interoperability between software. Among all the possible definitions, from our point of view, the better is the capability to develop a parametric model to share data between different professionals using different exchange standard formats able of carrying information in specific software to perform many tests. The idea, which is the basis of interoperability, consists on the ability to see the 3D model as a database rich of information that can be sorted and queried from time to time according to the specific simulation. For this reason, a BIM model should be planned in order to optimize the data exploitation. During the building process data filled in the parametric model can be inserted and removed through import/export processes from different professionals, which are able to improve the information model for different use-cases.

In the SEEMPubS project, the Politecnico di Torino campus was investigated as case study. It consists of different buildings in Turin, such as the Valentino Castle, the main campus and the Cittadella Politecnica. Their construction period ranges from the XVI century to the XXI century, thus including buildings very different in dimension, envelope construction characteristics and performance. For the heterogeneous case study different strategy for the modelling were adopted.

A detailed survey of architectural features of each case study (geometry, furniture and equipment, surface reflection/transmission properties, lighting/HVAC systems etc.) was carried out to make accurate 3D models for the selected rooms. The models were used to perform energy simulations (Trnsys for thermal analyses and Radiance and Daysim for lighting analyses), which were validated through monitored data and then used to estimate the building energy demand for different control strategies. As far as lighting simulations is concerned, Radiance was used to validate the models, comparing the simulated illuminance distribution to the illuminance values measured in the corresponding rooms, while Daysim was used to estimate the lighting energy demand and the savings obtained with the specific control strategies proposed for each case study. Indeed, Daysim allows running annual simulation for a site, accounting for the specific dynamic climate conditions.

Before starting the simulations, the use of BIM for architectural, HVAC and lighting systems modeling, as methodology to test the interoperability for energy efficiency simulations, was investigated. The BIM approach started with the creation of 3D models of each case study, including their external environments, through Autodesk applications. In particular Revit Architecture was used for architectural modeling and Revit MEP for the modeling of heating and lighting systems (Acquaviva, 2012).

The BIM method followed in SEEMPubS concerned to optimize the seamless data exchange, which is articulated around three steps, where each of them fulfills a particular task exploiting an iterative approach:

1. Defining the preliminary architectural model and testing its real interoperability using different formats such as Industry Foundation Class (.ifc), green building XML (.gbXML), .fbx, .dxf and 3ds;
2. Defining the integrated model and testing its applicability to existing buildings (such as the different buildings in Politecnico di Torino campus);
3. Appling the existing standards both for building geometry and for energy simulations (Osello, 2012).

In order to perform the lighting simulations, it was not possible to import the parametric model from Revit into Radiance/Daysim directly. Hence, the Ecotect software was used as interface to lunch Radiance/Daysim. As a result, the import from Revit into Ecotect was addressed: the first trial adopted the traditional approach based on the exportation in .ifc format, but it did not succeed because some elements were not exported or were displaced (Aghemo, 2013).

The second trial was based on the exportation from Revit by a gbXML file, but some geometrical discrepancies in the surfaces generated from the solid elements made the model unsuitable for the lighting simulation.

Finally, the third procedure was successful. It exploits 3DStudioMax as intermediate software used to convert the .fbx file exported from Revit in a .3ds file to import into Ecotect. Thanks to this approach, good results in terms of geometrical consistency of the exported model were obtained. This procedure has appeared to be the most appropriate for what concerns modelling in the Revit Architecture environment and for the analysis in Ecotect. Particular attention must be paid to a series of operation to avoid errors or absence of information in target software, such as the development of objects in Revit.

As an example the correct fill of the “Room” tool in the parametric model is fundamental to obtain good results in order to avoid the creation of air gaps, which influence the goodness of the simulations.

At the end of the interoperability process, lighting simulations were performed to validate the models and to use them to evaluate the potential energy savings related to the proposed control strategies.

In addition to these tests, to optimize the use of building information model, the facility management was investigated developing many interoperable tests exploiting Archibus.

At present the interoperable process is not error free and needs to be improved

Smart Energy Efficient Middleware for Public Spaces

In the context of Ubiquitous Computing and IoT, one of the main challenges is the coexistence of heterogeneous devices and technologies and, consequently, their interoperability. To deal with this issue, we employed the general purpose LinkSmart middleware (Eisenhauer, 2009) to design the *Smart Energy Efficient Middleware for Public Spaces* (SEEMPubS), which provides components specifically designed for energy efficient smart buildings applications (Patti, 2014; Osello, 2013).

Figure 4. Middleware Infrastructure

As shown in Figure 4, it consists of three-layered architecture with: i) *Integration Proxy Layer*, ii) *Middleware Layer* and iii) *Application Layer*. The middleware provides to developers a set of components, called managers. They are designed in a Service Oriented approach, and each manager exposes its functionalities as Web Services. The rest of this section describes in more detail each layer of the proposed infrastructure.

Integration Proxy Layer

As already mentioned, buildings are already equipped with heterogeneous devices, both wireless and wired, that exploit different communication protocol standards, such as ZigBee, EnOcean, BACnet, etc. The *Integration Proxy Layer* is in charge to allow the interoperability across different technologies exploiting the concept of *Proxy*. The *Proxy* is a middleware software component that acts as bridge between the middleware network and the underlying technologies abstracting them and exporting their functionalities as Web Services (Patti, 2013). It communicates directly with the heterogeneous devices receiving real-time information regardless of the adopted communication protocols, hardware or the network topology. Therefore, each technology needs a dedicated software interface, which is the key to ensure the communication.

In particular we have developed proxies to manage Wireless Sensor and Actuator Networks that communicate with the following protocol stacks: i) IEEE 802.15.4, ii) ZigBee and iii) EnOcean. Moreover, to enable backwards compatibility with wired technologies, we also developed a proxy for the OPC Unified Architecture, which incorporates all the functionalities provided by different standards, such as BACnet and LonWorks.

Middleware Layer

The *Middleware Layer* has its roots in the LinkSmart middleware. It provides components specifically designed for energy efficiency in smart buildings. In the following all the components are described:

1) *Network Manager:* It is in charge to enable peer-to-peer communication (Steinmetz, 2005) between the middleware's components and/or applications. Creating a SOAP tunnel, it routes the Web Service calls to the requested service endpoint (Milagro, 2008), no matter if it is behind a firewall or NAT (Network Address Translator).
2) *Event Manager:* It enables a data centric approach based on the publish/subscribe model (Eugster, 2003) for the middleware Web Services. This allows the development of loosely-coupled event-based systems. This approach decouples the production and consumption of the information removing all the explicit dependencies between the interacting entities. In Smart Buildings, where we deal a lot with events coming from both devices and distributed software, this mechanism is a key requirement to develop systems and applications. Thanks to the Event Manager, each device is able to publish events, which contain both measurement and timestamp. Software components interested in certain events can subscribe for those and consequently receive the information in real-time.
3) *Context Framework:* It manages the semantic knowledge about the application domain and the implemented system. This includes metadata about the devices (sensors and actuators) and their relation to domain model objects such as appliances, buildings, and rooms. Querying the Context Manager, it is possible retrieve information from a rich domain model, such as the list of all devices in a room or the functionalities of a certain device.
4) *Occupancy Framework:* It gives to the whole infrastructure a user-centric approach providing information about the occupancy of the rooms and spaces, both public and private, in a building. It is a key factor for correct accounting of consumption and its optimization. It processes real-time raw occupancy data monitored in the environment and integrates the results with existing context information; thus, it can be finally used for energy assessment, optimization, and forecast.
5) *Rule Framework:* Typically, building management functions can be expressed in rules that listen to certain events, process them on a given algorithm, and finally perform a resulting action. Therefore, composing different rules between them, specific control strategies can be developed. The Rule Framework provides standard interfaces as a basis for specific rule implementations. These rule implementations can be plugged together in a rule engine that executes the rules on incoming events. Rule logic and contextual information, needed to execute a rule, are kept separately, following the principle of separation of concerns. This approach allows reusing rule implementations in different contexts, e.g., to apply the same HVAC control strategy in different rooms, but with different settings, depending of the peculiarities of the room itself or even its occupants.

Application Layer

In the software infrastructure shown in Figure 4, the *Application Layer* is the highest layer, which is dedicated to the development of applications in order post-process the real-time information coming from the lower layers. It is worth noting that at this level the interoperability between heterogeneous devices is enabled, as well as, thanks to the Web Services approach, between third-party software (e.g. Archibus). Accordingly, it allows the development of applications to promote user energy awareness or to manage the building, such as control strategies to reduce energy consumptions.

Gamification approach

In the complex smart cities and smart building contest, user awareness is one of the main aspects on which project like SEEMPubS has to pay attention. To reach as many people as possible (in addition to technical and scientific ones), the main concepts of the energy saving based on the scientific results obtained with the project could be disseminate using a gamification approach aimed at children and young students (8-16 years old): the "Smart Users" of the future. The goal is to improve their awareness on this field in a funny way, easy to learn, exploiting augmented reality as innovative communication tool (see Figure 6). Therefore, in SEEMPubSDice the game ends when the first player arrives at the end. However, the winner is who saved more energy during the path between all the players. This is of course an educational target. The game involves mixed teams among younger generation and adults who have to compete with each other to save as much energy as possible following the will of the Dice. Moreover, the players have to measure with the augmented reality technology that boosts their sensory perceptions and allow them to interact with virtual actors of the project: wireless sensors, temperature sensors, light bulbs, old electric wires, etc.

RESULTS

About BIM and interoperability

As said in Section Background, interoperability between software is the basic instrument to achieve a successful building information model process as shown in Figure 5. The need to enrich the 3D model/database with many objects belonging to different domains has allowed simulating a real situation where many professionals are involved in a design/management project. However, traditionally the communication between all project team members is critical. As the matter of fact architects and engineers have follow different approaches in a building project with different mindsets.

In addition, the parts involved in a building process usually exploit different software applications that do not communicate each other.

Effective communication i) enables the sharing of ideas, ii) provides understanding and ii) greatly reduces errors. With the data sharing, it is possible to make a process more flexible, where each part can gives a contribution to improve the project with time and cost saving.

In SEEMPubS the sharing of information workflow was tested. Using the worksets tool in the Revit environment, it was possible to test the work sharing design method that allows multiple team members to work on the same project model at the same time. When worksharing is enabled, a Revit document can be subdivided into worksets. A workset is a collection of building elements in the building, such as walls, doors, floors, stairs, etc. Only one user may edit each workset, all other team members may view this workset, but are unable to change it, preventing possible conflicts. Team members, adding and changing elements in worksets, can save their work to a local file on the network or their own hard drive, and publish work to a central file whenever they choose.

So, through the connection between all the parts involved in the SEEMPubS project we tested this methodology thanks to the interoperable process as said before.

Figure 5. BIM and interoperability for the data management.

Smart building applications for management and user awareness

In order to move forwards the vision of Smart Building, one of main purposes of the SEEMPubS middleware is also provide a tool for developing event-based and user-centric application. The resulting applications are able to receive and process real-time information for developing control strategy, thanks to the Rule Framework, and for raising the energy awareness to the users that live and work in the buildings. In the following two main applications are introduced: i) the Community Web Portal and ii) the Android Application for BIM and real-time environmental data visualization.

Community Web Portal

In order to access the information coming from the building and to provide user awareness, a *Community Web Portal* (see Figure 6) has been developed. Its main purpose is to make the end user aware about the energy consumption and to encourage energy saving by displaying energy management analysis and providing feedbacks. Through the Web Portal, the user can access to: i) real-time environmental data; ii) occupancy status; iii) energy consumption comparison chart of rooms; iv) list of devices deployed per room; v) energy consumption of the appliances in the room; vi) daily, monthly and yearly view and historic environmental values and occupancy charts. Three kinds of users have been identified for access to information:

- The *Public User* has a limited access to the information of the rooms and may inspect only the public spaces;
- The *Office Owner*, after authentication, may examine information about his own office further public spaces;
- The *Technician*, after authentication, has a full access to the information about the entire buildings. Also in his private page, he can see warnings about any malfunction in the entire monitored buildings.

As an extension to the Web Portal, a mobile application can be used to allow the users in expressing their discomfort in a room by voting. The idea is to use specific QR-codes for each room in the building, once the code is scanned (usually with a smartphone) the user is redirected to the poll where he can vote. These votes can be used by the technicians to adjust temperature, light or other environmental factors.

Android Application for BIM and real-time environmental data visualization

All buildings, whether modern or historical, must undergo maintenance interventions that further highlight their criticalities. Hence, in order to enhance any possible maintenance works, as a SEEMPubS application, we developed an Android app to display building information exploiting both virtual and augmented reality. It aims to overcome the limits related to 2D visualization, presenting a 3D environment where real-time building information is merged to architectural data.

Exploiting the virtual reality (see Figure 6), the application shows the three-dimensional building models and merges them with real-time environmental data coming from the deployed devices across the building. It allows the user to navigate into the 3D scene and to selectively change the transparency of different layers in the scene to display the hidden systems of the visited room. In the 3D model also the deployed devices are represented, hence, when the user selects one of them, both real-time information and line chart of historical environmental data are shown.

Figure 6 shows an example of the Android app for providing information exploiting the augmented reality. In this context, Quick Response (QR-) codes have been used as marker to store two types of information:

- a Room ID, which is used to identify a unique room within the system;
- a Device ID, which is used to identify a unique device within the system.

In this scenario, the user first scans the QR-code about a room or a device. Then the Android application decodes the QR-code and retrieves the related real-time information by calling the proper SEEMPubS Web Services. Finally the app shows the monitoring information overlapped to the video streaming.

It is worth noting that not only real-time data coming from the deployed devices are visualized, but also room's information retrieved directly from Archibus, which is proprietary third-party software integrated in our software infrastructure exploiting the Web Services approach.

Figure 6. Community Web Portal, Android app virtual reality view and SEEMPubSdice game as different examples of data use and visualization based on interoperability.

FUTURE RESEARCH DIRECTIONS

Future works are strictly linked with the DIMMER (District Information Modelling and Management for Energy Reduction) in order to integrate BIM, distribution network models, sensor data (both from environmental and energy production/consumption monitoring systems) and user feedback exploiting QR Codes and web portals. It allows open access with personal devices and AR visualization of energy-related information to client applications for energy and cost-analysis, tariff planning and evaluation, failure identification and maintenance, energy information sharing.

CONCLUSION

Thanks to ICT it is possible to access real-time information about building environmental characteristics and energy consumption. For this reason ICT is becoming a key factor to enhance energy optimization in buildings/cities. BIM and interoperability represent an opportunity for the AEC industry to optimize the data exchange among different professionals for both new and existing buildings. In fact, thanks to BIM an integrated process can be used to explore the physical and functional characteristics of a building digitally. Therefore, a real integrated and interdisciplinary BIM approach allows to understand, evaluate, simulate and solve optimally complex problems associated with various types of information (e.g. architecture and HVAC and lighting systems) using interoperability. Furthermore, middleware technologies provide services to application developers, hiding the complexity of underlying device specifics.

The Android App provides an innovative tool for BIM process, which exploits both Virtual and Augmented Reality to provide real time data also related to the structural information about the monitored environments. Even if for this application it has been followed the approach of separation of data collection from presentation and visualization, it allows development and improvement of user functionality independent from the basic data structures of the collection modules.

If compared to just a decade ago, impressive and powerful ICT tools have been developed in such a way to reach people everywhere and affect their everyday lives. Such influential tools, if made available to common people, and in particular to children and student at schools, should enable a better understanding of their energy habits and spreading energy efficient mentality not only between their peers but also in the older generations.

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KEY TERMS AND DEFINITIONS

Building Information Model: it is a data-rich, object oriented, intelligent and parametric digital representation of the facility, from which views and appropriate data for various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility.

Building Information Modelling: it is a method based on a building model containing any information about the construction. In addition to 3D object-based models, it contains information about specifications, building elements specifications, economy and programs.

Distributed Systems: it is a software system where its components are distributed in different interconnected computers or devices, which communicate and coordinate their action exchanging information between them to achieve a common goal.

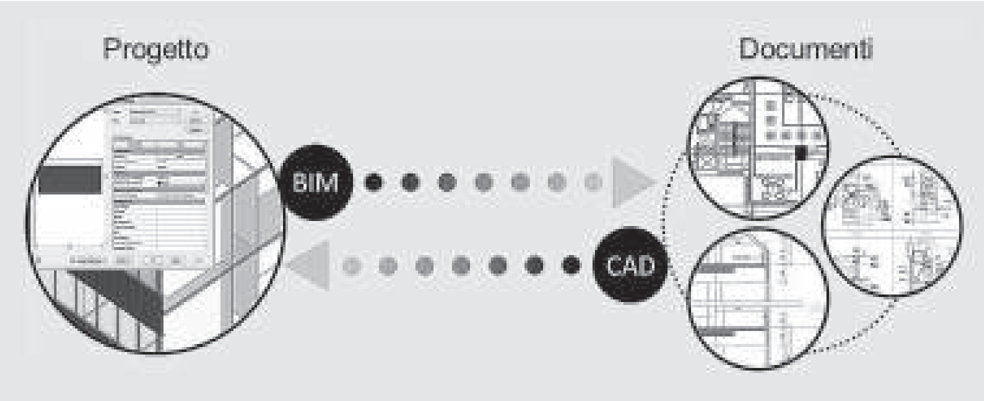
Facility Management: It is an integrated process to support and improve the effectiveness of the primary activities of an organization by the management and delivery of agreed support services for the appropriate environment needed to achieve its changing objectives

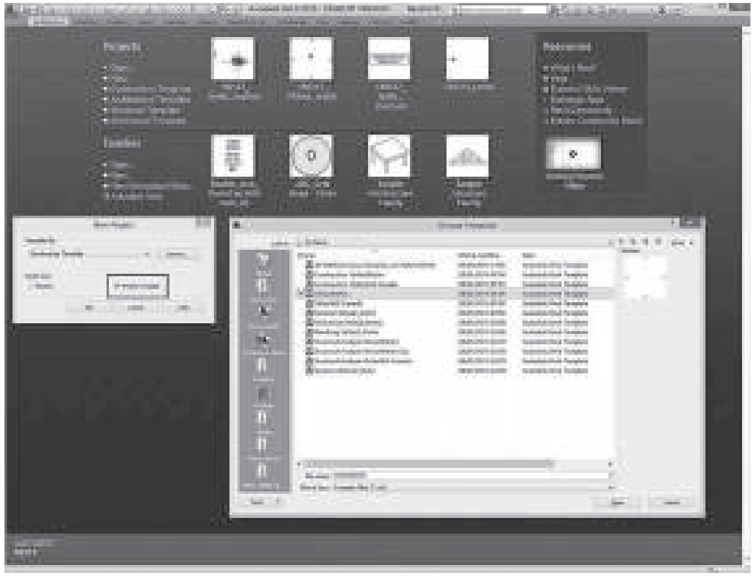
Interoperability: is defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged.

Middleware: it represents a set of computer programs whose objective is to enable communication and management of data in distributed applications. For instance, sensors for energy monitoring communicate with each other using their own computer languages, often created or implemented by different manufacturers. Consequently, the middleware works as a translator, thus allowing the sensors to communicate with each other.

Smart Building: according to the European Commission, “Smart buildings means buildings empowered by ICT (information and communication technologies) in the context of the merging Ubiquitous Computing and the Internet of Things: the generalization in instrumenting buildings with sensors, actuators, micro-chips, micro- and nano-embedded systems will allow to collect, filter and produce more and more information locally, to be further consolidated and managed globally according to business functions and services.”

Ubiquitous Computing: it is a concept where computing is made to appear everywhere and anywhere and users can access to the information exploiting any kind of device, in any location and in any format. The technologies for supporting Ubiquitous Computing include Internet, middleware, sensors, location and positioning.





1. Schema metodologico di BIM e CAD a confronto.

2. Interfaccia di Revit per la creazione di un nuovo template.

L'impostazione di un modello BIM per un edificio esistente

MATTEO DEL GIUDICE

Il processo edilizio può essere descritto come un **sistema complesso** costituito da una serie di fasi che si susseguono tra loro a partire dalla definizione degli obiettivi per arrivare alla realizzazione di un certo prodotto finito. L'iter progettuale può quindi essere assimilato a un processo iterativo, che comporta momenti di analisi, e momenti di sintesi che si susseguono e si precisano all'interno di un sistema complesso. Prendendo in considerazione lo scenario attuale in cui si trova l'industria delle costruzioni italiana (e non solo), risulta evidente come la necessità di una gestione più efficiente del patrimonio immobiliare esistente stia diventando il tema centrale di questi ultimi anni.

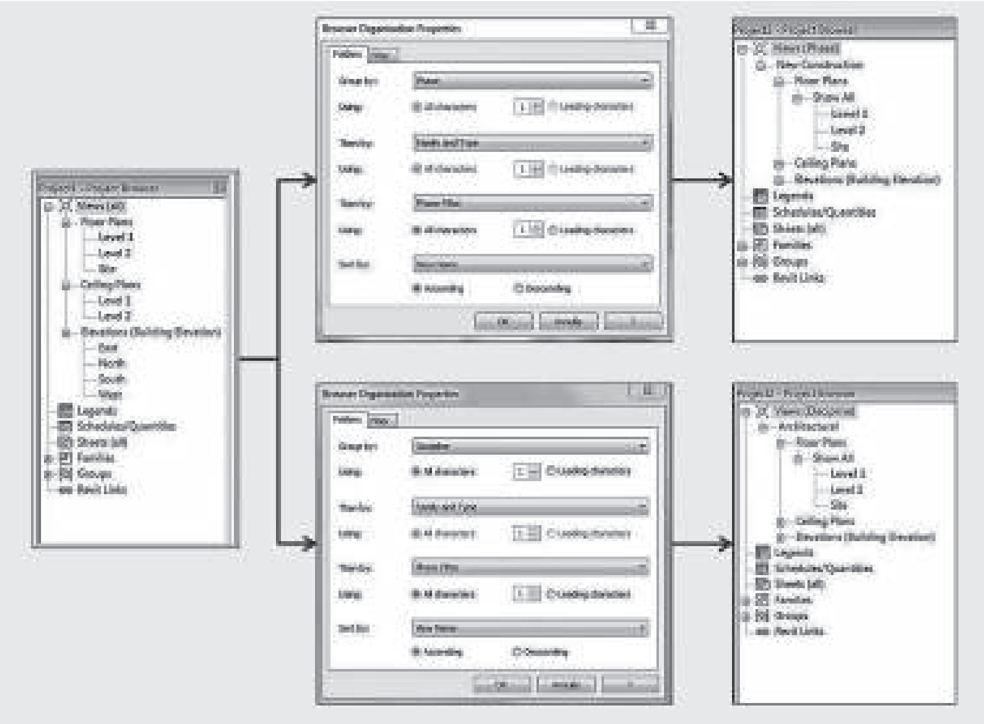
Se si considerano i problemi progettuali, economici, costruttivi, infrastrutturali, ecologici e di tutela che i proprietari di grandi patrimoni immobiliari si trovano ogni giorno a dover affrontare, diventa essenziale la presenza di un sistema di controllo e gestione delle varie attività urbanistiche ed edilizie, nonché la valutazione della loro compatibilità con le trasformazioni che continuamente investono la città. Per questo motivo si impone un rinnovamento nel modo di concepire l'iter progettuale basato su **strumenti di gestione e di comunicazione dei dati** innovativi.

Vozzola M., *BIM applicato alla progettazione: esperienza del Politecnico di Torino*, 2013.

Nel caso di un edificio esistente è necessario implementare il processo edilizio, prendendo in considerazione le fasi relative al reperimento dei documenti d'archivio e al rilievo geometrico dimensionale. Infatti, l'acquisizione di dati e di informazioni dettagliate è considerato uno dei temi fondamentali per la realizzazione di un sistema in grado di collezionare e rendere disponibili i dati ai diversi soggetti coinvolti.

A questo proposito il BIM può essere la via attraverso cui, rispettando la definizione di processo edilizio, sia possibile governare un patrimonio come quello immobiliare che le pubbliche amministrazioni, ma non solo, si trovano a dover gestire quotidianamente.

Paragonando il processo tradizionale con l'innovazione proposta dal BIM, è possibile affermare che più si avanza nel processo edilizio, maggiore è il costo relativo a eventuali modifiche al progetto. Ciò si ripercuote direttamente nella fase di realizzazione attraverso la formazione di potenziali ritardi, sprechi temporali ed economici. Il processo BIM sposta invece il momento massimo di sforzo nella fase iniziale del processo quando ancora i costi relativi a eventuali modifiche progettuali sono bassi. Così facendo, tutte le parti interessate al progetto sono coinvolte fin dall'inizio in modo che ciascun professionista possa elaborare le proprie scelte progettuali coordinandosi con gli altri, favorendo un approccio integrato all'elaborazione e alla consegna del progetto, evitando di commettere errori che causerebbero ritardi e aumenti in termini economici e temporali.



3. Differente impostazione del Browser di progetto per fasi e per discipline.

Qual è la finalità del modello BIM che si intende realizzare?

Avendo chiaro il significato del BIM, l'utilizzo di questa metodologia di lavoro implica l'elaborazione di un modello parametrico in grado di collezionare tutte le informazioni che dovranno essere condivise tra i diversi soggetti interessati. Per questo motivo è giusto sottolineare come l'elaborazione di un modello parametrico abbia quale beneficio principale il miglioramento della qualità di tutta la vita utile dell'edificio a partire dalla progettazione per arrivare alla gestione operativa. Volendo ripercorrere i momenti salienti che vedono coinvolto il professionista, la fase di pre-modellazione deve essere considerata non meno importante rispetto alle altre fasi. Infatti, ancor prima di partire con lo sviluppo del modello è necessario pensare a quale debba essere la **finalità** dello stesso, cercando di capire quale sia l'obiettivo che spinge a compiere tale atto.

Anche se potrebbe sembrare una banalità questo passaggio è tutt'altro che trascurabile. Infatti, a seconda delle finalità, il modello avrà caratteristiche differenti, partendo da quelle geometriche arrivando a quelle alfanumeriche.

Il professionista che si trova a seguire la metodologia BIM deve avere ben chiaro il quadro esigenziale e quello dei requisiti: deve conoscere in anticipo quali saranno le informazioni che vorrà inserire nel modello parametrico per poterle visualizzare nel modo corretto al momento opportuno. Tutto ciò in funzione del processo interoperabile che porterà all'utilizzo del modello per simulazioni di vari tipi con applicativi differenti. Partendo quindi dal **quadro esigenziale**, il professionista deve cercare di individuare i **requisiti** che il modello deve soddisfare in termini grafici alfanumerici e normativi, rendendolo sempre più **performante** e adatto al raggiungimento del proprio obiettivo.

In funzione di ciò, ciascun professionista potrà essere in grado di creare il proprio database di informazioni, sviluppando un modello parametrico adeguato per poterlo arricchire, interrogare, visualizzare e testare in modi diversi con differenti applicazioni.

Seguendo questo approccio è possibile confrontare il processo edilizio a un processo industriale valorizzando aspetti quali la qualità e la complessità del prodotto, l'automazione del processo di produzione e la producibilità in serie.

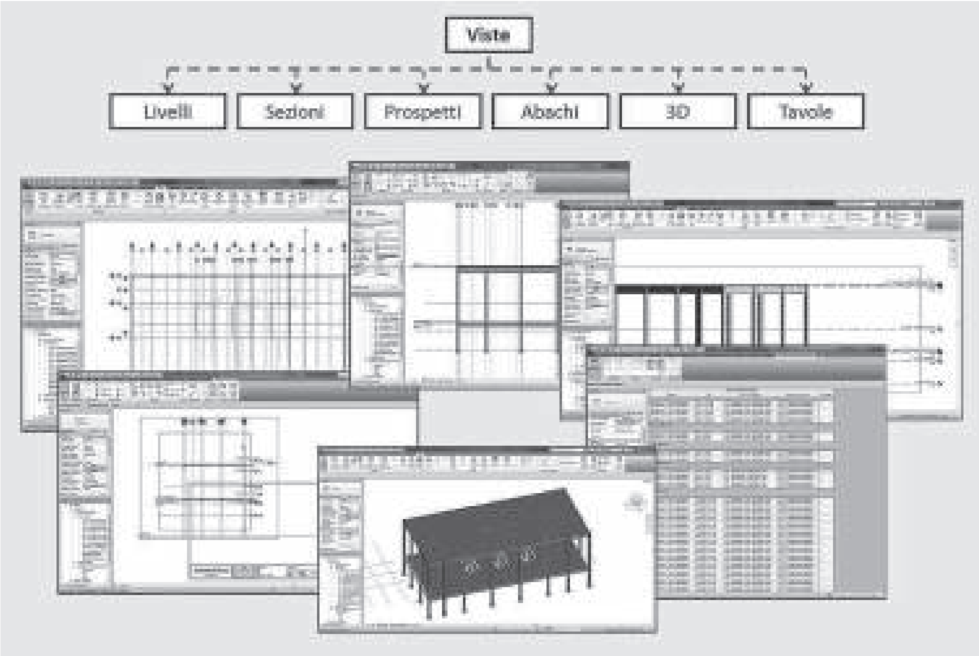
Le informazioni di partenza sono omogenee o eterogenee?

Avendo deciso di porre l'attenzione sugli edifici esistenti, è noto che le informazioni iniziali utili ai fini della comprensione del manufatto e necessarie per l'elaborazione del modello sono spesso tra loro eterogenee.

L'abilità del professionista, in questo caso, deve essere quella di comprendere quali siano le **informazioni corrette** da inserire e come queste possano coesistere tra loro. Questa operazione sposta notevolmente la curva degli sforzi all'inizio del processo progettuale, tuttavia spesso i neofiti in materia trascurano tale momento cedendo il passo alla fase operativa di modellazione. Questo errore potrebbe costare caro con l'avanzamento dei lavori.

Nel caso di un edificio esistente le informazioni che devono essere inserite nel modello BIM sono molteplici, a partire dai dati provenienti dai documenti d'archivio, dalle diverse tipologie di rilievo, sia esso speditivo, fotografico, topografico o laser scanner. Perciò, far convergere informazioni eterogenee in una stessa banca dati diventa una necessità. Certamente non bisogna pensare solo a come inserirle a livello di dato, ma bisognerebbe cercare di farle diventare parte attiva per la corretta realizzazione del modello. La difficoltà maggiore consiste nel far parlare i diversi dati in un ambiente comune in cui sia possibile sovrapporre le informazioni per poterle confrontare tra loro. In questo modo la realizzazione del modello parametrico risulterebbe il più possibile fedele e rispondente all'edificio reale.

La possibilità di comparare differenti documenti nello stesso ambiente di progettazione implica che il **database** sia strutturato in modo da utilizzare **filtri** opportuni che abbiano la caratteristica di attivare o disattivare la visualizzazione dei dati. Un ruolo chiave nella fase di importazione delle informazioni provenienti dalle diverse tipologie di rilievo è sicuramente l'interoperabilità tra i vari



4. Schema relativo alle differenti modalità di visualizzazione delle informazioni in Revit.

programmi che sono in grado di restituire fedelmente i dati geometrici raccolti in sito. Per quanto detto finora, un dato importante risulta la snellezza del file di progetto: bisogna sempre evitare di rendere il file molto pesante in termini di byte mantenendo il modello/DB il più possibile leggero ed efficiente.

A quale dettaglio deve essere realizzato il modello?

Dopo aver stabilito l'obiettivo per cui realizzare il modello è necessario stabilire il Livello di sviluppo e di dettaglio del modello. Molte definizioni di **Level of Development** e **Level of Detail** (LOD) sono reperibili a oggi nella letteratura internazionale, ma provando a sintetizzare il loro significato il livello di sviluppo può essere considerato come la quantità di informazioni che si possono inserire in un oggetto in funzione della **vocazione del modello**. Ovviamente queste informazioni possono essere di tipo grafico ma anche di carattere alfanumerico. Una volta deciso il livello di sviluppo si può passare a definire il livello di dettaglio a cui arrivare, ossia fino a che punto spingersi per specificare l'informazione.

Quando deve essere noto il flusso delle informazioni dell'intero progetto e con quante persone devono essere condivise le informazioni?

Un ulteriore livello di conoscenza che il professionista deve avere ben chiaro prima di iniziare la fase relativa alla modellazione è quello relativo alla consapevolezza del flusso delle informazioni durante la fase di progettazione ma soprattutto quello di gestione per quanto riguarda gli edifici esistenti.
Da questo punto di vista la presenza di un **BIM manager** assume grande importanza all'interno di una squadra di lavoro in quanto in grado di dirigere più efficientemente le operazioni relative all'arricchimento e all'interrogazione del modello parametrico nei diversi applicativi. Appare evidente, quindi, che la potenzialità relativa all'utilizzo di un modello parametrico BIM per la gestione del patrimonio immobiliare sia in stretta relazione con la condivisione delle informazioni tra i diversi utenti e professionisti durante tutta la vita utile del patrimonio immobiliare quale ad esempio quello della Pubblica Amministrazione.
A questo proposito, uno dei fattori più importanti su cui si basa il BIM è la **condivisione delle informazioni** che devono essere **inserite una sola volta** all'interno della banca dati. Ciò dà la possibilità di rendere immediato il passaggio delle informazioni: esso non prevede l'inserimento iterativo degli stessi dati già immessi, ma la loro implementazione attraverso l'aggiunta di altre informazioni. Ovviamente ciò è tanto più efficiente quanto più è valido il processo interoperabile tra i vari software di calcolo specifico. A questo proposito la realizzazione di un modello organizzato e realizzato in modo logico e funzionale alla propria attività può valere la differenza in termini di gestione dei dati tra i vari professionisti. A oggi, la condivisione delle informazioni attraverso il BIM, in un software come Revit ad esempio, può avvenire grazie alla presenza di un modello parametrico centrale a cui tutti possono sincronizzare i loro modelli locali attraverso i **worksets**, rendendo lo scambio e la visualizzazione dell'avanzamento del lavoro immediato attraverso una rapida verifica delle possibili interferenze tra le parti.

Come si deve iniziare un modello BIM?

La creazione del modello parametrico tridimensionale è quindi considerata uno dei punti fondamentali all'interno del processo BIM. Per iniziare il modello è possibile partire seguendo due vie: la prima è quella di utilizzare i file modello di default che un programma come Revit fornisce automaticamente; la seconda consiste nella creazione di un proprio file modello chiamato template in cui è possibile personalizzare la struttura della banca dati per orientarla verso le proprie finalità.
Ovviamente per prendere confidenza con lo strumento, inizialmente è preferibile utilizzare i file di default, ma nel caso in cui si debbano eseguire le stesse operazioni su larga scala per patrimoni immobiliari significativi è preferibile **personalizzare il modello** per velocizzare la fase di gestione dei dati: partire ogni volta dal file di default può risultare controproducente in termini di tempi e costi.

Che differenza c'è tra un file di progetto e un file di modello (template)?

Nell'ambiente di Revit ci si trova a utilizzare molteplici file con formati differenti, a partire dalle famiglie che vengono salvate in formato rfa, i file di progetto rvt, e i file di modello rfe. Questi ultimi sono detti anche template.
I file di modello sono file che vengono precaricati alla creazione di un nuovo progetto e contengono delle impostazioni fisse che facilitano l'utilizzo di Revit.
Di seguito vengono chiariti alcuni concetti chiave affinché l'utente possa comprendere come utilizzare correttamente lo strumento facendolo proprio utilizzando i file di modello attuando la metodologia BIM. Come già detto in precedenza, l'utilizzo dei template dà la possibilità di creare modelli personalizzati e performanti per ogni specifica necessità progettuale.
Aprendo la prima volta questi file si ha la sensazione che siano del tutto simili ai file di progetto: questo è vero anche perché prima di creare un nuovo progetto Revit richiede all'utente con quale file modello si vuole iniziare. Una volta scelto il template, questo viene aperto e la sua estensione viene trasformata immediatamente da rte a rvt.
La prima regola da seguire consiste nel creare una **struttura non troppo rigida del file**. Infatti, è meglio organizzare il file lasciando sempre la libertà di personalizzazione del file di progetto a chi dovrà realizzare il modello parametrico senza difficoltà eccessive.
Come già detto in precedenza, bisogna definire lo scopo del modello parametrico, organizzando in modo coerente ed efficiente le librerie che si utilizzeranno nel corso della modellazione, tenendo conto della normativa di riferimento. Ogni software fornisce già librerie di oggetti che possono essere usati, ma oltre a questo il consiglio è di creare nei limiti del possibile anche una libreria personalizzata di oggetti che saranno caratteristici del proprio modello. Questo vale soprattutto quando si lavora sugli edifici esistenti/storici, in cui ovviamente non tutti i dati sono presenti nelle librerie fornite dal software.
Quindi bisognerà pensare a quali dati dovranno essere estratti dalla banca dati per effettuare le verifiche necessarie: questi dati dovranno essere espressi con il corretto LOD in relazione agli utenti che dovranno utilizzarli come fonte di partenza per le specifiche elaborazioni. Ad esempio, potrebbe essere utile la visualizzazione di elaborati grafici con alcune tematizzazioni relative alla distribuzione dei locali per il settore del FM con accostati alcuni valori tabellari in grado di esplicitare i valori grafici in termini di superficie, volume, occupazione, ecc.

Perché creare un template?

La creazione di questo file agevola notevolmente il professionista che si trova a sviluppare e gestire il modello parametrico di molti edifici appartenenti a uno stesso portafoglio immobiliare. Infatti, una volta creato il template da cui partire, la realizzazione dei vari modelli parametrici verrà effettuata secondo le stesse modalità e seguendo le regole presenti all'interno del template stesso. In questo modo si eviterà ogni volta di impostare nuovamente le regole di visualizzazione, di interrogazione e di interfaccia che possono generare allungamenti nei tempi di realizzazione del modello BIM e inefficienze dovute alla ripetizione di alcune operazioni che invece dovrebbero diventare **standard** da seguire per tutti i modelli.
Il concetto che sta alla base della creazione di un template è la necessità di creare uno standard in grado di abbracciare le esigenze della committenza, soddisfacendo allo stesso tempo i requisiti prefissati. Questo richiede una riflessione su quello che si vuole ottenere dal modello che deve essere fatta prima di iniziare la fase di modellazione. Seguendo questa direzione, si riuscirà a rendere omogenei i dati che verranno inseriti nei vari modelli parametrici per poterli confrontare tra loro dando la possibilità ai proprietari di attuare delle politiche di gestione e manutenzione nell'ottica di efficienza in termini di tempi e costi.

Come standardizzare alcune informazioni generali di un modello parametrico come ad esempio il nome del file o delle viste?

Una delle prime attività della fase di modellazione è l'assegnazione di un **nome al file** di progetto: ciò risulta rilevante nel momento in cui molte sono le parti coinvolte nel processo. Utilizzando differenti file locali che devono essere sincronizzati a un unico file centrale secondo il processo della condivisione del lavoro appare evidente come non debbano verificarsi incomprensioni sulla proprietà di alcuni oggetti all'interno del modello. A livello internazionale molti paesi hanno creato una codifica per nominare il file di progetto: a titolo di esempio si riporta la modalità usata a Singapore, uno dei paesi in cui il BIM è maggiormente utilizzato, e dove ha sede il Construction Real Estate Network (CoRENet), la principale organizzazione coinvolta nello sviluppo e nella implementazione del BIM per i progetti governativi. Il nome è composto da cinque campi: il primo consiste nel codice identificativo del progetto, il secondo riguarda invece il soggetto che ha elaborato il modello, il terzo è utilizzato per distinguere i vari volumi di un'opera edilizia, il quarto è relativo alla versione di elaborazione del file. L'ultimo campo è opzionale ed è riservato all'utente che può inserire un codice caratteristico che gli permetta di poterlo identificare. Pertanto, a titolo esemplificativo si potrebbe avere: MLP1_A_01_A_XXXX. Oltre alla codifica del nome del file è necessario standardizzare il **nome delle viste** in funzione dell'utente che dovrà visualizzare il modello secondo una particolare modalità. Anche in questo caso si riporta l'esempio di Singapore in cui il nome della vista è composta da tre campi principali dove il primo è riservato al codice relativo all'ente a cui la vista è riferita, il secondo è relativo al tipo di vista (ossia se si tratta di una pianta, di un prospetto, di una sezione, di una vista 3D, di un dettaglio, di una tabella, ecc.), mentre l'ultimo è riservato al nome della vista. In questo caso, un esempio di nome di vista potrebbe risultare: BCA_FP_1stSTOREY.
Nel caso della Pubblica Amministrazione Italiana è necessario nominare le viste secondo gli enti che le dovranno utilizzare per rilasciare i permessi necessari all'esecuzione dei lavori.

Come visualizzare le informazioni?

Una volta definito l'obiettivo a cui bisogna tendere, occorre riflettere su quale sia la migliore organizzazione delle informazioni per poterle visualizzare nel modo più immediato possibile. A seconda delle diverse software house, le potenzialità degli attuali applicativi in commercio consentono di poter organizzare e visualizzare il modello attraverso differenti tipi di visualizzazione, tra cui quella in pianta, prospetto, sezione, prospettiva, ma anche attraverso abachi in grado di dare visione immediata delle quantità e delle caratteristiche degli oggetti presenti nel modello parametrico.

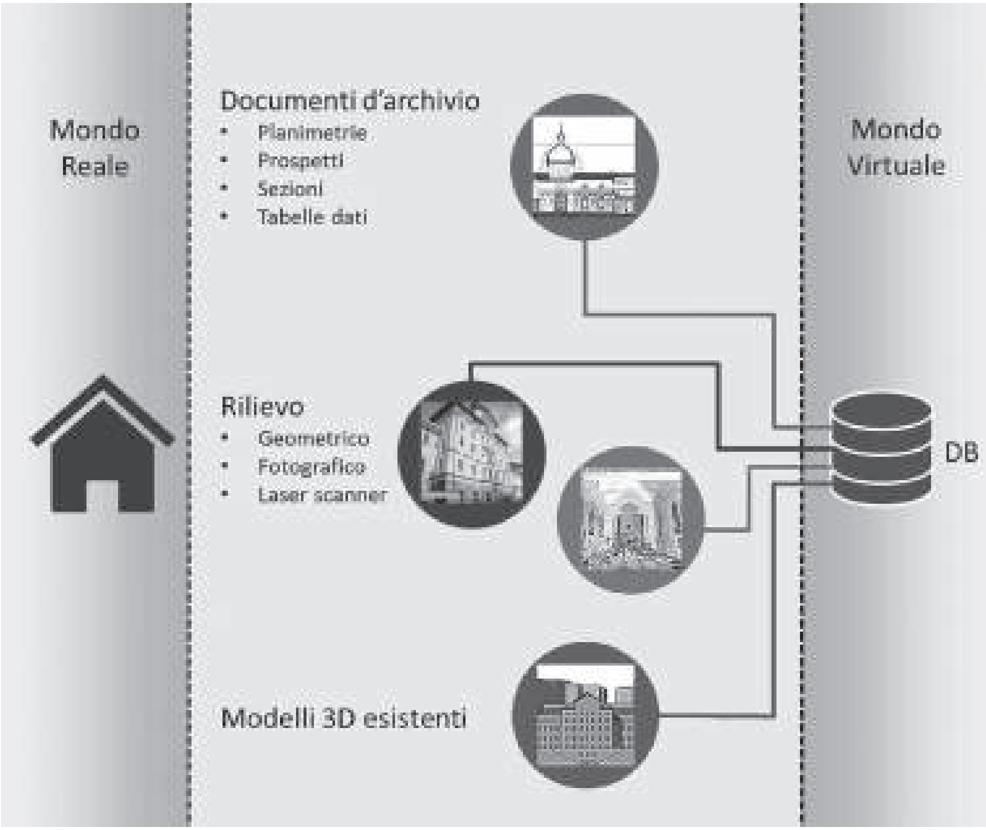
Prendendo a titolo di esempio il software Autodesk Revit, le informazioni al suo interno possono essere organizzate e visualizzate in modo differente grazie al Browser di progetto che offre la possibilità di ordinare **viste** e **tavole**, utilizzando un qualsiasi valore di proprietà per la vista o la tavola. Questo strumento consente di visualizzare secondo una gerarchia logica tutte le viste, gli abachi, le tavole, i gruppi e altri componenti del progetto corrente. Espandendo e comprimendo i singoli rami è possibile visualizzare gli elementi dei livelli inferiori. È anche possibile limitare il numero di viste visualizzate nel Browser di progetto applicando un **filtro**. Ciò è utile quando un progetto presenta un gran numero di viste o tavole e si desidera visualizzare soltanto uno specifico set di visualizzazioni. Ovviamente questa operazione può risultare notevolmente semplificata se si è utilizzato un criterio di codifica ben definito, come ad esempio quello descritto in precedenza.
Una volta terminato il modello parametrico, per poter estrapolare le informazioni a livello cartaceo è possibile creare delle visualizzazioni in grado di riprendere le informazioni visibili nelle varie viste per unirle in un'unica tavola anch'essa parametrica: pensare alle informazioni che devono essere inserite nel cartiglio di una tavola rientra nell'attività di standardizzazione del processo. Questo processo può essere automatizzato dagli applicativi attuali, utilizzando delle caselle di testo che vengono aggiornate automaticamente in funzione delle informazioni che si vogliono inserire. Ad esempio il nome e il numero della tavola possono essere studiati e sviluppati precedentemente nel template uniformando il nome delle varie tavole. In questo modo non si verificheranno problemi quali ad esempio la coerenza tra ciò che si visualizza nell'elaborato finale e l'informazione riportata nel cartiglio che esplica il contenuto della tavola. Considerando la gestione del Browser di progetto è possibile quindi organizzare le informazioni in modalità differenti secondo quanto detto finora: è possibile visualizzare una **gerarchia logica** di tutte le **viste**, degli **abachi**, delle **tavole**, di tutti i **gruppi** e di **altri componenti** del progetto corrente.
È possibile ad esempio organizzare le informazioni secondo la disciplina (Architettonica, Strutturale, Elettrico, Meccanica, Coordinamento) oppure secondo le fasi di progetto, o ancora secondo la gerarchia degli oggetti (categoria, famiglia, tipo, istanza) o anche considerandole tutte insieme ma organizzando le informazioni in modo gerarchico. L'utilizzo dello strumento delle fasi all'interno di Revit può consentire di discriminare la variabile tempo e associare dei filtri di visualizzazione specifici per ogni fase.
Si è detto che l'ingegnerizzazione del template è funzionale a un obiettivo, pertanto, in funzione dello scopo del progetto, le informazioni potranno essere organizzate anche, ad esempio, secondo fasi di progetto. Si deve sottolineare come sia essenziale la capacità del professionista di pianificare le fasi e le procedure che caratterizzeranno il progetto discretizzando in modo logico ogni singolo step senza eccedere troppo nello specifico. Come è vero che lo strumento fasi aiuta a organizzare il modello in modo temporale è anche vero che questo è uno strumento utile per la visualizzazione logica delle fasi che successivamente verranno analizzate in modo specifico a livello temporale attraverso strumenti di project management.

Bisogna modellare secondo il corretto orientamento geografico?

Partendo con la fase di modellazione è importante considerare fin dall'inizio la posizione geografica del manufatto. Questo anche in termini di successiva simulazione ad esempio in ambito illuminotecnico e/o termico. L'orientamento gioca un ruolo chiave anche nel caso in cui si stia utilizzando la tecnologia laser scanner: in questo caso la nuvola di punti georeferenziata facilita il professionista nell'attribuzione del corretto orientamento dell'edificio. Questa attività non deve spaventare l'utente anche perché il corretto orientamento può essere stabilito in un secondo momento quando la modellazione è già iniziata, grazie al comando di rotazione del Nord Reale presente in Revit. È infatti possibile utilizzare due tipi di Nord all'interno dell'ambiente parametrico: il *Nord Reale* consente di visualizzare correttamente la posizione dell'edificio nello spazio, il *Nord di Progetto* facilita il professionista nella fase di creazione del modello poiché consente di ruotare a proprio piacimento l'orientamento del modello stesso senza modificare la vera posizione geografica.

È possibile caratterizzare il modello aggiungendo parametri specifici?

All'interno del template è possibile precaricare alcune famiglie in modo tale che all'inizio di un progetto sia possibile utilizzare le famiglie appartenenti a una certa libreria senza ricaricarle ogni volta una a una. Revit fornisce poi la possibilità di personalizzare gli oggetti parametrici arricchendo le informazioni grazie all'utilizzo di parametri che possono essere inseriti in base alle esigenze specifiche. A questo proposito può essere interessante soffermarsi brevemente sulla gestione dei parametri personalizzabili all'interno dell'ambiente di progettazione.
In Revit si ha la possibilità di attribuire alcuni parametri che possono essere condivisi in differenti progetti: questi vengono chiamati **parametri condivisi**.
I parametri condivisi sono definizioni di parametri che è possibile aggiungere a famiglie o progetti come ad esempio nel caso in cui si voglia aggiungere una caratteristica a una stanza per indicarne la funzione (ufficio, corridoio, bagno, ecc.), è possibile aggiungere un campo all'interno della banca dati di Revit creando un file di testo in cui vengono collezionati tutti i campi personalizzati che possono essere usati per più progetti. Il file di testo viene poi caricato nel progetto in esame, rendendo possibile la compilazione del campo personalizzato e quindi l'arricchimento del database. Come già affermato precedentemente, quindi, le definizioni dei parametri condivisi vengono memorizzati in un file indipendente da qualsiasi file di famiglia o progetto di Revit; in tal modo è possibile accedere al file da diverse famiglie o diversi progetti. Il parametro condiviso può essere considerato come un contenitore di informazioni utilizzabili in più famiglie o progetti. Le informazioni definite in una famiglia o in un progetto mediante il parametro condiviso non vengono applicate automaticamente a un'altra famiglia o progetto utilizzando lo stesso parametro condiviso. Ad esempio, per utilizzare le informazioni di un parametro in un'etichetta, è necessario che il parametro sia un parametro condiviso.
Il loro utilizzo è da preferire al semplice uso dei parametri di progetto in quanto al momento della creazione dei parametri condivisi viene generato un file di testo txt che può essere caricato in differenti file. Questa è un'altra caratteristica che consente di accelerare le procedure di realizzazione del modello su una base di **standard prefissati**.



1. Schema generale relativo alla raccolta dati tra loro eterogenei.

La gestione delle nuvole di punti con il BIM

MATTEO DEL GIUDICE

Lo sviluppo di tecnologie BIM per il patrimonio edilizio esistente sta diventando uno dei temi principali di questi ultimi anni all'interno del mondo dell'industria delle costruzioni. Le attuali condizioni economiche in cui si trova l'Italia impongono una revisione sulla modalità di gestione del patrimonio immobiliare nazionale al fine di snellire e velocizzare il processo relativo alla gestione operativa degli edifici in termini di manutenzione, restauro, efficienza energetica, gestione dei servizi connessi, ottimizzazione degli spazi, ecc. Poiché il processo BIM si basa sull'elaborazione di un modello parametrico che man mano viene arricchito e interrogato durante le diverse fasi di utilizzo, in questo ambito di applicazione può risultare particolarmente utile.

Quali sono le difficoltà nel realizzare un modello BIM del patrimonio culturale esistente?

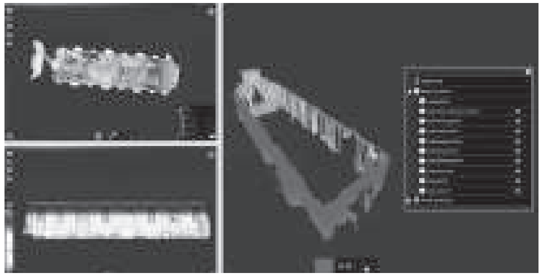
La gestione delle informazioni riferita alla creazione di un modello parametrico relativo a un edificio appartenente al patrimonio architettonico esistente necessita di una riflessione. Rispetto a un edificio di nuova costruzione un edificio esistente presenta spesso delle caratteristiche geometriche dimensionali che poco facilmente si adattano alla modellazione a partire da oggetti standardizzati che contengono al loro interno delle caratteristiche architettoniche e strutturali, energetiche, ecc.
Tuttavia, l'elaborazione di un modello parametrico implica necessariamente l'utilizzo di oggetti ricchi di informazioni non solo geometriche, tipiche delle diverse fasi del progetto. Per questo motivo è necessario pensare allo scopo finale del lavoro prima di iniziare la fase di modellazione, stabilendo il livello di sviluppo del modello e il livello di dettaglio dei vari oggetti che lo dovranno popolare.
La **modellazione di oggetti complessi** quali ad esempio capitelli, lesene, paraste, timpani, trabeazioni, appartenenti a un determinato stile architettonico può talvolta impensierire il professionista che si trova a elaborare un modello in cui devono essere inseriti oggetti non presenti nelle librerie fornite dai diversi software disponibili sul mercato. A questo si aggiunge una difficoltà legata al **mantenimento delle informazioni** geometriche e alfanumeriche degli oggetti durante il **processo interoperabile** per test specifici con applicativi diversi. Come già detto, ciò richiede una riflessione precedente alla fase di modellazioni in termini di requisiti e prestazioni che il modello deve soddisfare.
Questo lavoro rientra nell'ambito di un Progetto di Ricerca di Interesse Nazionale (PRIN) cofinanziato dal Ministero dell'Istruzione, Università e Ricerca scientifica il cui obiettivo è di sperimentare azioni che favoriscano il miglioramento delle politiche di gestione del patrimonio edilizio e di conservazione e valorizzazione del patrimonio culturale. Ciò è reso possibile grazie

all'innovazione tecnologica e di processo basata sul Building Information Modelling (BIM), visto anche come indispensabile innovazione della filiera delle costruzioni.
L'applicazione reale di questa metodologia agli interventi sull'esistente (soprattutto storico) a partire da tecniche di rilievo e modellazione 3D, deve ancora essere affrontato in maniera diffusa e integrata dai soggetti dell'industria delle costruzioni.
Questo progetto intende affrontare e approfondire questioni che sono proprie della qualità del processo edilizio in tema di standard (grafici e non) del progetto per il recupero e il restauro degli edifici pubblici, a partire dalla definizione di una precisa gerarchia di dati (Preliminary Requirements). L'obiettivo è sfruttare le tecnologie informatiche in maniera avanzata e, partendo dal concetto di interoperabilità dei software, definire una nuova filosofia di lavoro basata sul BIM anche in fase di monitoraggio, gestione e manutenzione.
Poiché l'obiettivo è la creazione di un modello 3D parametrico, nasce la necessità di definire la modalità di realizzazione sulla base delle fonti archivistiche e dei dati provenienti dalle varie tipologie di rilievo.
Si considerano sia il rilievo diretto, basato sull'uso di strumenti semplici "in situ" che danno la possibilità di conoscere in modo immediato il fabbricato, sia quello indiretto, che attraverso strumenti più complessi, sposta la fase conoscitiva al momento della restituzione dei dati.
La difficoltà principale consiste quindi nell'inserire informazioni tra loro eterogenee in un unico ambiente di modellazione per procedere con la comparazione delle diverse informazioni e sviluppare quindi il modello BIM il più possibile fedele alla realtà. Questa difficoltà è tale anche poiché ciascuna fonte è conservata in modo differente: a partire dal formato cartaceo per arrivare a quello digitale in pdf o dwg, jpeg, las, rcs, ecc. Già dalla fase di inserimento delle fonti risulta evidente come l'interoperabilità tra i programmi attraverso l'uso di diversi formati di scambio giochi un ruolo chiave riguardo alla condivisione delle informazioni per la realizzazione un unico archivio in cui sia possibile collezionare e interrogare tutti i dati relativi a un singolo manufatto.
Con questo contributo viene affrontato il tema della realizzazione di un modello BIM a partire dalla nuvola di punti prodotta da un rilievo eseguito con il laser scanner. Rispetto agli edifici di nuova costruzione in cui è fondamentale la fase di progettazione e quindi il flusso informativo necessario alla realizzazione di un manufatto, per gli edifici esistenti si pone la questione di come restituire a livello digitale i dati provenienti dalla realtà, siano essi grafici o alfanumerici.
A questo proposito risulta centrale il tema relativo ai Levels of Development (LOD) in relazione ai modelli specifici e ai Levels of Details (LOD) per quanto riguarda le librerie di oggetti che si devono utilizzare per l'elaborazione del modello.
Data la complessità degli oggetti che devono popolare il **database grafico** è fondamentale comprendere quale sia la vocazione d'uso del modello, ossia alla funzione a cui dovrà assolvere una volta realizzato. In funzione di ciò si stabilisce il livello di sviluppo del modello (se esso debba essere usato per la gestione dei locali, per le analisi strutturali, energetiche, impiantistiche, per la sicurezza antincendio, ecc.) e in funzione di questo viene fissato il livello di dettaglio a cui si dovrà tendere durante la modellazione dei singoli oggetti.
Questo momento che precede la fase di modellazione è tutt'altro che semplice in quanto si devono stabilire le regole che porteranno all'elaborazione del modello BIM.
Riguardo al PRIN, molteplici sono i casi studio utilizzati per questo progetto. Il Politecnico di Torino in collaborazione con l'Università degli Studi di Genova e l'Università degli Studi di Brescia ha scelto come caso studio l'Albergo dei Poveri di Genova, un edificio che risale nel suo primo impianto alla seconda metà del Seicento quale istituto di assistenza pubblica destinato all'accoglienza di varie categorie di cittadini disagiati. Questo edificio è stato sottoposto nel tempo a numerosi ampliamenti con differenti tecniche costruttive; attualmente si trova per la maggior parte degli spazi in stato di degrado anche avanzato. In alcune parti l'edificio ospita le facoltà di Giurisprudenza e Scienze Politiche dell'università di Genova.
La scelta di questo edificio è legata non solo alla necessità di conservazione e tutela della struttura esistente, ma anche alla possibilità di realizzare un progetto per un'aula magna per l'Università degli Studi di Genova.
Al fine di sviluppare correttamente il modello secondo la finalità del progetto di ricerca è stato necessario avviare innanzitutto una fase conoscitiva del manufatto oggetto di studio a partire dalla ricerca dei documenti d'archivio che ne descrivono la valenza storica e l'importanza culturale, e dalle diverse operazioni di rilievo atte a definire geometricamente le consistenze delle parti e del tutto.
Da questi dati, all'interno del modello BIM è essenziale riuscire a riportare le caratteristiche fondamentali sia della scala edilizia sia di quella urbana, in un sistema di rappresentazione codificato. Esso è necessario per comprendere l'opera nella sua totalità, cogliendone tutti i valori, da quelli dimensionali a quelli costruttivi, considerando anche quelli formali e quelli culturali.
Ovviamente, a seconda del tipo di informazioni che si vogliono ottenere attraverso il rilievo, deve essere scelto il metodo più corretto, che tenga conto di diversi fattori tra cui la precisione richiesta e i costi imputabili sia agli **strumenti utilizzati** che ai **tempi di restituzione dei dati**.

Perché un rilievo laser scanner?

Per questo caso studio si è scelto di utilizzare il metodo strumentale basato sul laser scanner per testare una tecnologia innovativa che porta con sé molti vantaggi ma anche degli svantaggi. Per un professionista o per una Pubblica Amministrazione l'utilizzo del laser scanner implica l'acquisto o il noleggio dello strumento che a oggi risulta ancora relativamente oneroso; tuttavia l'opportunità di esplorare con l'uso di un PC la nuvola di punti e di effettuare misure come se si fosse sul luogo di campagna, lo rende uno degli strumenti più appetibili per la realizzazione di un modello parametrico di un edificio storico caratterizzato da un'architettura complessa.
L'iter operativo consiste in due fasi distinte: una di campagna, in cui vengono raccolti i dati effettuando le scansioni con lo strumento (che in questo caso specifico sono state effettuate dall'Università degli Studi di Brescia), e l'altra di restituzione dei dati con l'ausilio di diversi applicativi che verranno descritti in seguito.
L'Albergo dei Poveri può essere considerato un edificio articolato dotato di un numero significativo di locali. Per questa ricerca, a titolo esemplificativo, sono stati presi in considerazione dei locali rappresentativi di questo tipo di architettura tra cui l'antechiesa, il corridorio adiacente e il salone d'entrata dell'edificio.
Al momento attuale il progetto si sta focalizzando sulla parte relativa all'antechiesa, dove sono state necessarie 37 scansioni con una campagna di rilievo durata un paio di giorni. La prima elaborazione della nuvola di punti iniziale contava circa 233 milioni di punti con un peso di circa 3,5 GB. Dopo aver allineato le varie scansioni e aver ripulito la nuvola dai punti non necessari il numero di punti è sceso a circa 18 milioni con un conseguente alleggerimento in termini di spazio su hard disk.

2. Schema relativo all'acquisizione/restituzione dati per creare la nuvola di punti.



3. Visualizzazione della nuvola di punti su Autodesk Recap PRO 2015.

4. Suddivisione della nuvola di punti in sottoregioni in Autodesk Recap PRO 2015.

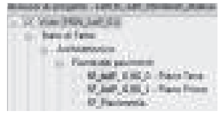
5. Visualizzazione della nuvola di punti attraverso i worksets.

Come gestire la nuvola di punti?

Le elaborazioni della nuvola di punti sono state eseguite con il software Faro Scene. Le varie scansioni sono state suddivise poi in sotto regioni considerando le appartenenze logiche ai vari locali. Dapprima la nuvola di punti è stata salvata in formato lsproj, creando un progetto di scansione che consiste in una memoria centrale che contiene tutti i dati condivisi di un progetto. Il progetto di scansione è formato dal workspace del progetto (la struttura gerarchica delle scansioni e degli oggetti definiti durante la scansione e dell'intero processo di registrazione).
Purtroppo questa scelta non ha portato a grandi agevolazioni se non a favorire la visualizzazione dei locali offrendo l'opportunità di focalizzare l'attenzione sulle diverse parti della nuvola di punti senza dover ogni volta caricare tutti i dati.

È necessario suddividere la nuvola di punti in parti logiche?

La nuvola è stata organizzata in modo logico e funzionale all'interno del software Autodesk Recap PRO 2015 all'interno del quale è stata dapprima importata con differenti formati di scambio (tra cui lsproj, las, pcg, ptg, pts), poi è stata suddivisa in molte sezioni. A questo proposito è necessario sottolineare che la decisione di **organizzare la nuvola secondo i locali**, è stata persa durante il processo di esportazione/importazione per cui la suddivisone logica secondo componente edilizio è stata svolta ripartendo dalla nuvola iniziale. In questa fase si è verificata una perdita di informazione che può essere dovuta al tipo di formato di scambio utilizzato e quindi al processo interoperabile, che non ha mantenuto l'informazione relativa al raggruppamento delle varie scansioni in sottogruppi, nonostante l'importazione sia avvenuta utilizzando il file di progetto già organizzato e non le singole scansioni. La nuvola di punti è stata quindi ripulita escludendo le parti non necessarie ed è stata suddivisa in regioni più piccole rifacendosi alle varie **classi di unità tecnologica**. Dopo aver scremato e organizzato la nuvola, le varie regioni sono state importate nell'ambiente di progettazione di Autodesk Revit.
Inizialmente, la nuvola è stata caricata all'interno di Revit in modo integrale in formato rcp, tuttavia questo ha generato un file molto "pesante" in termini di spazio su disco fisso e di accelerazione hardware per quanto riguarda la scheda video, causando un risultato negativo in termini di prestazioni del file di progetto. Per questo motivo è possibile affermare che la gestione della nuvola attraverso la realizzazione delle regioni è risultata vincente in termini di visualizzazione, di snellezza del file di progetto e di gestione delle informazioni per procedere correttamente con la modellazione
Come già detto in precedenza, l'organizzazione logica dei punti per componente edilizio è stata funzionale per ottimizzare la loro gestione all'interno del software di modellazione parametrica, agevolando la successiva fase di modellazione.



6. Organizzazione del Browser di progetto di Revit per ottimizzare la visualizzazione dei dati.

Perché l'utilizzo di fonti eterogenee può migliorare la realizzazione del modello BIM?

La presenza di molteplici documenti facenti riferimento a uno stesso fabbricato può far sì che il professionista sia in grado di riprodurre il modello BIM cercando di avvicinarsi il più possibile alla realtà. Infatti, l'analisi delle diverse fonti archivistiche si intrecciata con le indagini di

rilievo effettuate con il laser scanner, offrendo la possibilità di verificare la bontà delle informazioni derivanti da documenti storici o di provenienza incerta (come si è verificato con l'Albergo dei Poveri). Data la disponibilità di un modello 3D eseguito con Google Sketchup dall'Università degli Studi di Genova, realizzato prima ancora delle operazioni di rilievo con il laser scanner, il modello è stato messo in confronto con la nuvola di punti e il risultato è stato di una sostanziale coerenza per la visualizzazione in pianta, ma un'incoerenza rispetto alla visualizzazione in prospetto e in sezione. Si è quindi deciso di mantenere la scansione laser scanner come rappresentazione più vicina alla realtà.
La presenza di una fonte di dati diversa, come ad esempio il modello 3D sopracitato, è stata comunque funzionale all'elaborazione del modello, poiché ha permesso di comprendere come l'inserimento di dati tra loro eterogenei possa essere utilizzato come uno strumento utile alla realizzazione del modello parametrico. Prima di iniziare la fase di modellazione è stato creato un sistema di gestione basato sulla condivisione dei dati. Il modello è stato impostato adottando lo strumento dei worksets. Ossia, è stato realizzato un modello centrale dal quale sono stati creati modelli locali simulando l'attività di un gruppo di lavoro composto da diverse professionalità, ciascuna in grado di arricchire il modello con alcuni dati che poi vengono condivisi con le altre parti attraverso la sincronizzazione dei modelli. Questo è molto importante in termini di controllo delle interferenze tra i vari elementi costituenti il fabbricato, avendo una visione immediata di possibili criticità o veri e propri errori. La presenza di **dati eterogenei** provenienti da diverse fonti che possono derivare dalla **fase di rilievo** o dalla ricerca dei **documenti d'archivio** è essenziale per comprendere quali possano essere le criticità nello sviluppo di un modello parametrico di un edificio appartenente al patrimonio architettonico esistente.
L'inserimento delle diverse fonti all'interno del modello/database può anche essere funzionale poiché, grazie all'utilizzo dei parametri condivisi che danno la possibilità di attribuire alcune caratteristiche specifiche agli oggetti, durante l'elaborazione del modello è possibile assegnare la provenienza che ha spinto il professionista a inserire un certo oggetto; per cui una volta terminato il modello relativo allo stato di fatto è possibile determinare quale sia stata la fonte principale per l'elaborazione del modello parametrico, attraverso l'utilizzo di filtri di visualizzazione.
Oltre a ciò, la rappresentazione delle informazioni all'interno dell'ambiente Revit è stato caratterizzato modificando il browser di progetto secondo le fasi di progetto date dalla finalità del modello. Per ogni oggetto è necessario stabilire la **fase di creazione**: in questo modo sono ben distinguibili gli elementi appartenenti al fabbricato originale poiché vengono identificati attraverso la fase "stato di fatto", mentre quelli di nuova costruzione sono identificati dalla fase "stato di progetto".
Una volta completato il modello è possibile estrarre le informazioni relative alla comparazione tra l'edificio esistente e il nuovo progetto, dando la possibilità al professionista di identificare eventuali interferenze tra gli elementi che potrebbero portare in fase di esecuzione a stravolgimenti in termini progettuali con conseguente aumento di tempi e costi per la sua realizzazione.

Quali sono le criticità relative alla gestione della nuvola di punti?

Certamente quanto detto fin'ora a proposito dell'utilizzo della nuvola di punti come strumento di ausilio alla realizzazione del modello 3D parametrico fa ben sperare relativamente ai risultati attesi da questo tipo di attività sia in termini di rappresentazione delle informazioni sia sui dati necessari per la gestione operativa dell'edificio attraverso la nuova metodologia BIM. Tuttavia esistono ancora alcune **criticità** sulla nuvola di punti che richiedono ulteriori approfondimenti. Ad esempio, deve essere ancora verificato l'ammortamento del **costo** relativo alla tecnologia laser scanner rispetto ai benefici che esso produce all'interno del processo edilizio. Un'altra criticità consiste nella gestione di una così **grande quantità di dati** prodotti dal rilievo; infatti, attualmente la gestione della nuvola di punti richiede ancora l'utilizzo di elaboratori con elevata capacità di calcolo. Si è notato che a seconda dell'applicativo utilizzato diversi componenti hardware sono stati messi sotto sforzo, quali ad esempio il microprocessore (con Faro Scene) o la scheda grafica (per Autodesk Recap). In entrambi i casi si richiede una capacità di RAM elevata per poter manipolare la nuvola di punti in modo ottimale.

È possibile alleggerire le dimensioni della nuvola di punti nell'ambiente di Revit?

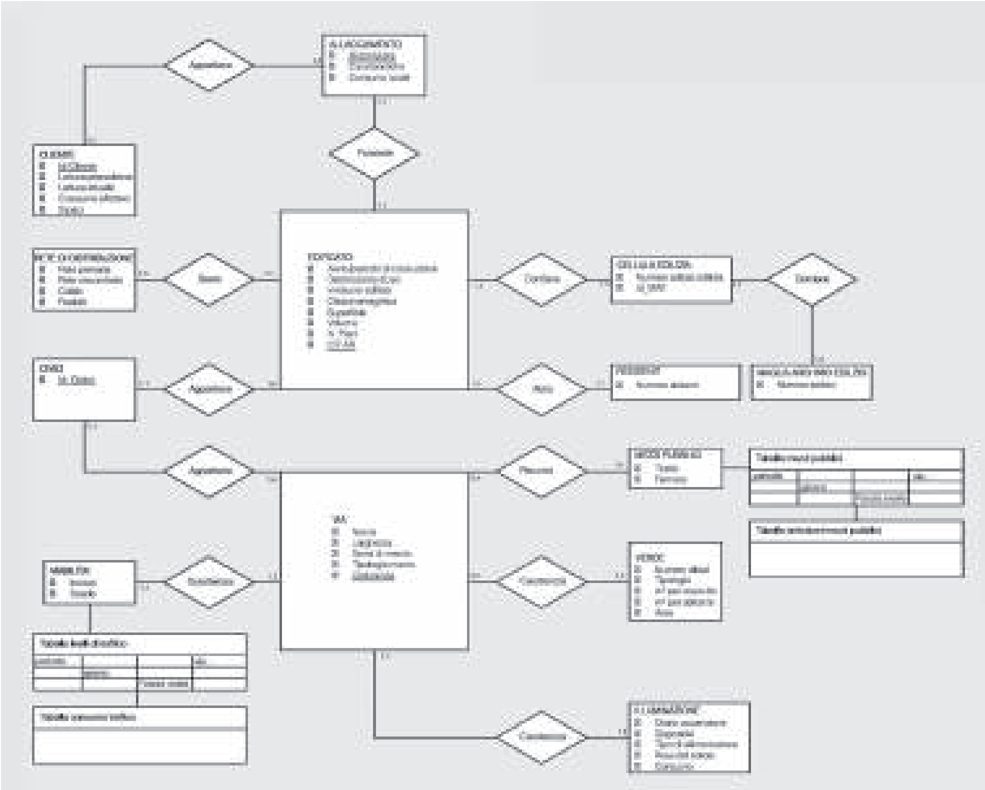
Per provare a risolvere il problema della gravosità del file della nuvola di punti è possibile non caricare direttamente la nuvola nel file di progetto di Revit, ma in **file secondari** che poi vengono linkati al file principale. In questo modo il file di progetto risulta più facilmente gestibile. Ovviamente trattandosi di un **link** bisogna porre attenzione alla posizione del file secondario rispetto a quello di progetto, in quanto l'esistenza del link si basa sul percorso di salvataggio del file, per cui, nel caso in cui il file venga spostato, il link viene perduto e bisogna ricaricare il file secondario.

È possibile ottenere una nuvola di punti di dimensioni e con tempi di elaborazione minori?

La realizzazione della nuvola di punti può anche essere effettuata attraverso un ulteriore metodo di rilevazione basata sulla fotogrammetria in cui è possibile ottenere una nuvola di punti/pixel con tempi di elaborazione minori e costi più bassi rispetto a quelli impiegati per il rilievo laser scanner. Ovviamente la **precisione del rilievo** si riduce per cui volta per volta occorre valutare oculatamente come intervenire, scegliendo gli strumenti di rilievo opportuni, in relazione alla precisione richiesta.

Bisogna impostare un template prima di procedere con la modellazione parametrica?

L'utilizzo di un template specifico per la realizzazione di un modello BIM a partire da differenti tipologie di rilievo - tra cui il laser scanner - consente di velocizzare le operazioni di importazione e di gestione della nuvola di punti, che può essere immediatamente visualizzata nel modo preferito dal professionista. Ovviamente tutto ciò rientra all'interno del concetto di **standardizzazione delle informazioni** che devono essere inserite o estratte dal modello parametrico. In un'ottica di gestione del patrimonio immobiliare storico, la possibilità di definire delle linee guida in grado di aiutare l'utente a seguire la metodologia BIM, anche per la gestione delle informazioni, è uno degli obiettivi prefissati dal progetto di ricerca in corso, così come anche la definizione dei LOD relativi al modello e alle librerie di oggetti che dovranno essere inserite nel modello.



1. Modello concettuale del GIS.

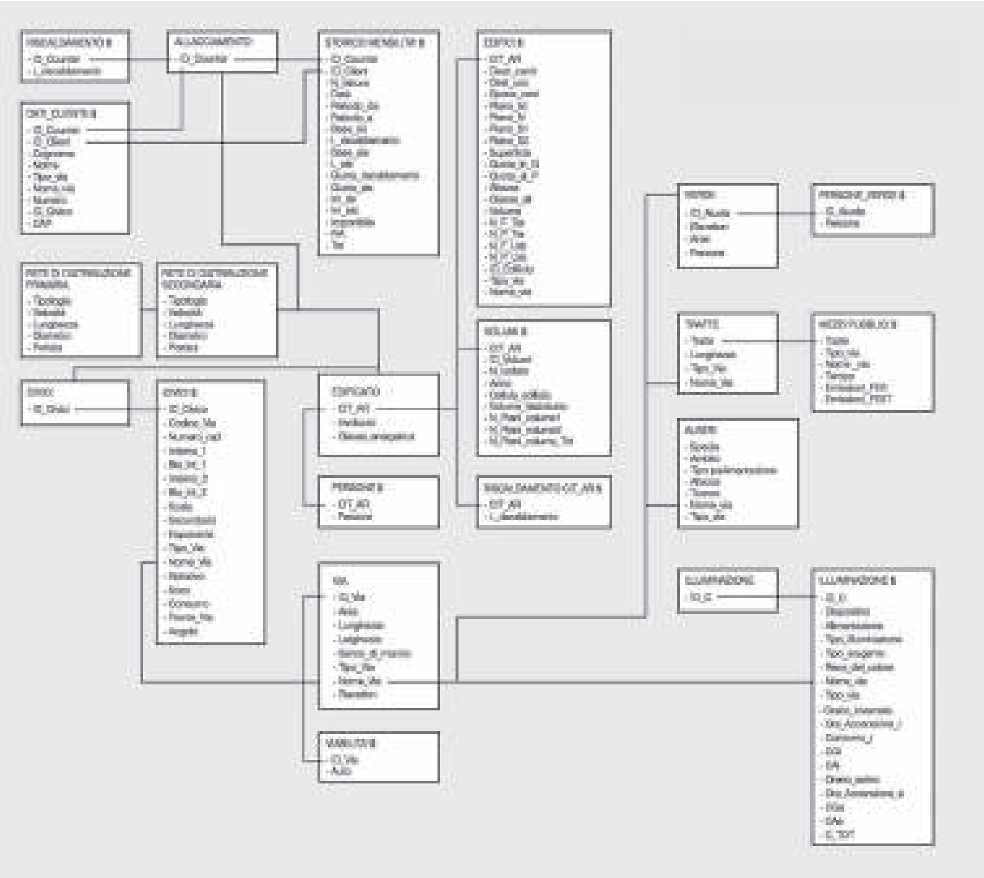
Il GIS per la gestione dei dati alla scala urbana/edilizia

MATTEO DEL GIUDICE

Quali sono le tappe da seguire per elaborare un GIS corretto?

Con questo contributo viene descritta una possibile applicazione di un GIS relativo alla gestione dei dati per il risparmio energetico nell'ambito del progetto District Information Modelling and Management for Energy Reduction (DIMMER). L'applicazione consiste nello sviluppo di un servizio informativo in grado di elaborare e visualizzare dati a livello urbano, anche in ottica di sviluppare strategie di gestione degli edifici e dei loro consumi. Per gli edifici come scuole e università, il progetto può avere un considerevole impatto educativo poiché consente di capire e conoscere come variano in tempo reale i consumi e l'utilizzazione dell'energia in relazione al tempo, allo spazio e all'utilizzatore stesso. Ciò si può ottenere considerando anche come strumento di comunicazione una interfaccia web per controllare i consumi e la produzione di energia rinnovabile.
La zona oggetto di studio è adiacente alla sede del Politecnico di Torino (corso Duca degli Abruzzi) ed è caratterizzata da un'edilizia omogenea, principalmente a carattere residenziale mista a negozi, uffici e attività commerciali.
L'obiettivo prefissato dal progetto è la costruzione del sistema informativo è l'analisi dei consumi energetici del quartiere.
Innanzitutto è bene prendere in considerazione le diverse tipologie edilizie per individuare un consumo specifico legato alle diverse destinazioni d'uso e alle differenti tecniche costruttive, in base al periodo di costruzione. Inoltre, l'analisi dei fabbricati consente di effettuare delle valutazioni preliminari in termini di rapporto volume-superficie, individuando per ciascun manufatto la relativa classe energetica. Invece, l'inserimento di dati relativi alla popolazione attuale è funzionale per l'identificazione delle aree a più alta densità: in questo modo è possibile effettuare varie ipotesi di relazioni con i diversi livelli di consumo energetico.
L'aspetto più importante di uno studio di questo tipo può essere ad esempio quello di individuare le diverse reti di distribuzione (elettrica, idrica, gas, teleriscaldamento, fonti rinnovabili) e i punti di allacciamento degli edifici. In questo modo è possibile eseguire valutazioni sia sull'infrastruttura tecnologica sia sull'erogazione del servizio e quindi del consumo. L'acquisizione dei dati è possibile grazie alla collaborazione con i diversi enti erogatori che consentono l'estrazione dei dati necessari alla valutazione energetica.
Inoltre, anche se esula dal progetto di ricerca DIMMER, sono stati presi in considerazione altri parametri: (I) la viabilità, in relazione alle emissioni di monossido di Azoto (NOx), relazionando i dati ai livelli di traffico, agli orari di punta, alla tipologia di mezzo pubblico; (II) l'illuminazione pubblica al fine di studiarne l'efficienza e la qualità (tra le informazioni inserite sono presenti il tipo di tecnologia installata, l'indice di resa del colore e la disposizione sul territorio); e (III) i filari alberati sui principali corsi che delimitano il quartiere oggetto di studio, per mettere in evidenza il loro effetto ombreggiante sugli edifici esistenti.

Questi parametri sono stati oggetto di esercitazione nell'ambito del corso di "Cartografia numerica e GIS" tenuto dal Prof. A. Lingua presso il Politecnico di Torino. Studenti: Matteo Del Giudice, Stefano Della Role e Enrico Osello.



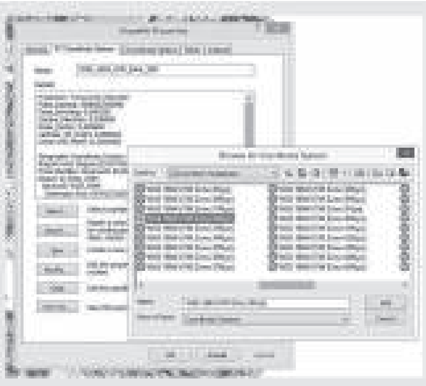
2. Modello logico del GIS.

Che cosa si vuole rappresentare (Modello entità-relazioni)?

Come è già stato anticipato nel capitolo dedicato al GIS per la gestione dei dati alla scala territoriale, per poter creare un GIS è necessario capire quale sia la finalità di quello che si vuole rappresentare, a partire dalla considerazione che la progettazione di un GIS possa essere considerata come un processo di modellizzazione che permette di descrivere la realtà percepita in un linguaggio utilizzabile in modo digitale tramite fasi successive di approfondimento-formalizzazione a partire dal modello concettuale per arrivare alla realizzazione vera e propria del sistema informativo.
La prima cosa da fare è l'elaborazione del modello Concettuale attraverso cui viene esplicitata la finalità del GIS creando un modello Entità Relazioni (ER). Le **Entità** sono la trasposizione nel modello degli oggetti che popolano la sfera di interesse, nella quale sono comprese le loro caratteristiche statiche; il campo identificativo di ogni entità deve assolutamente essere univoco. L'**associazione** rappresenta il legame logico fra più entità che nel caso oggetto di studio sono state organizzate secondo una logica ben precisa, in accordo con il fine ultimo di progettazione del sistema informativo. Pertanto sono state individuate le seguenti entità: Edificato, Cellula Edilizia, Maglia Archivio Edilizio, Civici, Residenti, Allacciamento, Cliente, Rete di Distribuzione, Via, Viabilità, Illuminazione, Verde, Mezzi Pubblici. Si può notare che per gli edifici sono state individuate due entità differenti, in cui per "Edificato" si intende la costruzione architettonica destinata a sede di attività umane e abitazione: essa è definita dal contorno e dalle dividenti di volume. Mentre per "Cellula Edilizia" si intende l'unità insediativa elementare che si caratterizza per la sua disponibilità per aggregazione di parti urbane di ordine superiore: essa può essere composta da più edifici e si raccoglie in più cellule che formano la maglia a scala urbana. Una volta esplicitate le diverse entità e ciascuna relazione si è passati all'elaborazione del modello logico in cui quello concettuale è stato "tradotto" in un linguaggio più affine a quello interpretativo del software.

Quale sistema di riferimento si vuole utilizzare?

Ogni qual volta si deve affrontare la rappresentazione del territorio in cartografia è necessario fissare un sistema di riferimento.
Per questo motivo è necessario definire un sistema di riferimento unico, con eventuali ridefinizioni per quei dati che ne hanno uno diverso.
Questa operazione deve essere eseguita prima di affrontare qualsiasi operazione di inserimento, modifica ed elaborazione delle informazioni. Nel caso oggetto di studio i dati utilizzati sono definiti con il sistema di coordinate UTM-ED50; e la rappresentazione in proiezione trasversa di Mercatore (Universal Transversal Mercator) sul datum europeo ED50, basato sull'ellissoide di Heyford. Volendo utilizzare il sistema di coordinate UTM-WGS84-ETRF2000 è necessario l'impiego di un software come ad esempio Cart_Lab 3 in grado di trasporre le coordinate dei relativi file di interesse in maniera automatica.



3. Definizione delle coordinate su ArcGIS.

4. Rappresentazione dell'entità "Edificato" (elaborazione di M. Del Giudice, S. Della Role, E. Osello).

Da dove provengono i dati? Quali categorie di file è possibile utilizzare?

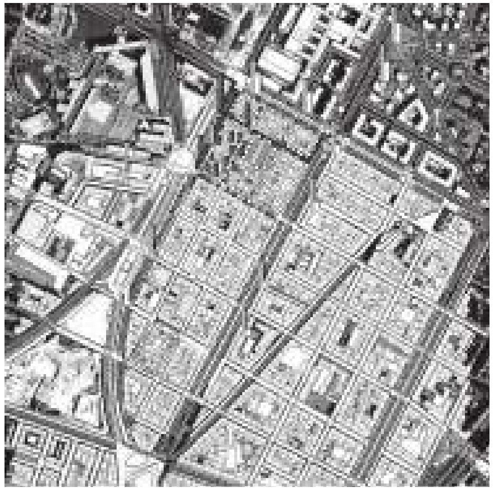
Un passaggio fondamentale, per quanto scontato, è l'immissione dei dati nel software. In questo caso viene utilizzato il software ESRI ArcGIS. L'aspetto cardine di questa fase è il controllo dei parametri di orientamento di ciascun file e del progetto in ArcGIS.
Tramite il comando *Add data* è possibile selezionare i file di interesse per poi immetterli nel DBMS; dopo di che è essenziale effettuare il controllo del sistema di riferimento per ciascun file. Come già detto, nel caso studio proposto è stato necessario definire il sistema di coordinate UTM-WGS84-ETRF2000 nel file di progetto poiché la macchina operatrice non è in grado di riconoscerlo in maniera automatica.
Procedendo nelle operazioni, è possibile utilizzare dei file compositi quali ad esempio i dxf (formati da tre entità geometriche distinte, point, polyline e polygon; rispettivamente punti, linee e aree) per la selezione degli elementi geometrici più interessanti e funzionali alle interrogazioni attese.
Anche se in generale le categorie di file più comunemente utilizzate in un GIS sono di tipo vettoriale e raster, è possibile utilizzare anche dei file denominati Triangulated Irregular Network (TIN) per un'efficiente rappresentazione di superfici, quali ad esempio la modellazione di un terreno.
Tra i tipi di file vettoriali più utilizzati si hanno gli shapefiles e i file CAD. Lo **shapefile** costituisce il formato più semplice per la memorizzazione di elementi geografici all'interno di un GIS; esso è in grado di contenere geometrie di una sola tipologia che vengono memorizzate all'interno di un computer in normali *directories*.
Per ciascun tipo di entità grafica come la fermata di un autobus, una strada o l'area di un edificio, il software elabora una serie di file che, pur riferendosi alla stessa entità, contengono informazioni di natura diversa, quali ad esempio l'informazione puramente geometrica. Pertanto, ogni shapefile è costituito almeno dall'insieme di tre files: (I) quello con estensione shp contiene l'informazione geometrica relativa all'elemento grafico (**database delle coordinate**); (II) quello con estensione dbf contiene la **tabella degli attributi** che possono essere collegati da ulteriori dati forniti dall'utente da tabelle esterne; mentre (III) quello con estensione shx è il "file indice" che memorizza la **lista degli indici spaziali** e che permette la costruzione del collegamento tra la geometria, l'informazione relativa alla posizione geografica e la sequenza degli attributi.
All'interno del file di progetto è possibile collegare file di tipo Web Map Service (WMS) che agevolano le operazioni di realizzazione del sistema informativo.
Questo standard consiste in una semplice interfaccia HTTP per richiedere immagini di mappe da uno o più server distribuiti in Internet. La risposta alla richiesta è una o più immagini di mappa (nel formato JPEG, PNG, ecc.) che può essere mostrata in un browser Internet. I file WMS consistono quindi in particolari procedure che riescono a produrre mappe di dati georeferenziati a partire da informazioni geografiche. Questo particolare formato di dati è una tecnica definita dall'Open Geospatial Constium (OGC).
Nel caso studio in oggetto sono stati inseriti i collegamenti WMS al fine di possedere una cartografia stradale più aggiornata rispetto a quella presente sul Geoportale del Comune di Torino.

Dove vengono collezionati i dati?

Terminata la fase di inserimento dei dati, si passa alla loro elaborazione, cercando di integrarli in maniera ottimale con lo scopo finale dell'attività progettuale del GIS; sostanzialmente si scelgono le informazioni relative alla sola zona interessata, limitando la selezione dei dati alla stessa.
Ogni entità viene identificata sul modello GIS attraverso diversi shapefile in modo tale da poter essere descritta in maniera completa ed esaustiva. Considerando ad esempio l'entità "Edificato" è possibile creare diversi file: quello che descrive i volumi dei fabbricati all'interno del quartiere interessato con il nome "Crocetta_Building_Polygon_U0032"; quello relativo ai volumi dei fabbricati appartenenti al complesso universitario del Politecnico di Torino e gli edifici residenziali adiacenti con il nome "Polito_Building_Polygon_U0032"; oppure, lo shapefile "Crocetta_docks_U0032", che rappresenta i bassi fabbricati e i box auto all'interno dei cortili dei singoli isolati; infine quello relativo ai cortili interni degli edifici "Courtyards".
La stessa procedura può essere seguita per tutte le entità previste.

Come possono essere relazionati i dati in ambiente GIS?

La definizione dei dati e la loro conseguente modalità di immissione devono essere definite in modo tale da rendere più dinamica e intuitiva l'aggiornabilità degli stessi. Per questo motivo può essere utile avvalersi di ArcGIS come visualizzatore finale dei dati, sintetizzandoli in maniera grafica sul modello.
L'elaborazione delle tabelle in questo caso specifico è effettuata in modo automatico a partire dai dati forniti dal CSI Piemonte (Consorzio per il Sistema Informativo) legando le informazioni provenienti da diversi fogli Excel. L'utilizzo del foglio elettronico è una scelta specifica, che ha l'obiettivo di agevolare la compilazione delle tabelle da parte di personale con conoscenza informatica di base: i principali file di compilazione dati come ad esempio gli indirizzi, o l'emis-



5. Rappresentazione dell'entità "Rete di distribuzione" (elaborazione di M. Del Giudice, S. Della Role, E. Osello).

6. Interrogazione dei contatori con la relativa clientela.

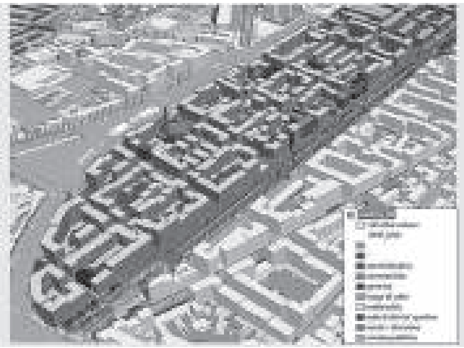
7. Rappresentazione finale del GIS in 2D (elaborazione di M. Del Giudice, S. Della Role, E. Osello).

8. Generazione del modello DTM con l'associazione delle ortofoto.

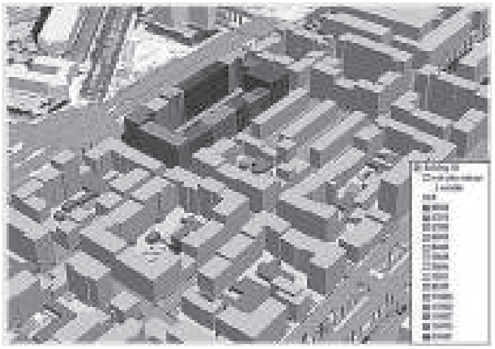
sione delle fatture energetiche sono basati sulla compilazione manuale dei fogli elettronici e quindi legati al sistema informativo tramite dei collegamenti logici riconosciuti dal programma (*join* e *relate*).
Attraverso questa rete di **collegamenti logici** si può ottenere un complesso **sistema di interrogazione** in cui è possibile associare ad esempio, a un singolo contatore una determinata lista di clienti e a ognuno di essi le informazioni relative ai dati storici delle fatture del servizio di teleriscaldamento. In conclusione è possibile calcolare per ogni contatore il consumo totale del servizio di riscaldamento in funzione delle informazioni prima descritte.

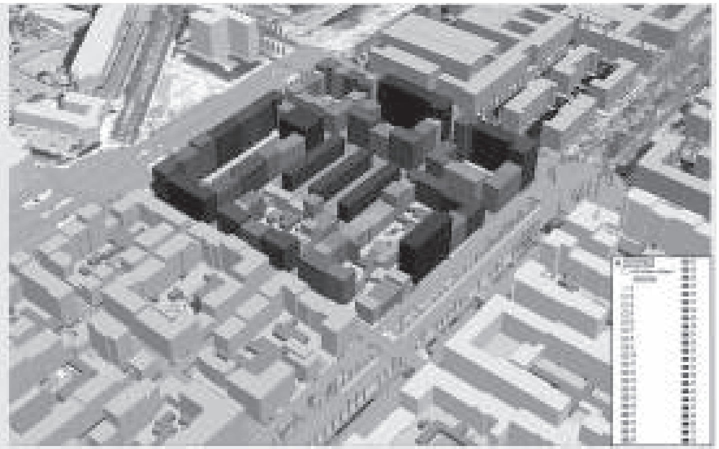
In che modo è possibile visualizzare i dati?

Una volta terminato il modello, nasce l'esigenza di interrogare il database nel modo migliore per poter estrapolare le informazioni necessarie. Il sistema informativo è realizzato in 2D, tuttavia è possibile visualizzare i dati graficamente anche in 3D grazie all'impiego dell'estensione ArcScene.
Dotare il sistema della terza dimensione implica l'utilizzo del file "Punti quotati.dwg" contente i punti quotati relativi al quartiere oggetto di studio. Il file Autocad deve essere convertito in shapefile tramite l'utility *Arctoolbox_Conversion tools_Features Class to Shapefile*, estrapolando l'informazione altimetrica come *Annotation*.
Il file viene poi elaborato con Cart_Lab 3 per il cambio automatico delle coordinate ottenute.
I punti all'interno di questo shapefile sono quelli utilizzati per la generazione del Digital Terrain Model (DTM) tramite il comando di *kriging* presente nell'estensione Toolbox. Il DTM, insieme agli altri shapefile, viene poi importato all'interno del software ArcScene. Come primo file normalmente si inserisce il modello del terreno andando a definire la sua proiezione spaziale all'interno dello spazio modello. In questa fase è possibile selezionare l'opzione di rendere il terreno secondo un modello precedentemente creato; nel caso studio in oggetto, il DTM è stato composto con l'utility di *kriging.* Successivamente vengono inseriti i restanti shapefile andando a specificare l'altezza di estrusione specifica e la rispettiva quota di livello al piede. Per impostare la quota di estrusione deve essere assegnata la funzione dell'attributo "altezza", in modo da imporre a ogni entità geometrica la rispettiva quota.
La visualizzazione dei dati in 3D può avvenire in modi differenti in funzione dell'interrogazione che si intende fare: infatti, è possibile visualizzare gli attributi dello shapefile in modo grafico scegliendo la rappresentazione preferita o quella in grado di evidenziare maggiormente le informazioni racchiuse nella banca dati.
Calando i diversi shapefile relativi agli edifici sul DTM e attribuendo il corretto valore di altezza già presente nella tabella degli attributi, è possibile visualizzare le informazioni geometriche bidimensionali in 3D.
In aggiunta, il modello 3D può essere caratterizzato utilizzando diversi tematismi basati sempre sui diversi attributi dello shapefile. Nelle **[FIGG. 9-11]** è possibile infatti notare come lo stesso quartiere può essere visualizzato in modo differente in funzione rispettivamente delle destinazioni d'uso, del consumo energetico relativo al riscaldamento e del numero di abitanti. Questa modalità di visualizzazione può aiutare notevolmente il professionista nelle fasi di progettazione o di ricerca delle informazioni a lui più utili poiché senza troppi passaggi si riescono a visualizzare le informazioni legate sia alla parte grafica che a quella alfa numerica.



9. Rappresentazione del GIS in 3D con tematismo delle destinazioni d'uso. (elaborazionI di M. Del Giudice, S. Della Role, E. Osello).





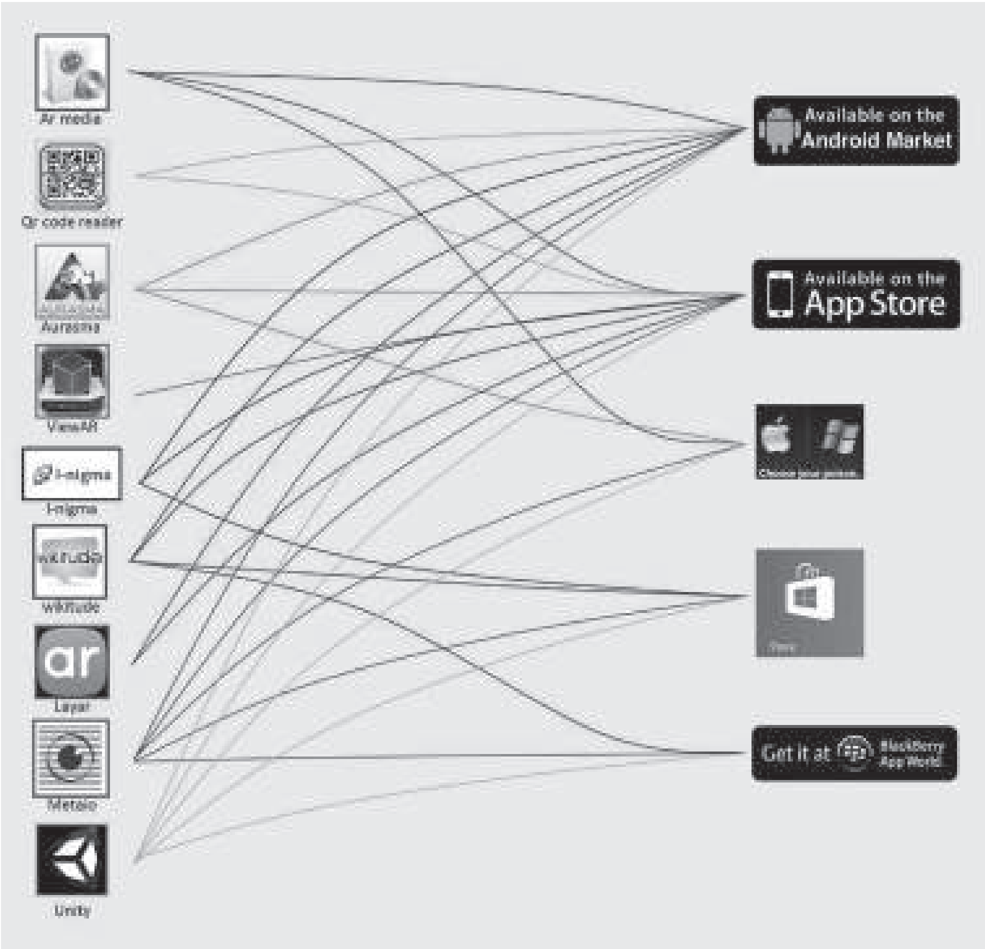
10-11. Rappresentazione del GIS in 3D con tematismo dei consumi relativi al riscaldamento (elaborazionE di M. Del Giudice, S. Della Role, E. Osello).

Al termine dell'attività progettuale è opportuno valutare i risultati ottenuti in relazione al tempo speso per la sua composizione, alle problematiche riscontrate e alla capacità del sistema di dialogare con diversi DBMS. In questo caso specifico, considerando il tempo in relazione al risultato ottenuto, si può affermare con assoluta certezza che ArcGIS consente di inserire una grande quantità di dati in un tempo relativamente breve; per quantità di dati si intende sia a livello spaziale, sia la compilazione dei dati alfanumerici relativi ai vari campi di applicazione (energia, viabilità, inquinamento ed emissioni, dati catastali, piani di manutenzione, gestione del verde, piani urbanistici, ecc.).

Nel caso studio proposto, tra i vari campi informativi studiati ed esplicitati è possibile realizzare una serie di collegamenti al fine di poter associare a ogni contatore del servizio di teleriscaldamento il numero e l'elenco dei clienti, e infine lo storico delle fatture annesse alla fornitura del servizio da parte dell'ente specifico.
Al contrario, per quanto riguarda la gestione del software, sono da sottolineare alcune criticità che potrebbero essere risolte tramite un'architettura del programma più dinamica. Durante le operazioni di costruzione del GIS a volte è possibile riscontrare una certa "macchinosità" nell'inserimento e nell'assegnazione delle coordinate a ogni file esterno che si intende caricare nel DBMS.
Questo è dovuto al fatto che ArcGis non riesce a individuare in maniera automatica le coordinate associate al file che si vuole immettere. Inoltre, si sono riscontrate alcune difficoltà nella condivisione completa dei vari progetti dovuta al mancato trasporto delle tabelle Excel legate al progetto. Infine, vengono generati numerosi file, che possono rendere la ricerca di file specifici (tramite la funzione di *Esplora risorse* di Windows) alquanto difficoltosa.
Potrebbe dunque essere utile adottare un file complessivo che racchiuda tutte le informazioni necessarie ai fini progettuali.
Apprezzabile comunque è la "snellezza" di ogni file, che permette sicuramente una certa velocità di gestione dei dati sia sull'estensione di ArcMap sia di ArcScene, e inoltre rende nel complesso il progetto abbastanza "leggero" con una risparmio di spazio fisico su hard disk.
Se si volesse ottenere un risultato simile dal punto di vista puramente geometrico e di rappresentazione tridimensionale tramite software BIM certamente si avrebbero file più "pesanti" ma con il vantaggio di poter lavorare su una modellazione con maggiori dettagli dal punto di vista della rappresentazione.
È chiaro che i due software hanno funzioni completamente differenti a livello concettuale, anche se entrambe offrono la possibilità di lavorare a una rappresentazione del territorio georeferenziata. Si tratta ovviamente di un ambito di ricerca ancora in fase embrionale e sicuramente molte evoluzioni saranno possibili anche in un futuro prossimo.

È possibile collegare il GIS con il BIM?

La creazione del GIS del quartiere Crocetta nel caso studio proposto con questo contributo ha il duplice obiettivo didattico e di ricerca; quest'ultimo con il proposito di approfondire il tema dell'interoperabilità fra differenti DBMS.
La condivisione delle informazioni, argomento principale e necessario nell'attività di ricerca attuale basato sull'interoperabilità dei dati, si pone come obiettivo quello di collegare banche dati differenti come ad esempio ArcGIS e Revit. L'approfondimento di questo argomento consente di passare dal concetto di BIM a quello di DIM - Disctrict Information Modeling: partendo da una rappresentazione strettamente legata alla scala dell'edificio (BIM), concentrandosi sulle interrelazioni tra gli edifici e le reti, come ad esempio quella del teleriscaldamento, che compongono il District, si arriverà a interrogazioni tipiche della scala urbana, ottimizzando il processo di inserimento dei dati.



1. Schema generale in cui sono riportate alcune applicazioni di Realtà Aumentata e la loro rispettiva compatibilità con i diversi sistemi operativi.

L'utilizzo della AR per la responsabilizzazione degli utenti con un approccio al gioco

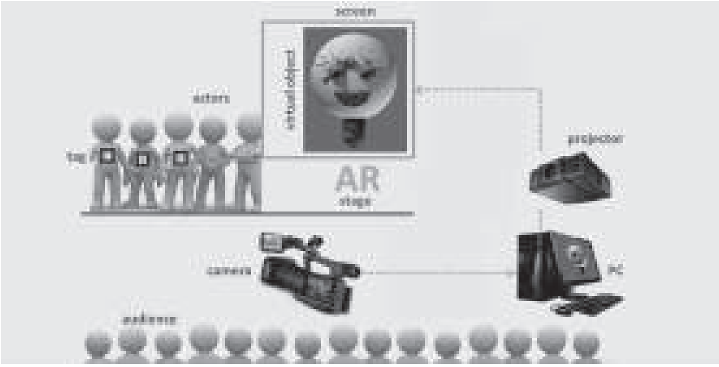
MATTEO DEL GIUDICE

Che cos'è la AR e quando può essere utilizzata?

La Realtà Aumentata permette di visualizzare in maniera diretta un particolare scenario reale arricchendolo con dei dati virtuali, come se si sovrapponessero ulteriori livelli, ad esempio: elementi bidimensionali, tridimensionali, video, animazioni e suoni […]. La AR è una tecnologia che permette di **arricchire e aggiungere informazioni** utili per l'utente attraverso l'uso di dispositivi, che oggi sono diventati di uso comune, in modo tale da agevolare e facilitare la conoscenza di dati semplicemente guardando la realtà che ci circonda. Questa tecnologia permette di alterare la realtà intorno a noi, senza cambiarla o sostituirla, con un altro mondo (virtuale) […] .
Negli ultimi anni il concetto di città intelligente o smart city è diventato uno degli argomenti principali di studio e approfondimento da parte dell'Unione Europea. In un contesto di cambiamenti economici e tecnologici causati dalla globalizzazione e dal processo di integrazione, le città europee stanno affrontando la sfida di coniugare competitività e sviluppo urbano sostenibile. Questa sfida potrebbe avere un impatto sui temi della qualità urbana come l'abitare, l'economia, la cultura e le condizioni sociali e ambientali.
In questo ambito si inserisce il progetto Smart Energy Efficient Middelware for Public Spaces (SEEMPubS), con l'obiettivo di affrontare la riduzione del consumo di energia e delle emissioni di CO_2 negli edifici e negli spazi pubblici esistenti senza dover intervenire con significativi lavori edilizi, utilizzando un servizio intelligente di monitoraggio e di controllo del consumo energetico basato su tecnologie ICT e sulla responsabilizzazione degli utenti (in particolare delle giovani generazioni) sul tema del risparmio energetico.
Questo approccio è dovuto al fatto che lo sviluppo intelligente della città non è solo legato all'inserimento di dispositivi elettronici all'interno dei locali, ma parte dal presupposto che gli utenti della città debbano essere parte attiva della città stessa, contribuendo significativamente alla sostenibilità ambientale. È noto che la società attuale si trova in un contesto con risorse ridotte, per cui si rende essenziale una presa di coscienza sui temi relativi alla sostenibilità ambientale e quindi al risparmio energetico.
A questo proposito, nell'ambito del progetto SEEMPubS e senza soluzione di continuità anche nell'ambito del progetto DIMMER (Distrcit Information Modeling and Management for Energy Reduction), le giovani generazioni vengono stimolate attraverso l'elaborazione di giochi da tavola e attraverso l'allestimento di spettacoli teatrali in cui i temi relativi al risparmio energetico negli edifici la fanno da padrone. Entrambe le attività vengono continuamente sviluppate

Milgram P., *Augmented Realuty: a class of displays on the reality-virtuality continuum*, SPIE Vol.2351, Telemaniulator and Telepresence, 1994).

Giovannitti S., *Storia urbana aumentata*, Tesi di laurea di I livello in Ingegneria edile, 2013).



2. Schema esplicativo del funzionamento della Realtà Aumentata.

e implementate utilizzando la AR, ossia una «tecnologia emergente che consente di fondere assieme l'informazione digitale, elaborata da un calcolatore, con l'informazione proveniente dal mondo reale per mezzo di opportune interfacce computerizzate, in tempo reale».

La Realtà Aumentata nel futuro della stampa e dell'editoria. Opportunità e prospettive, white paper, AR-media.

La AR è oggi un tema di ricerca e discussione che attrae l'entusiasmo degli addetti ai lavori nel settore dell'innovazione, delle nuove tecnologie, della didattica e dei media. Si ricorda a questo proposito che il termine "Realtà Aumentata" è stato coniato nel 1992 dal ricercatore Thomas Preston Caudell della Boeing Caudell, che ha utilizzato questa espressione per descrivere un sistema di nuova generazione che avrebbe aiutato nell'assemblaggio e installazione dei cavi elettrici negli aerei. Negli anni successivi, l'AR è stata studiata, implementata e sviluppata in vari laboratori e università nel mondo.

Caudell & Mizell 1992.

Milgram & Kishino 1994; Azuma 1997.

Negli ultimi due anni, grazie anche alla rapida diffusione degli smartphones di ultima generazione, una nuova tipologia di applicazioni di AR ha fatto il suo ingresso sul mercato. Come dimostrato anche dai capitoli precedenti, le applicazioni AR per dispositivi mobili permettono agli utenti di visualizzare immagini "aumentate" del proprio intorno immediato, direttamente sul display del proprio tablet o smartphone, utilizzando il flusso video catturato con la telecamera come sfondo, e collocando contenuti e layer informativi in posizione relativa a dove l'utente si trova.

Come può essere utilizzata la AR?

La costruzione di un ambiente AR si basa su 3 fasi principali: (I) analisi della realtà, (II) creazione delle nuove informazioni sulla base della realtà, (III) rappresentazione di realtà con aggiunta di informazioni. Nella maggior parte dei casi però l'analisi della realtà è attuata attraverso il semplice riconoscimento di un simbolo in bianco e nero (**marker**), spesso stampato su un foglio dall'utente, sulla cui base viene visualizzato sullo schermo un oggetto 3D o un'animazione. Attualmente esistono anche altre applicazioni che consentono l'uso dell'AR senza marker grazie al riconoscimento di immagini e alla geolocalizzazione. Per il lavoro che viene presentato in questo contributo è stata utilizzata la tecnologia con i marker.

Che cosa serve per utilizzare la AR?

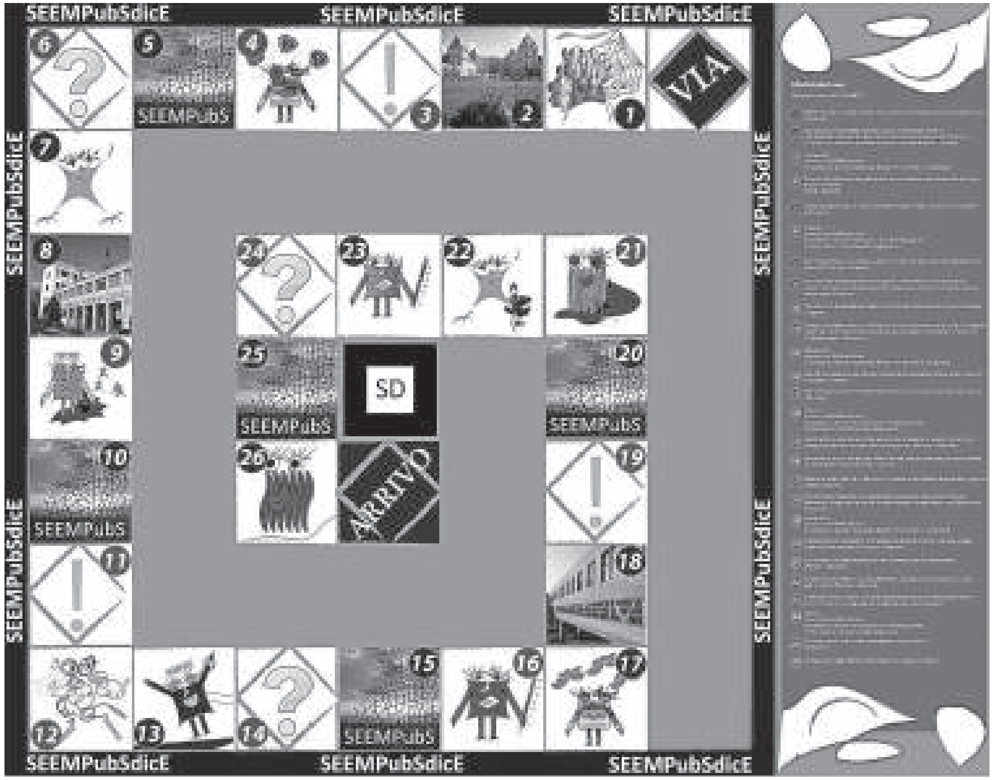
Per poter usare questa tecnologia è sufficiente la presenza di un elaboratore, una telecamera/fotocamera/webcam, uno schermo, i markers, e una eventuale connessione a internet in funzione dell'applicativo usato. Certamente è possibile utilizzare anche dispositivi mobili quali smartphone e tablet in cui l'elaboratore, lo schermo e la webcam sono integrati in un unico dispositivo. La AR ha come obiettivo quello della fruizione dell'informazione in maniera sensibile a un contesto fisico. In generale, le tecnologie necessarie per il suo corretto funzionamento richiedono l'impiego di dispositivi dotati di opportuni sensori, i quali permettono di interagire con un ambiente. Uno dei sensori più comuni nelle applicazioni AR è la **webcam**. Questa viene utilizzata come "occhio elettronico" in associazione ad algoritmi di visione artificiale che estraggono "features" dal flusso video dell'informazione. Altri tipi di sensori usati sempre più frequentemente per contestualizzare il contenuto digitale sono il GPS, gli accelerometri, la bussola e i giroscopi. Questi sensori sono ormai dotazione standard dei dispositivi mobili di ultima generazione, come per esempio gli iPhone e i Samsung Galaxy. In generale quindi, le applicazioni di AR sono sempre più diffuse e accessibili proprio perché i tipi di dispositivi che le rendono possibili sono sempre più comuni tra gli utenti.

L'utilizzo della AR è costosa?

L'utilizzo della AR normalmente non comporta costi eccessivi poiché è sufficiente utilizzare normali computer e smartphone. Ovviamente può essere necessario l'acquisto di licenze professionali dei software, come ad esempio ARmedia, per avere la possibilità di creare in maniera autonoma i marker, riuscendo così a personalizzarli e potendo in questo modo sfruttare la tecnologia anche con più markers contemporaneamente.

Come può essere utilizzata la AR per la comunicazione di dati scientifici come ad esempio quelli del progetto SEEMPubS utilizzando un approccio al gioco?

Lo scopo di un gioco come quello sviluppato per il progetto SEEMPubS (SEEMPubSdice - Il Dado di SEEMPubS) è simile a un classico gioco dell'oca in cui però l'obiettivo non è quello di arrivare primi alla fine di un determinato percorso, ma piuttosto quello di risparmiare più energia possibile totalizzando un certo numero di punti sulla base delle informazioni che provengono dalla ricerca scientifica, e che per l'occasione vengono semplificate utilizzando delle rappresentazioni opportunamente elaborate.
La AR viene utilizzata per coinvolgere i giocatori nelle attività previste dal gioco, facendoli misurare con una tecnologia in grado di amplificare le percezioni sensoriali, permettendo di interagire con i protagonisti virtuali del progetto: sensori wireless, sensori di temperatura, lampadine a incandescenza, ecc., che nel gioco rappresentano le pedine. Ovviamente ciascuna pedina è costituita da un marker e solo attraverso l'utilizzo del computer o dei dispositivi mobili è possi-



3. Gioco e regole di SEEMPubSdice.
(elaborazione di M. Del Giudice, D. Rinaudo)


4. Salone del Libro 2013.


5. Notte dei ricercatori 2013.

bile vedere i personaggi in 3D. Si tratta quindi di una vera e propria attività ludica che mira ad **accrescere la consapevolezza** del pubblico sul tema dell'efficienza energetica negli spazi pubblici, coinvolgendo direttamente gli utenti finali. Infatti, i giocatori, dai più giovani ai più anziani, acquisiscono quelle informazioni relative al consumo energetico e al tempo stesso si cimentano nell'utilizzo di una tecnologia in fase di costante sviluppo. Per l'elaborazione del gioco sono necessari software come ARmedia per la realizzazione dei markers (da utilizzare anche contemporaneamente, associati alle diverse pedine in gioco), e Autodesk 3Ds Max per la modellazione 3D dei personaggi del gioco.
L'elaborazione dei marker deve essere eseguita a partire da una indagine sui differenti tipi di simboli che a oggi vengono utilizzati per applicazioni di questo tipo: nonostante siano molto diffusi quelli riportanti i pixel bianchi e neri, tipici dei QR Code, in casi come questo è di maggiore effetto l'utilizzo di **immagini simboliche** in grado di far riconoscere all'utente quale sia la propria pedina anche senza l'ausilio della realtà aumentata. Sebbene questo possa rappresentare una semplificazione in termini di utilizzatore finale, in un primo momento di sviluppo del gioco si può rivelare una criticità dovuta al fatto che maggiore e complessa è l'immagine che deve essere riconosciuta dall'elaboratore, maggiore è il tempo impiegato da quest'ultimo per far visualizzare il modello 3D sullo schermo. In casi come quello appena presentato, anche se questo aspetto non deve essere trascurato, vista la finalità comunicativa del gioco lato utente rispetto alla capacità di riconoscimento delle informazioni da parte dell'elaboratore, la scelta deve ricadere ovviamente sulla rappresentazione più complessa, seppur opportunamente semplificata.

Quali possono essere gli utenti attivi e passivi di un gioco come quello di SEEMPubS?

L'elaborazione di un gioco come quello proposto fa sì che tutti i cittadini possano essere coinvolti all'attività. Infatti, il gioco è stato proposto durante la notte dei ricercatori 2013, riscuotendo un successo in termini di partecipazione al gioco e di interesse ai temi del progetto. Al termine di questa attività è possibile suddividere i cittadini in soggetti attivi e passivi. Rientrano nella prima categoria le persone che partecipano in maniera attiva al gioco. Si tratta in particolar modo dei bambini/ragazzi che hanno un'età compresa tra i 4 e gli 16 anni, che hanno modo di utilizzare la AR giocando con i personaggi virtuali. Rientrano invece nella seconda categoria tutte le altre persone, tra cui in particolare i genitori e gli insegnanti che assistendo allo svolgimento di questa attività si interessano sia alla tecnologia adottata che ai temi trattati, che in questo caso specifico, come si è già detto, sono relativi al risparmio energetico.

La AR può essere considerata uno strumento didattico?

Attraverso questo lavoro è possibile dimostrare che la AR ha un enorme potenziale per un suo utilizzo in termini didattici, poiché crea nuovi ed entusiasmanti modi per gli utenti di interagire e confrontarsi con l'ambiente circostante attirando la loro attenzione e dando loro la possibilità di approfondire i temi che tradizionalmente vengono trattati tra i banchi di scuola in maniera "tradizionale".

www.realta-aumentata.it/
realta-aumentata-scuola.asp

second, is related to the opportunity of performing from the early design phases some energy related checks (thanks to software interoperability) aimed at optimizing the design. In this case, utilizing the gbXML scheme, the model is imported in Ecotect Analysis and IES Virtual Environment and data are compared. The issues encountered are similar to those described in the previous case study.
For what just described, it appears clear that one of the extremely beneficial aspects of using a building information model in the design phase is the ease and speed of modifying project choices, in addition to the possibility of collecting a large amount of data within the model itself. Concerning ease and speed we should however point out that these can be limited in the case of projects run on existing buildings, where mostly everything must be modeled from scratch, without the possibility of using software libraries or elements available on the internet.

Avendo a disposizione un modello tridimensionale, questo controllo è sicuramente facilitato; inoltre in commercio esistono delle applicazioni specifiche che realizzano dei report relativi ai conflitti (CLASHES) tra i modelli collegati.
La terza fase, in realtà contemporanea alla seconda, si riferisce all'opportunità di effettuare sin dalle fasi preliminari della progettazione delle verifiche di tipo energetico (grazie alla interoperabilità tra i software) finalizzate alla ottimizzazione del progetto. In questo caso, utilizzando lo schema gbXML, il modello viene importato in Ecotect Analysis e in IES Virtual Environment e i dati vengono comparati. Le problematiche riscontrate sono simili a quelle descritte nel caso studio precedente.
Per quanto appena descritto, risulta evidente che uno degli aspetti estremamente vantaggiosi dell'utilizzo del building information model in fase progettuale è costituito dalla semplicità e dalla velocità di modifica delle scelte di progetto alla quale bisogna aggiungere anche la grande quantità di dati che è possibile raccogliere all'interno dello stesso modello. A proposito della semplicità e della velocità, è però necessario puntualizzare che queste possono essere limitate nel caso di interventi su edifici esistenti, dove quasi tutto deve essere modellato ex novo, senza potere usufruire delle librerie dei software o degli elementi reperibili in rete.

Case study 12. Setting up a database for critical data interpretation

Cristina Boido, Matteo del Giudice

Having examined some key concepts of BIM, with this case study [17] we proceed to analyzing the critical issues that those intending to use this method may encounter. Therefore this case study is different from the previous ones because, even though it is still concerned with building information models and software interoperability, here no model is developed and no interoperable process is tested. All data analyzed and processed with this case study derive from the previous ones (with the exception of n. 3 and 5) and from the research work described in the following chapter, in the attempt of methodically classifying the different subjects

Caso studio 12. L'impostazione di un data base per l'interpretazione critica dei dati

Cristina Boido, Matteo del Giudice

Esaminati alcuni concetti chiave del BIM, con questo caso studio [17] si procede con l'analisi delle criticità che si presentano a chi vuole utilizzare questo metodo di lavoro. Pertanto, questo è un caso studio anomalo rispetto ai precedenti perché, pur essendo la sua ragione d'essere il building information model e l'interoperabilità tra i software, nessun modello viene realizzato e nessun processo interoperabile viene sperimentato. Tutti i dati analizzati e rielaborati con questo caso studio derivano dai precedenti (ad eccezione dei n. 3 e 5) e dal lavoro di ricerca presentato nel capitolo successivo, nel tentativo di catalogare in maniera metodica i diversi argomenti trattati, collegarli tra

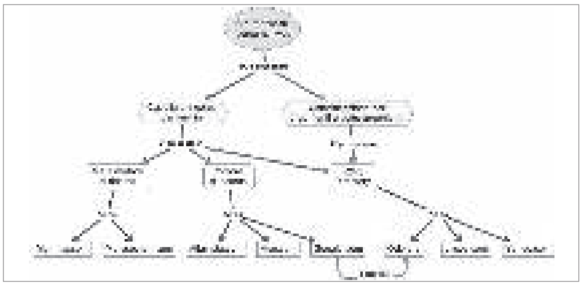


Fig. 104 - above/sopra

Example of a conceptual map describing and summarizing a subject related to information search on the internet.

Esempio di una mappa concettuale che descrive e sintetizza un argomento relativo alla ricerca di informazioni in internet.

http://it.wikipedia.org/wiki/Mappa_concettuale

Fig. 105 - above/sopra

Example of a solution map representing a project's WBS for the realization of a web-oriented system.

Esempio di una solution map che rappresenta la WBS di un progetto per la realizzazione di un sistema web-oriented.

http://www.lemappedelpensiero.it/wordpress/le-solution-map

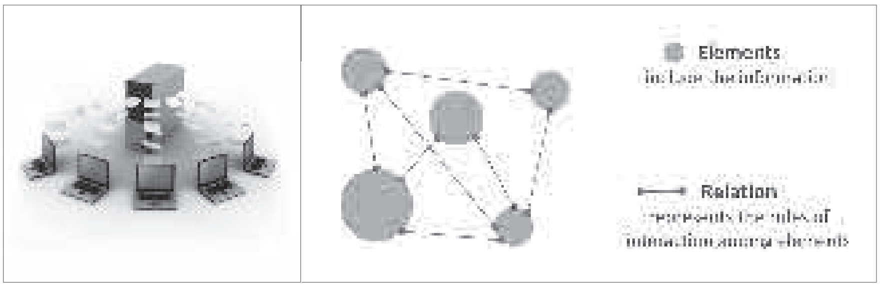


Fig. 106 - on the left/a sinistra

Example of a database's structure.

Schema esemplificativo della struttura di un database

discussed, link them to each other and derive some useful considerations for overall process improvement.
This work's starting point stems from the consideration that, when exporting a file from one application to another, data losses often occur due to a series of issues, not always easy to identify, connected for example to the type of format in which the file has been saved in the original application, or to the steps followed during the importation into the destination application. Data loss often makes it more complex and laborious to perform the processing with the following application. For instance in order to perform certain thermal simulations of a building, it is essential to know the characteristics of materials composing the building's envelope; data loss in the importation phase makes the following calculation very laborious, lengthening design times and increasing the possibility of making mistakes.
Thus, aim of this case study is to try to find, analyze and classify all issues related to data exportation/importation, made visible by some errors, that don't allow to take full advantage of software interoperability. When managing the large amount of information that is being collected over time and with the different case studies, a fundamental operation is their organization in a well defined structure. A method that can be taken as a reference are *thought maps* where large importance is taken by the graphical development of ideas tied to the logical line that one intends to follow, which help in gaining awareness of one's own conceptual logic building modalities. Three types of these thought maps exist: mind maps (creative), conceptual maps (cognitive) and Solution Maps. Mind maps appeal to creative and personal (or group) capabilities, to subconscious mental resources, on synesthesiae created with colours and images, on natural information restructuring processes leaving every time more than one interpretation key open. They are characterized by a hierarchical associative structure comprised of a center from which two types of relations among conceptual elements depart: hierarchical and associative. Conceptual maps on the other hand are created to represent the main concepts and the related links within a certain subject. They contain conceptual nodes, associative relationships and labels helping in a better understanding of relationships. Normally they can be recognized by their structure consisting in grids of nodes

loro e trarne delle considerazioni utili per il miglioramento del processo nel suo insieme.
Il punto di partenza di questo lavoro deriva dalla considerazione che quando si esporta il proprio file da un programma ad un altro, spesso si verificano delle perdite di dati dovute ad una serie non sempre facilmente individuabili di problematiche legate ad esempio al tipo di formato con cui il file è stato salvato nel programma di partenza, o ai passi che si sono seguiti per l'importazione nel software successivo. La perdita di dati rende, molte volte, più complessa e laboriosa l'elaborazione che si vuole affrontare con il programma successivo. Ad esempio, per eseguire alcune simulazioni termiche di un edificio, è indispensabile conoscere le caratteristiche dei materiali di cui l'involucro è composto; la perdita di questi dati nella fase di importazione rende molto laborioso il calcolo successivo con allungamento dei tempi progettuali e relativo incremento della possibilità di commettere errori.
Obiettivo di questo caso studio è dunque il tentativo di individuare, analizzare e catalogare tutte le criticità dovute all'esportazione/importazione dei dati, rese visibili da alcuni errori, che non permettono di sfruttare correttamente l'interoperabilità tra i software. Nella gestione della grande quantità di dati che si sta raccogliendo nel tempo e con i diversi casi studio, operazione fondamentale risulta la loro organizzazione in una struttura ben definita. Un metodo a cui fare riferimento è quello delle *mappe del pensiero* in cui assume molta importanza lo sviluppo grafico delle idee legato al filo logico che si intende seguire e che aiutano ad acquisire consapevolezza sulle modalità di costruzione delle proprie logiche concettuali. Esistono tre tipologie di queste mappe di pensiero: le mappe mentali (creative), le mappe concettuali (cognitive) e le Solution Maps. Le mappe mentali fanno leva sulle capacità creative e personali (o di gruppo), sulle risorse mentali inconsce, sulle sinestesie create con colori ed immagini, sui processi che spontaneamente ristrutturano le informazioni e che ogni volta lasciano aperta più di una chiave interpretativa. Questa tipologia è caratterizzata da una struttura gerarchico associativa composta da un centro da cui si dipartono due tipi di relazioni tra gli elementi concettuali: gerarchiche e associative. Le mappe concettuali invece sono nate per rappresentare i concetti principali ed i rispettivi legami all'interno di un certo argomento. Al loro interno sono presenti

Fig. 107 - on the left/a sinistra

The elements present in a database.

Gli elementi presenti in un database.

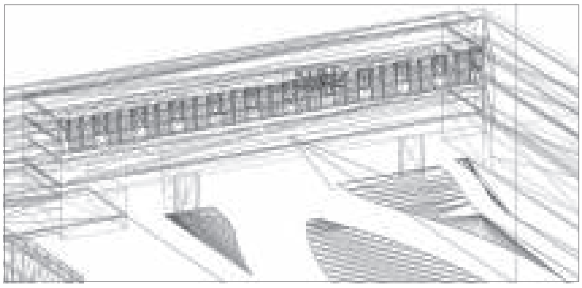


Fig. 108 - on the left/a sinistra

Error in the importation of a .3ds file in Ecotect: every surface is triangled, making the file heavier and the following work phase more complicated.

Errore dovuto all'importazione del file .3ds in Ecotect: La triangolazione di ogni superficie appesantisce il file rendendo più laboriosa la successiva fase di lavoro.

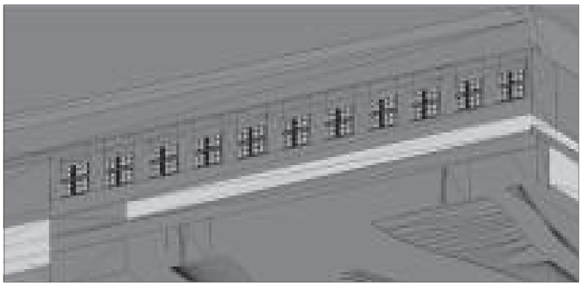


Fig. 109 - above/sopra

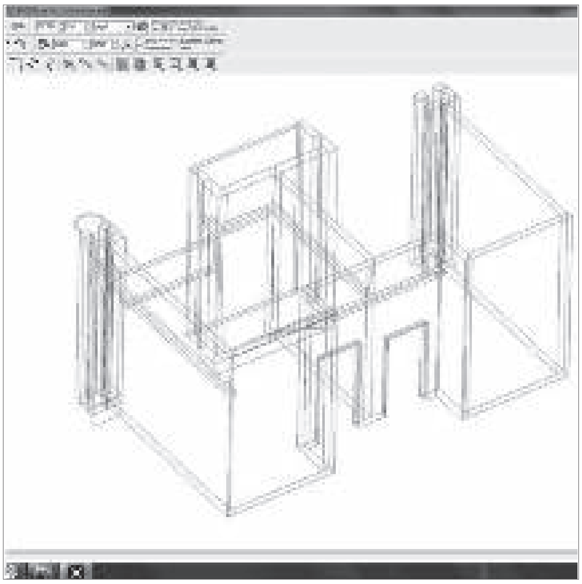
Error in the importation of a .3ds file in Ecotect with a different representation style.

Errore dovuto all'importazione del file .3ds in Ecotect con un diverso stile di rappresentazione.

Fig. 110 - on the right/a destra

Error caused by the fact that solids created in Revit are decomposed in surfaces when importing the file in Ecotect.

Errore causato dal fatto che i solidi creati in Revit vengono scomposti in tante superfici nel momento in cui si importa il file in Ecotect.



connected by arcs representing meanings through a graphical-textual combination. Solution Maps finally inherit properties both from the mind and conceptual maps, with the additional feature of element dynamicity.

Another data structuring system, still related to mind maps, implies the creation of a database allowing management of all collected information, that is the errors produced in the transfer process, and in addition allows querying the loaded data, becoming therefore a valuable tool for recognizing the causes that have created a certain issue and for subsequently finding corrective operations.

Different database typologies exist: relational (RDBMS) where data are stored in interrelated tables, with entries in one table related to another table's entries; object oriented databases (OODBMS); and non relational databases (NRDBMS) using files to store their information. In this last kind of database, data are not linked to each other. After considering the different possibilities, we decided to build a relational database, that is a system composed by a set of elements and rules defining the reciprocal links, where each element may in turn represent a sub-system. The higher the database complexity, and therefore the higher its application spectrum, the wider is its spatial dimension and the more articulated is the relationship among the collected information pieces. Once data and their relations are known, firstly an interface is created allowing who did not create the database to easily utilize it: this is possible through the creation of reports and specific templates. In addition an interrogation system is set up by building dedicated queries combining, filtering or sorting data before these are viewed by the user. It is therefore of fundamental importance to create a structure as functional and usable as possible, paying attention to avoiding data redundancies that could burden the system.

To start with, we decided to use as data to be analyzed and stored those deriving from the interoperability of parametric modelling tools (Revit Architecture) and those for parameter calculations related to physics and environmental applied physics (Ecotect Analysis, Revit MEP, TRNSYS and IES Virtual Environment 6.3) and to structural analysis (Axis VM 10 and Revit Structure). At the moment we are studying the behaviour of the .fbx format that facilitates data exchange among different creation packages contained in Autodesk and provides support for some third-party and proprietary applications. This

nodi concettuali, relazioni associative ed etichette, che possono aiutare a comprendere meglio il significato delle relazioni. Solitamente sono riconoscibili dalla loro struttura costituita da reticoli di nodi collegati da archi che rappresentano significati mediante una combinazione grafico testuale. Le Solution Map invece ereditano proprietà sia da quelle mentali che da quelle concettuali con in più la caratteristica della dinamicità degli elementi.

Un altro sistema di strutturare i dati, legato pur sempre alle mappe mentali, implica la creazione di un database che permette la gestione di tutte le informazioni raccolte, ossia degli errori prodotti nei processi di trasferimento, e, in aggiunta, consente l'interrogazione dei dati inseriti, diventando quindi un valido strumento per il riconoscimento delle cause che hanno prodotto una certa problematica e per la successiva individuazione delle operazioni correttive.

Esistono varie tipologie di database: quelli relazionali (RDBMS), in cui i dati sono memorizzati in tabelle correlate, dove i dati di una tabella sono collegati ai dati di un'altra tabella; i database orientati ad oggetti (OODBMS); ed i database non relazionali (NRDBMS), che usano file per memorizzare le loro informazioni. In quest'ultimo tipo i dati non risultano collegati gli uni agli altri. Valutate le diverse possibilità, si è deciso di progettare un database relazionale, ossia un sistema costituito da un insieme di elementi e da regole che ne definiscono i reciproci legami, in cui ogni elemento può rappresentare a sua volta un sotto-sistema. Maggiore è la complessità del database, e quindi più ampio il suo spettro di fruizione, maggiore è la sua dimensione spaziale e più articolata è la relazione tra le informazioni raccolte. Noti i dati e le relazioni tra essi, per prima cosa viene progettata un'interfaccia che permetta, a chi non ha creato la banca dati, di utilizzarla con facilità: questo è possibile grazie alla creazione di report e maschere specifiche. Inoltre viene impostato un sistema di interrogazione dei dati con la realizzazione di apposite query che combinano, filtrano oppure ordinano i dati prima che questi vengano visualizzati dagli utenti. Risulta quindi di fondamentale importanza creare una struttura il più possibile funzionale e dalla massima fruibilità, facendo attenzione a non creare ridondanza di dati che potrebbero appesantire il sistema. In prima istanza si decide di utilizzare come dati da analizzare e da archiviare quelli derivanti dall'interoperabilità fra i programmi di modellazione

Fig. 111 - on the left/a sinistra

Summary of an engineering approach for the solution of design problems.

Schematizzazione di un approccio ingegneristico per la risoluzione dei problemi progettuali.

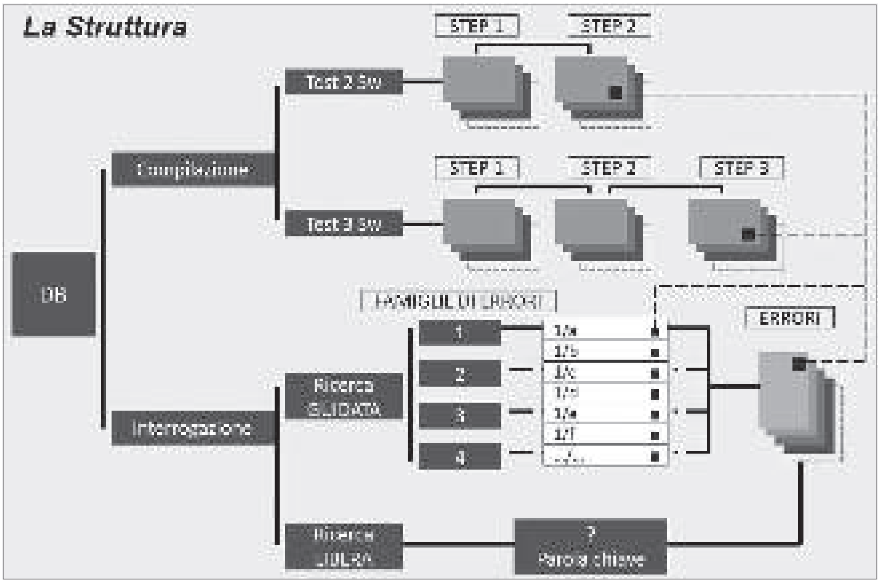


Fig. 112 - on the left/a sinistra

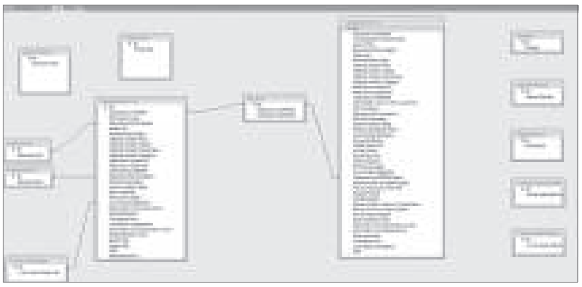
Conceptual scheme of the database.

Schema concettuale del database.

Fig. 113 - on the right/a destra

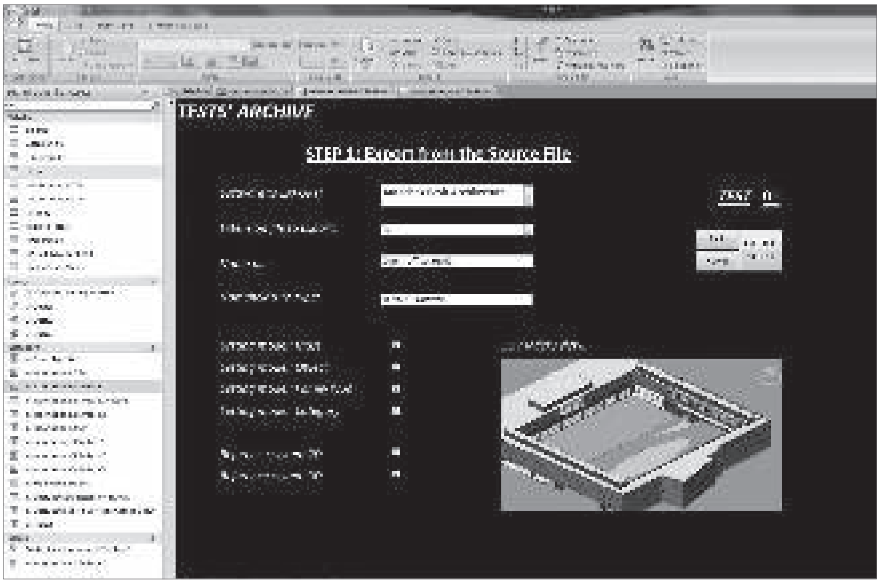
The database's structure.

Struttura del database.



format's characteristic is that files must be saved in the 3D model view and not in the plan, elevation or section view; however this could be considered a flaw, because in the subsequent importation it could be necessary to provide the reference coordinates to place the model in the desired position. One of the first issues encountered concerns the model setup: the utilization of masses, objects, families and categories in Revit makes the model change at the time of importation into another tool like for instance 3D Studio Max or Ecotect. Any kind of modelling has some characteristics that may be modified or completely lost, creating problems in the use of different software in the following phases.
In this work, the first step to take is the database structure processing. The unwritten rule followed for its realization is that, the better is its design, the better will be its application; the longer time is dedicated to the implementation phase, the quicker we will be able to complete the system. The database is conceived to be used even by individuals with little or no familiarity with the Access environment. Therefore we tried to make it as useable as possible in both its utilizations: data entry and query. For data entry it is decided that the database's primary function must be to archive the data obtained from the different tests. For what concerns queries we thought of providing an assistance to professionals that may query the database to try and solve the issues found in their work. Therefore a part is dedicated to data query to be done in two ways: the first is a guided search where the user follows a path with the goal of finding the relevant data; the second is a free, more direct search, where the user may directly access the relevant data by inputting a keyword.
For instance, let's now analyze a part of the data entry procedure: once the data related to the different tested interoperable processes are obtained, the question is how to classify the information. Because some exportation typologies require the use of more than two software tools, the issue arises of how to classify the Export/Import processes involving only two programs as well as those also involving a third one. For this reason two different tables have been realized, containing a set of fields describing the characteristics of the performed Export/Import trials: the first ones appearing in the table are those related to the software tool from which the process is started (SOURCE FILE), the format chosen for the

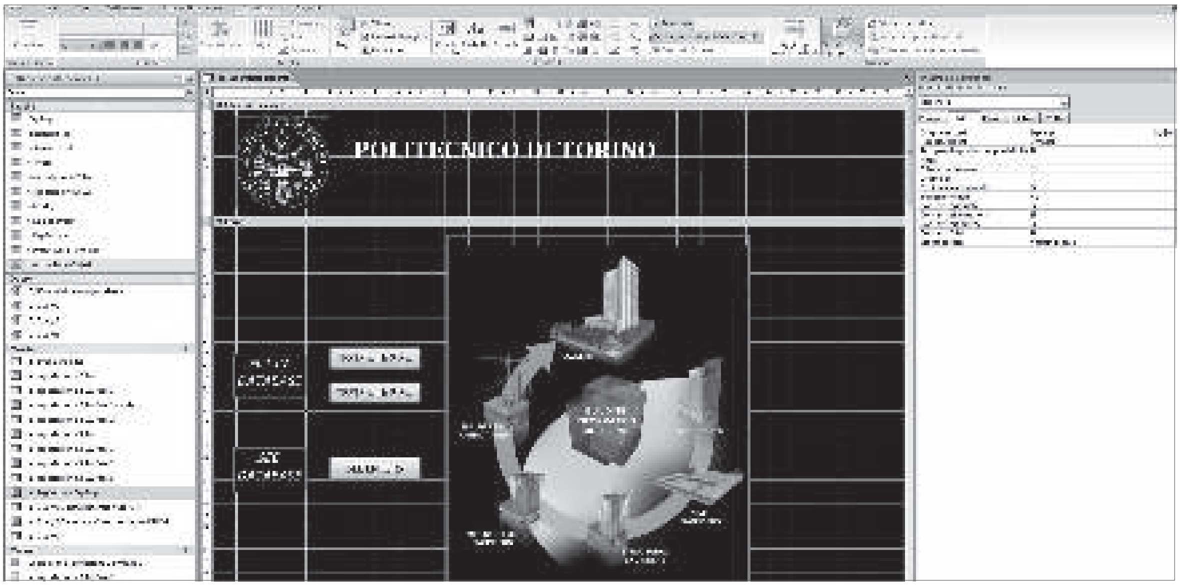
parametrica (Revit Architecture) e quelli di calcolo dei parametri riconducibili sia alla Fisica Tecnica Ambientale (Ecotect Analysis, Revit MEP, TRNSYS e IES Virtual Environment 6.3), sia alla Tecnica delle Costruzioni (Axis VM 10 e Revit Structure). Al momento si sta esaminando il comportamento del formato .fbx che facilita lo scambio di dati tra diversi pacchetti di creazione contenuti in Autodesk e fornisce il supporto per alcune applicazioni di terze parti e proprietarie. La caratteristica di questo formato è che il salvataggio del file deve avvenire nella vista 3D del modello e non in pianta, in prospetto o in sezione; tuttavia questo potrebbe essere considerato un difetto perché nella successiva importazione potrebbero essere necessarie le coordinate di riferimento per andare a posizionare il modello nella posizione desiderata.
Una delle prime problematiche riscontrate riguarda l'impostazione del modello: l'utilizzo delle masse, degli oggetti, delle famiglie e delle categorie su Revit fa variare il modello stesso nel momento dell'importazione in un altro software come ad esempio 3D Studio Max ed Ecotect. Ogni tipologia di modellazione ha delle caratteristiche che si possono modificare o completamente perdere, creando dei problemi nell'utilizzo del software nelle fasi successive.
In questo lavoro, il primo passo da affrontare è quello del tema di elaborazione della struttura del database. La regola non scritta che si è seguita per la sua realizzazione è quella secondo cui tanto migliore è la sua progettazione, tanto migliore sarà la sua applicazione; più tempo si dedica alla fase di implementazione, più velocemente si riuscirà a completare il sistema. La banca dati è pensata in modo che possa essere rivolta anche all'utente con poca familiarità con l'ambiente di Access. Si cerca quindi di renderlo il più possibile fruibile nelle sue due accezioni: la compilazione e l'interrogazione. Per la compilazione si decide che il database deve avere come prima funzione quella di archivio delle informazioni ottenute dai vari test. Nell'interrogazione invece si è pensato di fornire un ausilio ai professionisti che possono interrogare la banca dati per cercare di risolvere i problemi riscontrati nel loro lavoro. È quindi presente una parte dedicata all'interrogazione dei dati che può avvenire in due modi, nel primo modo si attua una ricerca guidata in cui l'utente segue un percorso che ha come obiettivo il raggiungimento dei dati interessati; nel secondo modo è possibile una ricerca libera, più diretta, in cui l'utente,



Figg. 114-115 - on the left and below/a sinistra e sotto

Populating the database (Step 1) and STRUCTURE VIEW *of the database's home page.*

Compilazione del database (Step 1) e VISUALIZZAZIONE STRUTTURA *della home page del database.*



importation procedure (EXTENSION FILE TO EXPORT), the file name (NAME FILE) and the model setup used for modelling (MASS, OBJECT, FAMILY TYPE, CATEGORY) and finally the reference system (2D or 3D) at the moment of saving the file to be exported. Afterwards the field NOMENCLATURE TYPE is introduced, describing the way the various modelled objects are named (if in English or Italian and the number of characters utilized).
Moving on to the query section, we have programmed a guided path where the user with limited Access capabilities may view all errors of a certain typology (guided query); while for an expert user a field was added in which it is possible to enter keywords related to the error, allowing a free inquiry.
The database is under continuous evolution because it is updated and implemented every time that an error or an interoperability issue with different software tools comes up. In conclusion, the goal in designing such a database is to develop a tool allowing us to overcome the current barriers among software tools, avoiding errors that could make the design process longer and optimizing the time required by a project, allowing therefore a quick model modification and subsequent check both at the performance and operating level.

inserendo una parola chiave, arriva direttamente ai dati che lo possono interessare.
A titolo esemplificativo, analizziamo ora parte della procedura di compilazione: una volta ottenuti i dati relativi ai vari processi interoperabili testati, si pone il problema di come catalogare queste informazioni. Poiché alcune tipologie di esportazione necessitano l'utilizzo di più di due software, si presenta il problema di come catalogare sia i processi di Export/Import che richiedono due soli programmi sia quelli che necessitano di un terzo applicativo. Per questo motivo sono state realizzate due tabelle distinte, nelle quali sono stati inseriti dei campi che descrivono tutte le caratteristiche proprie dei tentativi di Export/Import effettuati: le prime a comparire sono quelle relative al tipo di software da cui partire (SOURCE FILE), il formato scelto per la procedura di importazione (EXTENSION FILE TO EXPORT), il nome del file (NAME FILE) e l'impostazione del modello utilizzata per la modellazione (MASS, OBJECT, FAMILY TYPE, CATEGORY) e infine il sistema di riferimento (2D o 3D) al momento del salvataggio del file da esportare. Successivamente è stata inserita la voce NOMENCLATURE TYPE in cui si richiede il modo in cui i vari oggetti modellati sono stati nominati (se in inglese o in italiano ed il numero di caratteri utilizzati).
Passando alla sezione di interrogazione, è stato realizzato un percorso guidato in cui il soggetto poco abile con Access può arrivare a visualizzare tutti gli errori appartenenti alla stessa tipologia (interrogazione guidata); mentre per l'utente abile, è stato aggiunto un campo in cui è possibile inserire le parole chiave relative all'errore, consentendo così una interrogazione libera.
Il database, ad oggi, è in continua evoluzione in quanto, ogni qualvolta si presenta un errore o una problematica legata ad un processo interoperabile effettuato con software diversi, esso viene aggiornato ed implementato. L'obiettivo nel progettare questa banca dati è, in conclusione, quello di fornire uno strumento che ci aiuti a superare le attuali barriere tra i software, evitando di commettere alcuni errori che potrebbero allungare l'iter progettuale, ottimizzando il tempo impiegato in un progetto, consentendo quindi una rapida modificazione del modello e una conseguente verifica a livello prestazionale ed esecutivo.

Smart data management with BIM and AR in Malaysia

Matteo del Giudice, Stefano Giovannitti*, Anna Osello*,Azria Aris**, Robert Thomas Bachmann****

Actually, many researchers are fusing on Building Information Modelling (BIM) for data management of the architectural heritage. BIM method is based on a 3D parametric model where users can add heterogeneous data. The Malaysian architectural heritage has been analyzed through an archival research, a photographic/drone survey to investigate new and cheaper technologies for points cloud.
This paper aims to show a multidisciplinary methodology for the existing buildings' refurbishment. Augmented Reality (AR) is also used for the data visualization to develop smart cities in Malaysia.

Keywords: BIM, smart city, AR, Malaysia, Interoperability

Introduction

In recent years, economic and population growth in Southeast Asia, especially in Malaysia is evident. This has a strong influence on the AEC Industry which is one of the sectors that has been developing most. Relating to this, the use of BIM methodology can be adopted to optimize the management of the Malaysian real estate.

It is one of the new emerging technologies to be deployed in the design, construction, and facility management in which a digital representation of the building is being created to facilitate the exchange and interoperability of information in digital format. The enhancement of BIM implementation in the Malaysian construction industry is due to the positive effects of BIM applications in construction projects (Zakaria et al. 2013), such as visualizing project models, previewing design clashes analysis, and assisting in preparing project design, cost estimation, and project scheduling (PWD 2011, Ahmad Latiffi et al. 2013, Barati 2013). The implementation of BIM in the Malaysian construction industry is expected to increase due to its benefits to construction projects.

Usually, BIM methodology is applied to new buildings, but it can be also used the existing ones to improve the life style city quality for the development of a smart city. For this work the Malaysian architectural heritage has been analyzed. Focusing on the Kuala Lumpur architectural heritage, it is visible both the presence of many new buildings, especially skyscrapers, and existing buildings which are divided in high rises and the traditional malaysian houses.

University Kuala Lumpur city campus building, located in Kuala Lumpur, was taken into account as a case study. It has a rectangular shape and it is composed by 31 floors. This is a skyscraper existing building and it is the main campus of UniKL.

As it is considered an university building where every day many students come there to follow lessons, issues such as energy saving, daylighting, facility management need to be investigated for the development of a smart building.

Referring to the Smart Energy Efficiency Middleware for public Space (SEEMPubS) European project, which was focused on the reduction of energy usage and CO2 footprint in existing public buildings and spaces without significant construction works, the creation of a BIM model can be one of the most important steps for the smart refurbishment of the building.

So, the development of a 3D parametric model about an existing building requires many information coming from different sources, such as archival research documents, different kinds of survey, CAD drawings, pictures, etc. In this area, merge heterogeneous data in just one dataset is a research challenge and interoperability become very important in term of data exchange.

This topic is fundamental also in term of data visualization: the use of AR has been tested with different applications to display data coming from the BIM model. In this way should be possible to visualize all data filled in a graphical database and to extract them in different ways generating a smart data management.

Methodology

The development of the 3D parametric model for the smart data management starts from the data collection as visible in fig.01 which represents a part of the building process. In this phase it becomes really important to manage a big amount of data coming from different sources, as e.g. archive documents, geometrical, photographic or laser-scanner survey.

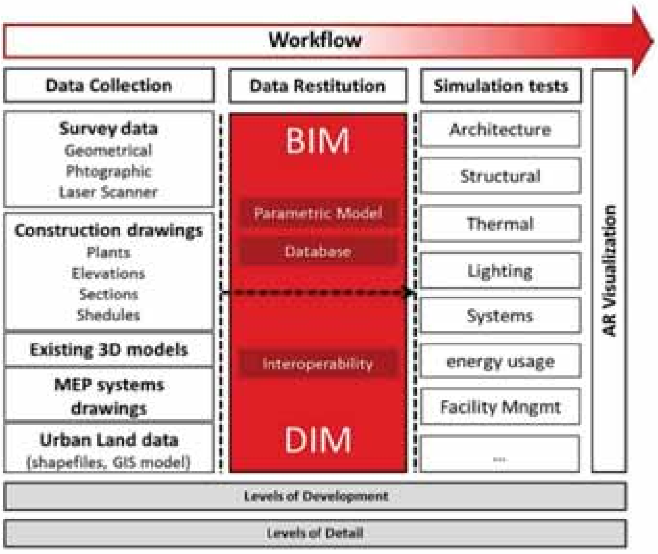
For this project a points cloud survey was developed starting from a photographic survey that it was done using a camera with GPS integrated. A .KML format file was generated and it was visualized on Google Earth. In this way checking the survey was easier to discover places where the pictures were done and where more photos are needed. Adding to this, another survey with drone was developed in order to collect more data for the development of the points clouds for the upper part of the high rise. The DJI Phantom drone was used for the flight and a GoPro camera has been connected with it for taking videos from which the images were extracted.

The points cloud generation was done processing these pictures with different software applications such as Autodesk Recap 360 and Agisoft Photoscan that differ in term of data processing. The first one is very user friendly and is web based. The second is more accurate in term of topographic data and points cloud density, but requires good hardware because it works on the local laptop.

Another kind of data are CAD drawings about the building which were founded through an archival document research. Overall 128 drawings were found related to the architectural, structural and system part of the building. Also 3D existing models developed using Google SketchUp were downloaded from Google Earth as knowledge about the building. Usually the presence of a 3D urban model about the neighborhood can help the professional who has to develop the BIM model because he can merge geometrical and alphanumerical data into the BIM environment. Unfortunately, for the UniKL city campus the urban model was not founded.

The presence of multiple documents referring to the same building can ensure that the professional is able to create the BIM model reproducing as close as possible the reality.

1/ Schema of a part of Building process workflow



The analysis of the various sources twisted with the photographic survey has provided the ability to verify the quality of the information from older documents or provenance uncertain.
After this phase, the data restitution step has been started with the development of the 3D parametric model created with Autodesk Revit.
A correct template was chosen to simulate a real case of refurbishment following rules that are really applied for the submission of design project to the city hall. The BIM Singapore standard has been used and then has been adapted for the Malaysian environment. Using this template has been interested in order to understand how the model can be queried and data can be represented in different ways for different end users such as the Building Construction Authority (BCA), the Central Building Plan Unit (CBPU), Fire Safety and Shelter Department (FSSD), etc.
The BIM model was developed as basis for design and data exchange: the Worksets tool was used to simulate the work sharing data in a professional work team as visible below in fig.02.
The creation of local models connected with only one central model allows the professionals to visualize in real time the project, checking the interferences between different components. So, data coming from different sources were inserted in Revit environment in different worksets in order to display clearly the interferences, making the file lighter in term of megabyte and easier for the management of the BIM objects.
Then, data visualization was investigated using AR. As UniKL is a university, the visualization of the model has been thought also starting from the point of view of the students. For this work was tested the AR with marker through ARmedia software and markerless technology using Aurasma software. In the first case the 3D model has been explored using clipping planes that allow the students to discover the university, such as visualizing the building through section plane.
Using Aurasma, the plan of each floor was used as *trigger* image in order to overlap the image of the floor plans with more information about the Room category as visible in the fig.03. The Aurasma's channel is public, in fact to display added information coming from AR is enough to be follower to Politecnico of Torino Channel, called PoliToAR. The use of this tool is allowed without internet connection. Thie added information was extracted from the BIM model.
ARmedia was used as plug-in of Autodesk 3D Studio Max. In this case the BIM model was exported from Revit in FBX format to avoid data loss during the interoperable process. Unluckily, it was necessary to import again the Points Cloud because this format does not support this kind of data. Then, the model was associated to a marker in order to be visualized with the AR.

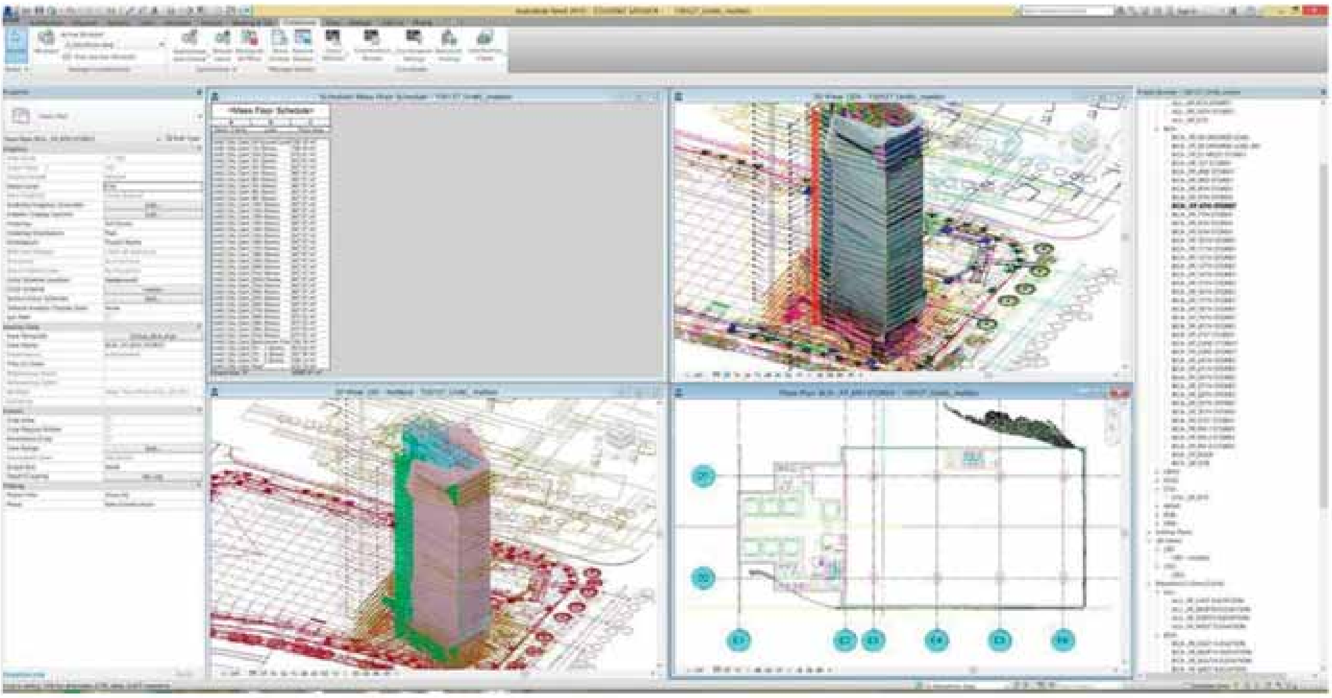
Results

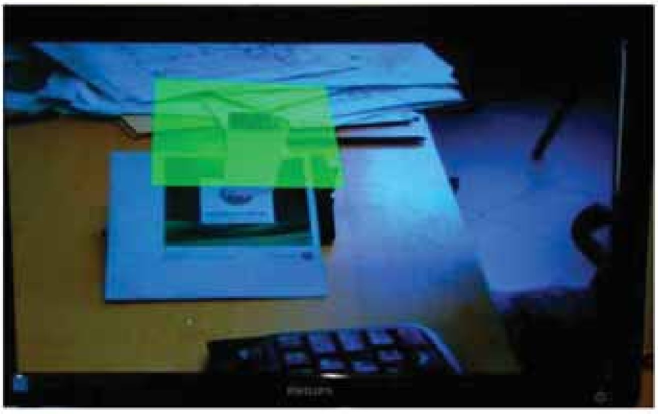
With this study it is clear the power and the importance of BIM. Following this methodology can give a great contribute to develop a smart building optimizing the data management. In fact, one of the important idea of BIM is the fact that data has to be inserted only one time in just one storage/database.
The main issue of this study was to find a way to insert in just one environment such as a BIM model heterogeneous data with different file format starting from the point cloud arriving to CAD files and extract them in different way in order to test the BIM model, using also AR.
Several incoherencies appeared overlapping different information mentioned above, such as for example the different position of the columns and the structural walls.
Many information can be extracted and visualized in different way depending on the end user, such as the professional for the refurbishment of the building, the management office for the facility management and room occupancy and also by the students for the discovery the university to find the lecturers or check the time schedule of the lessons.
Regarding to Aurasma, the fig.03 shows the overlapped data coming from the BIM model on the layout of the plan that is present on each floor. In this way students can understand where is the lecture room, but also this information can be useful for who needs to do a maintenance in specific area of the floor. The visualization of the BIM model in Aurasma at present is not error free too. This software supports files not too heavy (around about 250 MB). For this study, views of the BIM model were extracted in order to add information to the reality.
Exploring the building using the marker connected with the model was possible with ARmedia software. This could became an instrument for the student which need to check in which floor he needs to go starting from the lobby, avoiding mistake using the elevators which are currently very congested.
fig.04 shows one of three cladding planes. Furthermore, is possible to choose one of these and "cut" the building in horizontal or vertical way.

2/ BIM model view with worksets

3/ AR with Aurasma

4/ AR with ARmedia





This tool is very important to many points of view starting from the display of the correct location of the columns, arriving to the room interior design. Furthermore, the file can be exported and viewed on a smartphone with Android or IOS processor for easier viewing of the building. Another benefit that may result from the use of AR is related to marketing. Using AR the university could advertise itself better by offering the opportunity to interested parties to navigate the model even remotely just by using this technology.
Obviously this technology needs to be investigated more because at present the use of AR software has highlighted some critical issues related to the type of file to be used in different platforms. Currently, the visualization of the points cloud with ARmedia plug in 3DStudio

Max is unavailable. Although it is possible to import the points cloud in 3DsMax, this information is still lost at the time of the representation with the AR. This could be caused by the kind of data that are not supported not only by ARmedia but maybe also by the power of the PC's graphic card.
At present the BIM model needs to be enriched to perform daylighting simulations, filling data also for the spaces' management.
The points cloud survey needs to be improved adding other photos because actually in some parts such as the roof there are not point which describe the building. As visible from this study interoperability plays a key role in term of data management and needs to be improved through other tests starting from a BIM model that needs to became the reference for each professional involved in a project.

Conclusions

The interest on BIM is growing in the AEC Industry especially in Malaysia where population growing and technological progress is rapidly developing. Data management related to the same building is considered one of the first steps for the refurbishment of an existing building and needs to be improved in term of interoperability.
BIM methodology will allow the user to speed up the building process related both to new and to existing buildings with time and costs saving. All data concerning the building will be managed in smart way through the use of only one database that needs to be shared with all the user and the data visualization through AR. It is desirable that in the future thanks to innovation technology, sharing data will be easier without data missed, allowing users to optimize data management for the building process.

Notes

* DISEG, Politecnico di Torino, Corso duca degli Abruzzi 24, Turin, Italy, matteo.delgiudice@polito.it, stefano.giovannitti@studenti.polito.it, anna.osello@polito.it
** Head of Technology R&D, IntelSec Sdn Bhd, Kuala Lumpur, Wilayah Persekutuan, Malaysia azrin.aris@tm.com.my.
*** Universiti Kuala Lumpur, Kuala Lumpur, Malaysia.
bachmann@unikl.edu.my

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AUGMENTED REALITY AND GAMIFICATION APPROACH WITHIN THE DIMMER PROJECT

A. Osello[1], M. Del Giudice[1], A. Marcos Guinea[1], N. Rapetti[1], A. Ronzino[1], F.M. Ugliotti[1], L.Migliarino[2]

[1]Politecnico di Torino (ITALY)
[2]Primo Liceo Artistico Statale di Torino (ITALY)

Abstract

Innovative learning methods as well as research projects dissemination can be achieved by digital technology. AR (Augmented Reality) can play a key role in the education field in order to transmit knowledge to young generations. AR is used to develop a playing cards game for children based on energy saving topics within the DIMMER (District Information Modelling and Management for Energy Reduction) European Project, where energy consumption awareness is one of its main aims. The DIMMER system enables the integration of BIM (Building Information Modelling), distribution network models, real-time data from sensors and user feedback through QR Codes and web portals. The energy performance of buildings is analysed from their actual utilization and especially from users' feedback. Despite pervasive sensors implementation is a necessary tool to monitor buildings, the more effective way to reach real energy saving is to pursue user awareness and promote good practices in energy using. In fact, energy information sharing has been intended as the main focus in the DIMMER game, since children can adopt good habits that will be reflected on adults behaviour. The game conception has been reached by the collaboration between Politecnico di Torino and Primo Liceo Artistico Statale, as well as the staging of a theatrical show about these issues. In this way a connection between University and High School has been established about current research topics and the uses of new technologies for pedagogical purposes. AR is investigated in order to promote an interactive game for children in which the differences between good and bad practices in terms of sustainability and energy efficiency are discussed. It indeed turns out to be an effective means of communication with immediate impact on children learning. Cards are characterized by markers which are linked to 3D models through a specific software that enables their visualization on personal devices in AR. In the game, natural elements that are capable to generate energy (sun, fire, earth, water and wind) define the seed of every card. Attractive and colourful figures are used to represent renewable energy sources and their applications, while dark images represent the most polluting solutions. The DIMMER game purpose is not to pick up the higher number of cards, but saving energy through positive figures, avoiding those that involve pollution generation. This kind of approach establishes an interaction between children and the energy problem by encouraging active learning through the game and raising their awareness. Children are stimulated by AR multimedia elements that make learning more interesting and entertaining.

Keywords: Augmented Reality, DIMMER Project, gamification, user awareness, energy saving.

1 INTRODUCTION

Nowadays in Europe energy consumption is one of the most discussed issues related to economic and environmental conditions. For this reason the Horizon 2020 Program [1] underlines the **needs to reduce energy and to increase citizens' awareness** on these topics. In order to achieve these objectives, the extended and integrated use of **the Information and Communication Technology (ICT)** potential allows correlating data, processes, systems and methods that are often very different from each other with the aim of making them available through **new communication systems** as the QR Code, **AR** [2]. The main goal of this action is to develop systems for **displaying information related to buildings and their energy consumption**. This information can be available in real time through personal devices and can be used both to empower users to save energy (students and tourists) and to optimize technical data management (by energy and facility managers or maintenance workers). In the smart cities and smart building contest user awareness is one of the main aspects and **school represents a strategic hub to promote educational programs and involves the adoption of new lifestyles based on the idea of energy saving.**

In this perspective these new systems are employed to **communicate the purposes of DIMMER Project**, funded under the Seventh Framework Program of the European Community. The project aims at **optimizing the energy consumption in existing buildings and at urban scale by using ICT technologies in order to manage them**, and by also considering smart grids and users' empowerment. The goal of this project is to develop an integrated BIM, based on **3D models at district urban scale** where, due to the **installation of sensors** within the most significant buildings, data from the models can be managed in real time according to the **feedback** given by user's behaviour in terms of **energy consumption.**

The employment of technologies is not enough to turn a traditional building into a smart one because **people consciousness** is required for its utilization. The **awareness-oriented phase represents a key point** for the dissemination of this project and of its objectives, and it has been specifically exploited to establish a **relationship between University and High School for children learning**. In this particular work, **AR** has been intended to be a helpful tool to get a higher level of consciousness: it has been used by young students in order to develop a playing cards game and a theatrical show both based on energy saving strategies and related to the DIMMER Project.

2 METHODOLOGY

2.1 DIMMER Project's overview

The DIMMER Project is based on the main results of the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) Project which consists in developing a web-service oriented open platform with capabilities of real-time district level data processing and visualization [3]. The technologies that will be used and improved within this project will be: real-time data collection; advanced middleware technology for data integration; simulation and virtual visualization; user/social profiling, visualization and feedback; energy efficiency and cost analysis engine; web interface and interaction. The demonstrators of the project are located in Turin (Italy) and Manchester (UK). Focusing on Turin case study, Politecnico di Torino adjacent district has been chosen because it includes a wide range of building typologies, both private – residential – and public – schools, offices, etc. Moving from urban to building scale, different types of models have been developed and correlated between each other. From this point of view the use of BIM and GIS potentialities offer 3D data models able to provide information about buildings and their surrounding environment [4]. For this reason, the creation of a digital parametric model becomes fundamental since it includes information related to the buildings and, what is more, to their electrical power and thermal distribution networks. As visible in Fig. 1, different type of district and buildings data, like geometrical, historical and Building Automation Systems (BAS) outputs, can be collected and extracted in many ways for different users (i.e. children, students, workers, facility and energy managers, etc.). The same data can be visualized following various strategies and tools. For example, energy data can be displayed by the city/building energy manager to suggest more efficient policies, by residential users for costs saving calculations or by the instruction sector for arise young generations' awareness on sustainability issues.

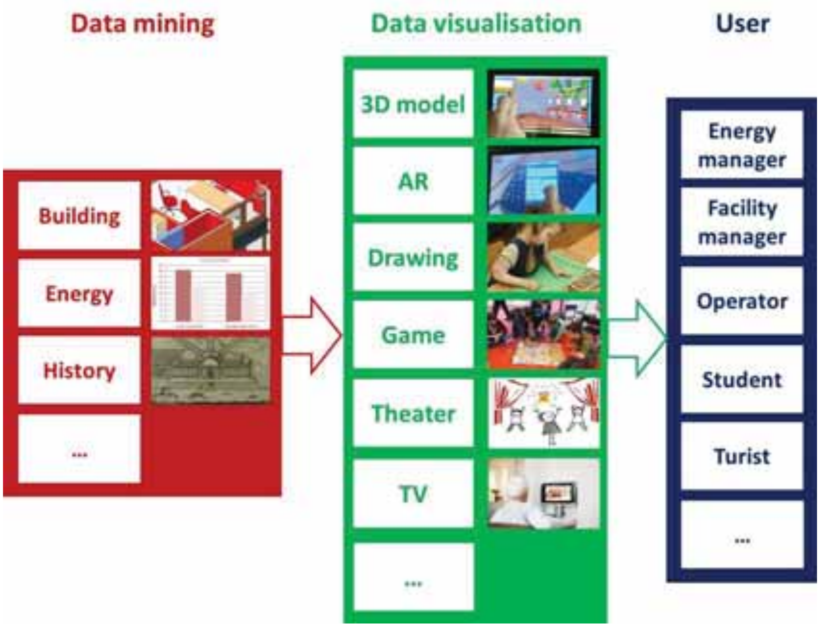

Figure 1 - Chart of the information flow from data to end users

In order to disseminate the methodology about 3D parametric models and sensors networks, different channels of communication have been exploited, including games and theatrical shows for children and young students (8-16 years old), who will be the future “Smart Users”. The goal is **to improve awareness in a funny way**, easy to be learned in everyday life. In order to enhance education in an optimal way, **AR and Gamification have been combined for the creation of an energy saving “ECO card” game and of the “ToBeSmart” show**, as described below.
The activities have been carried out by involving the students of Primo Liceo Artistico di Torino (High School) who got some classes and workshops about sustainability, energy saving strategies and AR; both the game and the theatrical show were conceived as the final result of the collaboration with Politecnico di Torino. Thanks to the coupled gaming/showing approach, awareness has been entirely reached, while the creative capabilities of teenagers have been stimulated by focussing on energy saving. Even younger children have been able to heed the importance of these topics by both playing the AR cards game and watching the show.
In the last years the AR technology has been introduced in many fields such as education, maintenance, manufacturing, medicine, business, public service, military, gaming and entertainment [5]. New technologies as Sony’s new mobile gaming platform "PS Vita", considered a good example and a best practice for the DIMMER Project dissemination, offer a more immersive gaming experience to a younger generation able to be more stimulated by interactivity, allowing a more efficient feedback and a faster assessment. Nowadays virtual objects containing text, graphics, video and audio can be made visible by using specific devices according to the Reality–Virtuality (RV) continuum approach [6], where real and virtual objects are presented together within a single display defining a generic Mixed Reality (MR) environment.

The introduction of technology in education becomes an essential support to engage and motivate them about specific topics [7]. In our case study this purpose has been reached by involving the students in the **creation of 3D models and their related AR markers**. The game has been conceived by using simple and not expensive technologies, as shown in Fig. 2. The base-components which are necessary to make the whole process work are:

- Hardware: personal computer, monitor or display screen, camera;
- Software: app or software running locally;
- Markers: physical objects or places where the real and virtual environments are fused together

The camera gets the information represented by each marker and **by means of a specific software (AR Media) each tag is coupled with its respective 3D model realized with Autodesk 3ds Max Design.** The Mixed Reality is then visualized on a display screen.

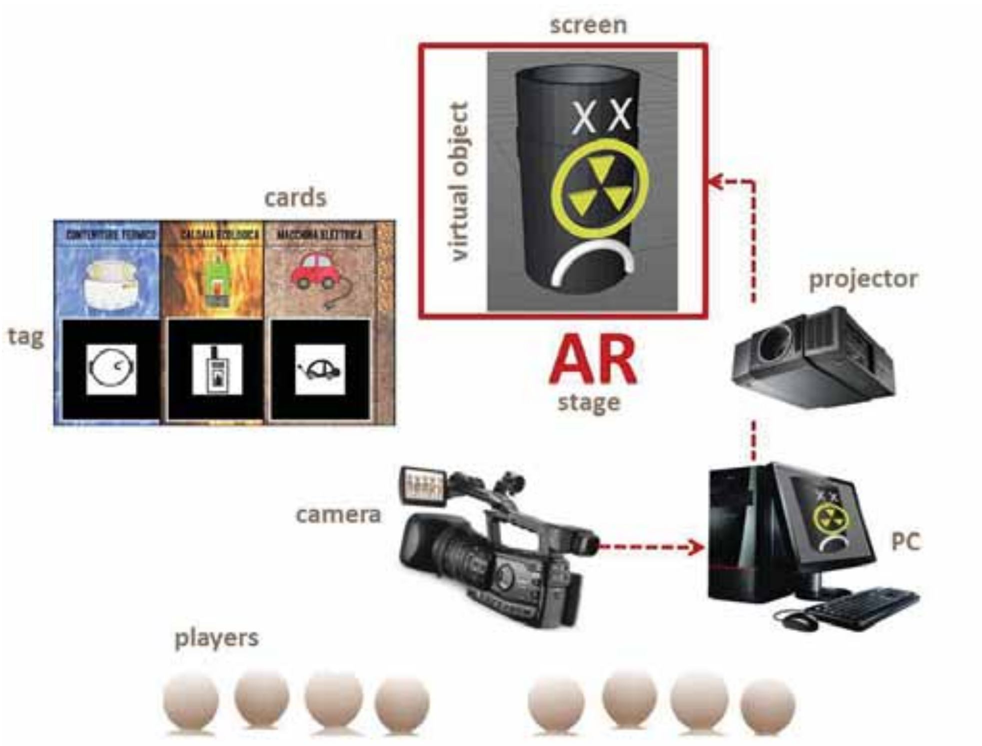

Figure 2 - Example of the use of the proposed technologies for a game

2.2 Gamification activities’ overview

The main point of the game is the **importance of clean energy generation**, so the winner is the one who saves more energy and not the one who picks up the higher number of cards. In this way children learn easily to think to a long-term future and realize immediately the value of taking good practices instead of bad ones referring to their behaviour towards the environment. To allow this kind of working the game is composed by sixty cards organized into forty roles, ten bonus and ten ‘energy element’ cards. In Fig. 3 it is possible to see an example of every type of card, which are described below.

Figure 3 - (from left to right) Positive and negative role cards, bonus DIMMER card and energy element card.

The game is divided into ten turns in which an ‘energy element’ card establishes the dominant seed of each turn, with a maximum of two cards with the same seed. Since a limited number of fifty cards is provided, it is advisable to play the game with a maximum of five children. It is necessary to deal two bonus cards per child and the same number of role cards to everyone. The game starts from the younger child and it works counter clockwise. For every turn the children drop the card they prefer, paying attention to the dominant seed for energy saving, because its points will be stronger than points from the other seeds. It is possible to use bonus cards whenever the player wants – just one bonus card per turn – in order to take advantage in the game by changing the seed of the turn or playing another extra functionality, like picking up all cards or doubling points in the current turn.

Within role cards there are twenty-five positive figures that show different energy saving strategies, divided into five seeds representing the natural elements that are capable to generate energy: sun, fire, earth, water and wind. There also are fifteen negative cards related to elements that generate pollution to the environment. All role cards have points on them, in a scale from one to five, that will be determinant to the game’s resolution: after every turn and at the end of the game, the points obtained by saving energy will be added whether points got by polluting practices will be taken off. The child with the higher score wins. In case of a hypothetical tie at a single turn or even in the final count, a three-question quiz about energy saving will be done to solve the situation.

It is important to notice how awareness in terms of sustainability is always present in the whole game contest: in addition to the perspective of **winning by saving clean energy and refuting pollution**, some advices or reminders are explained at the bottom of ‘energy element’ cards, in order to integrate learning at every phase of the game. As introduced before, **the key element that allows to maximize the desire effect of children’s consciousness is the use of AR by adding markers to the cards**. Every single role card has a drawing on the top that represents a particular way of energy consumption (either positive or negative) and a marker on the bottom that schematizes it. **The marker is linked to an appropriate 3D model** that simplifies the energy element’s icon of the card. While playing the game, a video camera gets the markers of the dropped cards, making 3D models appear on the screen according to the connection previously explained.
In the Fig. 4 below it is possible to see an example of this drawing/maker/3D model threefold representation. In this way the children will see the renewable energy sources they choose for playing represented by attractive and colourful 3D figures on the screen, while they will link up polluting solutions with ungraceful and dark images, understanding immediately the difference between good and bad approaches in terms of energy generation.

Figure 4 - Example of the threefold representation of the elements

AR enables children to learn in an interactive and entertaining way, so they get easily interested and motivated about relevant topics as **energy consumption**. This way they may become aware at an early stage of their lives, influencing their own habits and behaviours towards the environment and reaching even to affect the way of thinking of the adults around them.

For what concerns the theatrical show, developed by the students of Primo Liceo Artistico di Torino (High School), it stages the energy problem in an engaging and easy way to let little children concentrate and understand the importance of the topic. In order to include the idea of **energy saving strategies within the world of building constructions**, the play takes place in Turin and represents a discussion between an old building and a new one, both chosen among the DIMMER Project demonstrator. After an initial argument between them, the older building realizes to be too much polluting and it accepts the idea it is not a clean solution for the environment, allowing the building's administrator for its energy refurbishment in order to be transformed into a smart one, through an intervention of Politecnico di Torino.
As said before, the activities have been promoted as part of the DIMMER Project's dissemination, which represents the most important step to ensure the adequate implementation and sharing of the scientific progress. As shown in Fig. 5, this particular performance is part of the project's diffusion strategy, which aims to reach either the smart city's community or the educational sector through two different channels of communication.

Figure 5 - Overview of the DIMMER Project's dissemination strategy

3 RESULTS

The DIMMER Project aims at motivating people to care about energy reduction by data monitoring, letting them to manage and visualize information through their personal devices – i.e. smartphones or tablets. A technical system based on ICTs has been developed in order to manage both the energy data coming from sensors and the Building Management System (BMS) through an interoperability process [3]. Fig. 6 is useful to understand how the ICT is used by the DIMMER Project for collection, management, sharing and visualization of data needed to fulfil the district information platform in the cloud system. The level of development of this research can be visualized reading the chart in a vertical way. In this context the exploitation of technology aims at introducing citizens into the energy saving field and at making them an active part of smart cities by improving their environmental consciousness and their behaviour.

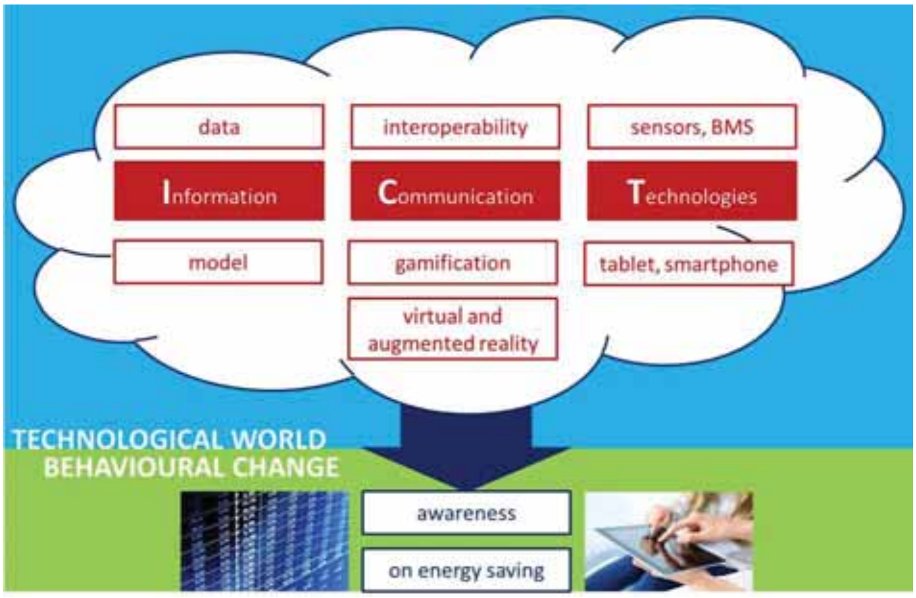

Figure 6 - The technological world for a behavioural change

The application of the behavioural change among the young generation can be possible by **introducing innovative technologies in the educational sector** and by **connecting** the latter **to the research field**. Nowadays, teenagers use technology in a very intuitive manner. This approach simplifies their assimilation of concepts and allows them to have fun while learning about energy usage. As a result, the students of Primo Liceo Artistico have transferred the classes and workshops contents into the children's cards game and the theatrical show described before. Energy saving strategies and air pollution reduction have been promoted at different levels of awareness in a simple and friendly mode to make all generations smarter. Due to the wide range of existing immersive games young people usually prefer to play within a new virtual environment instead of playing in a conventional way. For this reason, a **re-elaborated version of traditional games** has been carried out with the **introduction of multimedia content through AR** in order to attract them. Consequently, a link between traditional games and innovation has been created for the **involvement of different generations** on issues that currently play a key role at a worldwide level.

With the participation at the “Researchers’ Night 2014” event in Turin, the achievements previously mentioned and an actual dissemination of the project have been pursued. For this occasion an eight-hour contribution that involved both gaming and theatrical staging has been performed by Politecnico di Torino and Primo Liceo Artistico. The available time was dedicated to both the gaming and the staging part by spacing out the cards game with the thirty-minute show played by the students in front of a children audience. Despite the periodic breaks from gaming, the learning experience was not interrupted but rather continued during the show thanks to the funny discussion between a poor energy efficient building and a smart one. **This way sustainability was always the protagonist of the evening and consciousness was reached through two different ways of dissemination.**

In order to know the extent of the intervention, data from the event have been studied and compared with results from another traditional game which was tested in a similar contest previously: an innovative version of 'Game of the Goose' with multimedia content using AR – from now mentioned as 'SEEMPubsdicE' game [8]. For what concerns the gaming part of "Researchers' Night 2014" event, 80 people were involved, of which 76 children – with an average age of 13 years old – and 4 adults. Although DIMMER cards game was developed for children use, the percent of adults participation reported on Fig. 7 demonstrates that **a family involvement on energy awareness through gamification is possible.**

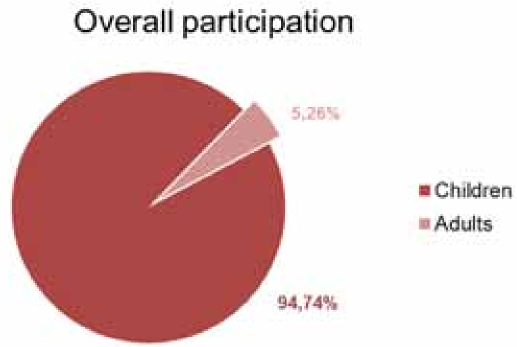

Figure 7 - Distribution of overall participation on DIMMER cards game

Considering that every single game is reduced to five people, the total amount of participants were able to play a sum of 16 games during the entire event. Regarding to the collected data, they give an approximate duration of 20 minutes per game including the explanation of the rules. Comparing the performance of the year before, the 'SEEMPubsdicE' game involved 143 people – of which 137 children with an average age of 10 years old – distributed into 39 games of 12 minutes each. In Fig. 8 it is possible to see a graphic that schematizes this comparison.

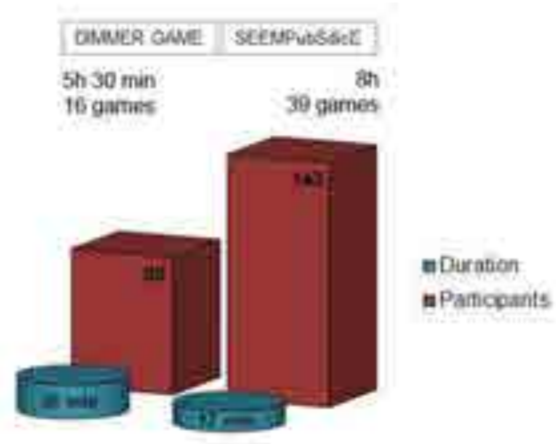

Figure 8 - Comparison between DIMMER and SEEMPubsdicE games in terms of duration and number of participants

After analysing the collected data, how **real capability of dissemination is influenced by the duration and the easiness of the different games** has been noticed; these will be aspects to take into account for future works related to gamification. The second experience confirmed that an **approach to education through the game gives very good results, corroborating the educational value of AR and extending it to its capacity to optimize the communication process.**

4 CONCLUSIONS

AR has turned out to be a relevant achievement for the development of smart cities when used for **dissemination, becoming part of a complex process that requires an interdisciplinary strategy** of all parties involved, allowing for a simple and optimal way to disseminate. Taking into account the importance of **adapting methods to the particular end users**, **employing the appropriate technologies for each case** becomes fundamental. For this reason our aim is **to continue**

developing the application of AR and its technologies to create alternative ways of teaching, in order to **make learning more enjoyable and productive for students**. Gamification and theatrical showing are interesting tools that can be easily exploited through AR **to stimulate children's creativity and critical thinking**. At the moment these two mechanisms represent just an early stage on the DIMMER Project's dissemination strategy but have already shown they shape a reliable educational approach –in Fig. 9 the difference between a game-based education and the traditional one has been represented. Their profits have been checked out by the success of "Researchers' Night 2014" event, which has given an extra impulse to our team for future developments and researches on the field.

Figure 9 – Difference between a traditional and a gamified education

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Postgraduate Symposium 2014

BIM: A NEW METHODOLOGY FOR THE REFURBISHMENT OF THE ARCHITECTURAL HERITAGE

M. Del Giudice [1,a], A. Osello [2,b], R. T. Bachmann[3,c]
[1,2]Politecnico di Torino, DISEG, Turin, Italy. [a]Email matteo.delgiudice@polito.it, [b]Email: anna.osello@polito.it
[3]Universiti Kuala Lumpur, Kuala Lumpur, Malaysia. [c]Email: bachmann@unikl.edu.my

***Abstract*— In recent years, the themes of energy efficiency of existing buildings has been the subject of much research in the national and international level in an extremely specialized and sectorial method. Adding to this the attention towards the building heritage preservation and protection assumes all along a role of fundamental importance for the culture and personality of every country. This paper represents the first results of an interdisciplinary activity that aims to define a way of intervention easily replicable at the national and international level, defining with clarity methodology which operation have to be performed, their cost and what are the benefits that can be drawn.**

***Keywords*—Building Heritage; BIM; Interoperability; Energy assessment.**

INTRODUCTION

The sensibility for the Building Heritage preservation is already farback shared, the tools for analysing and understanding these assets are nowadays changing. In particular, the added value, if compared with the traditional techniques, is the interdisciplinary and systemic approach with whom different kinds of knowledge are integrated in a dynamic and interoperable way.

Even if the process remains unchanged, composed by survey, representation and data processing phases, it becomes now enhanced with the more up-to-date tones offered by the Building Information Modeling (BIM).

Currently at the Politecnico di Torino two research projects explore these themes: the Built Heritage Information Modeling and Management (BHIMM) project focuses the attention on the existing real estate through BIM technologies, and the District Information Modeling and Management for Energy Reduction (DIMMER) project which is focused on the development of a web-service oriented, open platform with capabilities of real-time district level data processing and visualization. Thanks to the web-service interface, applications can be developed exploiting such an interface to monitor and control energy consumption and production from renewable sources.

For this work, a heritage hotel from 1926, situated in the centre of Georgetown, Penang (Malaysia), was used.

Fig. 1. A view of the case study

In this way it was possible to test the methodology already tested in Italy, focusing on the Malaysian cultural heritage.

It is clear how the interdisciplinary has to be considered a fundamental topic in order to obtain good results relating to the energy efficiency for the cultural and architectural heritage. Working on these projects may enable us to extend to the common goal of fitting the principles and philosophy of BIM – conceived for new constructions - to the 'as-build' field and in particular to an historical asset.

These challenges are therefore translatable in an interoperable methodology work planning that concerns the whole process. from the first phases of survey till the data processing. The process is primarily based on tridimensional survey data, which are adaptable to the historical building characteristics and which can easily communicate with parametric software.

METHODOLOGY

Taking into account the whole building process it is possible to affirm that the survey phase is essential in order to know the original conditions of the asset to be redeveloped. In this phase it becomes really important to manage a big amount of data coming from different sources as archive documents. geometrical, photographic and laser-scanner survey. The survey of an historic building and its context could be considered as a necessary step of the building process of requalification because it allows to know all aspects of the building.

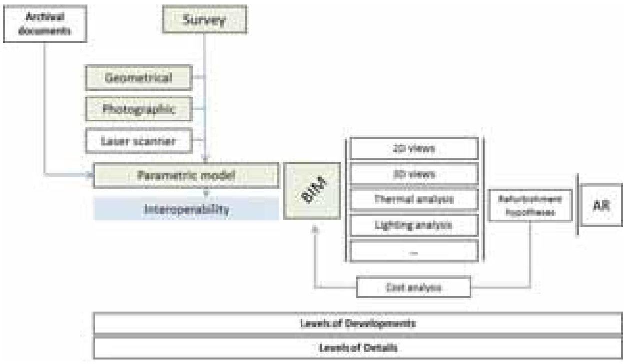

Fig. 2. The BIM Workfow

Figure 2 shows that in existing buildings, the BIM methodology is placed between the output arising from the survey, and the input necessary to the generation of drawings.
It is necessary to obtain several documents that have to be analyzed and interpreted in order to become the vehicle for the realization of the parametric model, tool useful not just during the first phases, but also in the last ones of building management and maintenance.
For these reasons and in order to optimize the data utilization, it is better to establish a hierarchy of the information that will take part in the BIM process: through an adequate predisposition it will be indeed possible to easily and accurately extract information and obtain the necessary inputs for specific analysis as structural and illuminating calculations, rooms management, etc. For this reason, it becomes of particular relevance the representation of the parametric model data in relation to the project level of development and level of detail. It is so necessary to underline the difference between survey, parametric model and real building.
With regards to the whole building process, the first step considered was the survey of the existing building and the acquisition of archival data. These data were essential to analyze the building in its entirety. From the sources analyzed and from the survey executed on site, information have been obtained concerning the type of construction used and the construction details. The structure is composed of precast elements such as columns and beams.
Naturally, numerous inspections need to be carried out in order to perform a geometric survey which allowed to confirm or vary the assumptions obtained from the analysis of the archival documents.
The second phase is the development of the parametric model. For this step at the beginning was used Google SketchUp to develop the geometrical model and after this the model was imported in Autodesk Revit 2015 in order to increase the amount and the quality of information. The development of the database was carried out at the architectural and structural level.

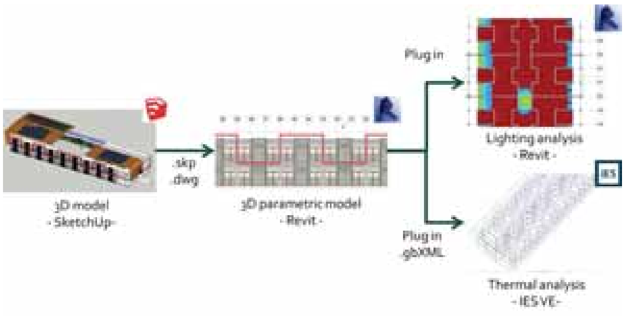

Fig. 3. The process followed for this work

Particular attention has been given to the definition of each element: from the standard families contained in the software each element has been modified to make an accurate model of the existing building.
After the modeling stage, the model was exported into a specific calculation software such as IES Virtual environment for the Overall Thermal Trasmission Value (OTTV) calculation using both the green buildingXML (gbXML) format and the IES VE plug in for Revit. Adding to this the "Lighting analysis for Revit" plug-in was tested as visible in Fig. 4. This tools is a fast cloud service that uses A360 Rendering to expose electric and solar lighting results directly on the Revit model. The results are validated against Radiance, a commonly used simulation tool, and displayed in-canvas more quickly. The service also offers automated daylighting analysis for LEED.

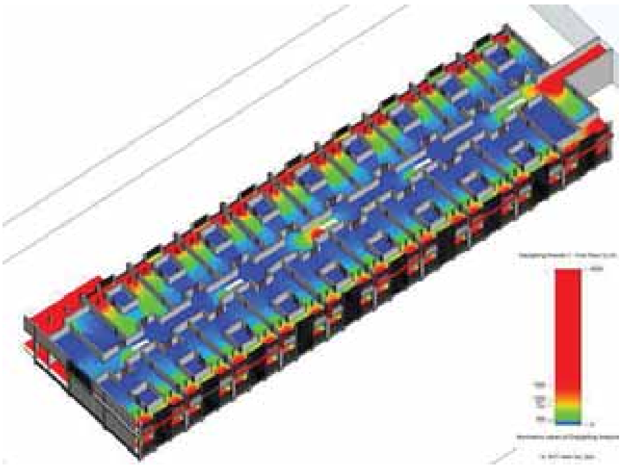

Fig. 4. Daylighting analysis with Lighting analysis for Revit" plug-in

The building has a non-perfect East-West orientation, but for this project it is assumed that it has an East-West orientation in order to proceed in an easy way with the Solar Heat Gain Coefficient (SHCG) calculation following the tables in MS 1525:2007. Later, it has been built a 3D model containing all useful information for the lighting and thermal analysis. For these calculation the "Room" command was used in order to optimize the interoperability process. Moreover, the model has been correctly oriented in accordance with the geographical coordinates and the cardinal axes, modeling the shading elements able to influence the test.

In order to perform specific calculations, the interoperability between programs and formats used to exchange files among them was crucial. To avoid the loss of data a lot of test have been carried out through the following formats: .ifc, .gbXML, .fbx. The IFC (Industry Foundation Classes) is the only interchange format recognized by IAI (Intemational Alliance of lnteroperability) based on the ISO/PAS 16739; however, it still has some limitations as it does not always allow the smooth passage of information between software. This causes a loss of important data.

For these tests was preferred the gbXML format; adding to this was tested also the IES VE plug in. This way allowed the connection with IES VE without indirect procedures. The use of the gbXML format allowed to correct and improve the energy analysis

Certainly the second way was optimal in terms of data retention. However, it must emphasize that, in this case, we cannot speak of real interoperability; in fact two programs belonging to the same software house has been used: this verified what the author Finith E. Jernigan AIA in 'BIG BIM little bim' defined as *little bim*, (tools to facilitate the design methodology BIM).

RESULTS AND FUTURE DEVELOPMENTS

The imported model into IES VE allows to make a first test to obtain data about the actual status of the building.

The OTTV calculation developed with IES VE was compared with the same calculation developed in Microsoft Excel. The two values are slightly different, due to the geometrical errors that occur during the export/import process.

Obviously the model needs to be implemented in order to be improved the energetic analysis, avoiding errors related to export/import steps.

Concluded the first analysis, it is possible to search various hypotheses of redevelopment through an iterative process of calculations. Of course, the results will prove to be the best tradeoff between the intervention costs and the obtained benefits.

Another important result that can be achieved during future development of research is the possibility to use of new ICT tools, such as the augmented reality, for quickening the view of energetic data of the internal environment of the building using a portable device. The augmented representation is not only a mere picture of the system but it could be used as an active tool in the maintenance stage and in the structural, and energetic, redevelopment of the building.

The final goal is that this methodology can be adopted with sufficient easiness, defining the intervention criteria for the redevelopment of existing buildings in terms of energy, systems, structural and architectural.

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DIMCloud: a distributed framework for district energy simulation and management

Francesco G. Brundu[1], Edoardo Patti[1], Matteo Del Giudice[2], Anna Osello[2], Enrico Macii[1], and Andrea Acquaviva[1]

[1] Dept. of Control and Computer Engineering,
[2] Dept. of Structural, Construction and Geotechnical Engineering,
Politecnico di Torino, Italy.
{francesco.brundu,edoardo.patti,matteo.delgiudice,anna.osello,enrico.macii,andrea.acquaviva}@polito.it

Abstract. To optimize energy consumption, it is needed to monitor real-time data and simulate all energy flows. In a city district context, energy consumption data usually come from many sources and encoded in different formats. However, few models have been proposed to trace the energy behavior of city districts and handle related data. In this article, we introduce DIMCloud, a model for heterogeneous data management and integration at district level, in a pervasive computing context. Our model, by means of an ontology, is able to register the relationships between different data sources of the district and to disclose the sources locations using a publish-subscribe design pattern. Furthermore, data sources are published as Web Services, abstracting the underlying hardware from the user's point-of-view.

Key words: Smart City, middleware, Ubiquitous Computing, Pervasive Computing, Internet of Things, District

1 Introduction

A single district and urban model is necessary for many purposes, including: i) design or refurbishment of buildings; ii) maintenance and monitoring of energy consumption; iii) data visualization for increasing user awareness. Unfortunately, the design of such model is more difficult than collecting and analyzing data. For example, the different technologies used to collect such data produce heterogeneous information, which is difficult to integrate. Moreover, data coming from different platforms are encoded with a specific data format, and therefore not portable. Furthermore, data is usually stored in different locations and accessed using different protocols.

A common scenario involves different technologies. For instance, Building Information Model Systems (BIMs) [7] build a 3D parametric model of buildings, enriched with semantic information, such as measures, materials and costs [12]. On the other hand, Geographic Information Systems (GISs) [16] map the geographical location of buildings, energy distribution networks or other elements (such as smart meters). GISs are used for data automation and compilation, management, analysis and modeling of advanced cartography [5]. Finally, it is possible to have System Information Models (SIM) databases, to outline the structure of energy distribution networks with a 3D parametric model, and measurements databases, to store data collected by sensors.

In addition, a district model must satisfy the following constraints: (i) the use of underlying hardware (e.g. sensors) must be transparent from the user's point-of-view; (ii) each data source must be able to be registered into the system without needing to restart the whole infrastructure; (iii) the system must communicate by means of shared open protocols; (iv) the system must handle the data integration; (v) the data format must be open and independent from data source.

Currently, we believe there is a lack of interoperability, regarding information exchange, in district information management. Hereby we propose a distributed infrastructure for district management, which integrates and interconnects different models [6] and data sources, and delivers information by means of Web Services. This article is organized as follows: Section 2 presents the state-of-art in the fields of heterogeneous devices integration and BIM/GIS integration. Section 3 introduces the DIMCloud concept, outlining the different aspects of the system. Finally, Section 4 reports conclusions and future directions.

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2 Background

Nowadays, one of the major challenges in Ubiquitous Computing and Internet of things concerns the interoperability between heterogeneous devices. Considering a district context, this problem is even more challenging. However, middleware technologies and Services Oriented Architectures (SOA) [11] can be considered as the key issue to provide low-cost integration for enabling the communication between such heterogeneous devices. In the context of big environments, such as buildings and public spaces, middleware technologies should implement the abstraction software layer, which is the key issue to achieve a true interoperability between heterogeneous devices. In addition, they should also integrate the already existing and deployed Building Management Systems. The authors of [2] developed a modular open infrastructure, which is a complete SOA ecosystem designed to provide the capabilities of the integrated embedded devices. Finally, Stavropoulos et al. [15] introduces the aWESoME middleware, which provides uniform access to the heterogeneous Wireless Sensor and Actuator Networks (WSAN), enabling fast and direct discovery, invocation and execution of services.

Several concepts have been proposed to integrate heterogeneous data and to promote information exchange. For instance, [9] integrated BIM and GIS data to provide a Supply Chain Management framework for Construction. In this case, the BIM model traced cost and materials, while the GIS model minimized the logistics costs. Microsoft Access was used for information exchange. The authors of [4] proposed the USIM concept, an Indoor GIS Building Information Model for context-aware [3] applications. The compatibility was achieved following the IFC standard. In [8] the integration of GIS and BIM models optimized the installation of tower cranes. The GIS model located tower cranes to minimize conflicts between them. On the other hand, the BIM model represented each tower crane area to check the spatial coverage of the system, and was used to estimate the operator point-of-view. The BIM model was exported using a database (e.g. with Microsoft Access). In [10] the authors used Schema-Level Model Views, i.e. partial sub-models taken from the BIM (IFC) model and translated to the geo-spatial context into a ESRI Geodatabase (geo-spatial[1] database) or a ESRI Shapefile (a file format used to represent the geo-relational model[2]).

On the other hand, from the district energy consumption point-of-view, [17] introduced the CDIM (City District Information model) concept, which aim at integrating and managing data, to support the conception and the simulation of district energy consumption. CDIM integrates data by means of object-relational databases.

In our work, we propose a framework for simulation and visualization of energy consumption in a district context, by means of middleware and SOA concepts. To achieve it, the framework enriches BIM and SIM with real-time data collected by devices deployed in buildings and energy distribution networks.

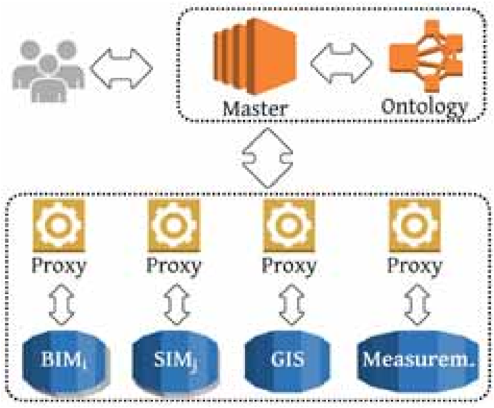
3 Distributed Framework for District Energy Simulation and Management

In a Smart Cities context, we designed our concept DIMCloud (District Information Model Cloud) to ease the visualization and simulation of energy consumption in a city district. DIMCloud (depicted in Figure 1(a)) links the district energy consumption data with semantic and geographic information, such as the building in which the data has been collected. In this way, it is possible to monitor in real-time the district as a whole or with a more fine-grained perspective, e.g. each single house, abstracting the pervasive distributed infrastructure of sensors. DIMCloud abstracts data sources by means of a set of specific proxies, contained in the data layer. Each proxy responds to data requests retrieving the correspondent data, adapting them to a district context (for instance, labeling them as belonging to a specific building) and converting them to a shared unique format. There are two types of proxy: Device-proxy, if data comes from a device (see Section 3.1), Database-proxy, if data comes from a database (see Section 3.2). The requests enter the integration layer and are dispatched to the

[1] `http://support.esri.com/en/knowledgebase/GISDictionary/term/geospatial+technology`

[2] `http://support.esri.com/en/knowledgebase/GISDictionary/term/georelational+data+model`

correct proxy by the cloud's master node, as shown in Figure 1(a). The references between different databases are modeled by means of an ontology and are exploited by the master node during the integration of different data (for instance, to integrate the data of a building with its geographical location and sensors measurements).



(a) DIM Cloud schema

(b) Device-Proxy schema

Fig. 1. Framework for energy simulation and management in the district.

DIMCloud exploits the SEEMPubS service-oriented middleware [13]. It provides components, called managers, to develop distributed software based on both user-centric and event-based approaches. SEEMPubS, thanks to the *Network Manager*, is in charge to establish a peer-to-peer communication across the different entities in the middleware network. The SEEMPubS event-based approach is given by the *Event Manager*, which implements a publish/subscribe model. Hence, the middleware allows the development of loosely-coupled event-based systems removing all the explicit dependencies between the interacting entities. Finally, the concept of SEEMPubS *Proxy* [14] has been extended to enable the interoperability between heterogeneous devices and also to integrate the different databases, as described respectively in Section 3.1 and 3.2. It abstracts and eases the integration of a specific technology, device or service into a SEEMPubS application providing Web Services and registering it at a Network Manager.

3.1 Enabling Interoperability Across Heterogeneous Devices

Figure 1(b) summarizes the schema designed to implement the Proxy, which integrates heterogeneous devices into the DIMCloud and enables the interoperability between them. The Device-Proxy is a service layer for abstracting the underlying heterogeneous wireless and wired technologies. Different Device-Proxies, one for each considered technology, were developed to provide the following main features:

- enabling the integration of heterogeneous devices and interfacing them to the whole proposed infrastructure by means of Web Services, through which access sensor data;
- collecting environmental data coming from sensor nodes into a local database, which can be accessed in an asynchronous way and protected against network failures;
- pushing environmental information into the infrastructure via an event-based approach, thanks to the Event Manager;
- allowing the remote control of actuator devices.

Therefore, the Device-Proxy, as shown in Figure 1(b), is a software which communicates directly with the heterogeneous networks and consists of three layers. The dedicated Interface, the lowest layer, directly receives all the incoming data from the devices, regardless of communication protocols, hardware or network topology. Each technology needs a specific software Interface, which interprets environmental data (e.g. Temperature, Humidity, Power Consumption, etc.) and stores them in an integrated database, which is in the second layer. Since data are stored locally, the database makes the whole infrastructure flexible and reliable with respect to backbone network failures. Finally, the SEEMPubS Web Services layer interfaces the different technologies to other components of the infrastructure, easing remote management and control, and enabling the interoperability between heterogeneous devices. From this layer, trough the Event Manager, real-time data collected by sensors are sent to other applications, such as the *Measurements Database*, which collects data coming from the district's devices.

In particular, we developed proxies for IEEE 802.15.4, ZigBee and EnOcean protocols, which are wireless technologies. Moreover, about wired technologies, it was developed a specific proxy to allow the interoperability with the OPC Unified Architecture[3], which incorporates all the features provided by different standards, such as SCADA or BACnet.

3.2 Abstracting Underlying Data Sources

Different databases store district data. Unfortunately, the integration to a unique database is not feasible, because of heterogeneity (different formats) and conflicting values (the same key can be used to identify different objects in different databases). Furthermore, the update of such database would be laborious.

In our distributed infrastructure, each database is accompanied with an interface (Database-proxy), which provides data retrieval from the database publishing a Web Service. Simultaneously, a master node of the infrastructure stores the relationships between the available proxies into an ontology. In this way, the user queries a single entry point (the master node) to receive proxies URIs. Afterwards, s/he receives the Web Service URIs of the proxies and the relationships between them. Finally, s/he retrieves the data using the proxies' Web Services and is able to integrate them.

[3] `https://www.opcfoundation.org/UA/`

3.3 Information Modeling and Data Export

To export the models behind the Database-proxies in the DIMCloud, it was necessary to use Autodesk Revit and ESRI ArcGIS 10. The Level of Development and the Level of Detail were carefully chosen before the modeling step, referring to the American Institute of Architects (A.I.A.)[4]. In Revit we developed the model of the building with *Local Masses*. Afterwards, we enriched the BIM model with semantic information. The building and the context models were oriented and located appropriately. In addition, more informations could be inserted using *Shared parameters*. Working on ArcGIS, we defined the geographic coordinates' system and we made shapefiles (.shp) of buildings and of addresses. Shapefiles are used to store non-topological geometries and attribute informations [1], such as construction typology or data, and were developed to describe the GIS model.

Parametric models need an export / import process, to share data between different applications. Therefore, several formats have to be tested to avoid errors and data losses. For instance, IFC[5] and CityGML[6] are two predominant standard exchange formats in the building industry. We decided to export BIM and GIS models by means of relational databases.

3.4 Exploiting Ontologies to Relate District Entities

When the master node search for the Web Service's URI of data source, it refers to an ontology. The ontology stores a model for the whole district. This model is a tree, in which the root node identifies the district and its global properties (e.g. Web Services for GIS Database-Proxy URI), and defines the relationships between different data sources. In the ontology each node connected to the root node describes a building or an energy distribution network, and it is labeled with a unique id. Each node stores:

– the Web Service's URIs for both BIM or SIM Database-Proxy;
– the ID of the BIM or SIM in the GIS Database-Proxy;
– a dictionary containing, for each sensor, its ID in the measurements' database.

Figure 2 depicts the ontology's schema. From the root node, it is possible to reach every data source in the district. Each found leaf node discloses the necessary references to query the related data sources.

3.5 Use Case: District Data Query

Figure 3 depicts the sequence diagram to retrieve the data related to a district, which can include real-time measurements, BIM and SIM models for N selected buildings and energy distribution networks respectively. The Client, for instance an application for simulation or data visualization, asks the Master (step 1) for

[4] `http://www.aia.org/groups/aia/documents/pdf/aiab095711.pdf`
[5] `http://www.buildingsmart.org/standards/ifc`
[6] `http://www.citygml.org`

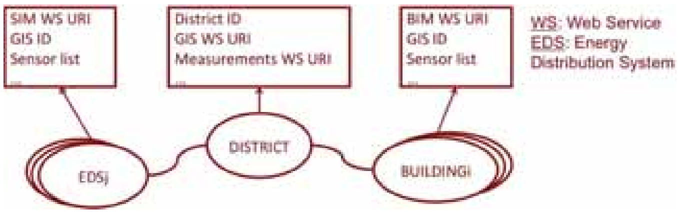


Fig. 2. Ontology schema

data and Web Services URIs (proxies). The Master checks the ontology and returns (2) all the information for the requested GIS, BIM, SIM and their relative measurements. In (3) the Client asks for geographical data for the required BIM and SIM IDs to the GIS proxy, which responds in (4). Afterwards, the Client retrieves measurements data from the Measurements Proxy (5, 6). Finally, in (7) and (8), in (9) and (10) and, generically, in (BRn) and (BSn) and in (SRn) and (SSn), the Client retrieves the data from the N BIM and SIM models invoking the Web Services for the related proxies.

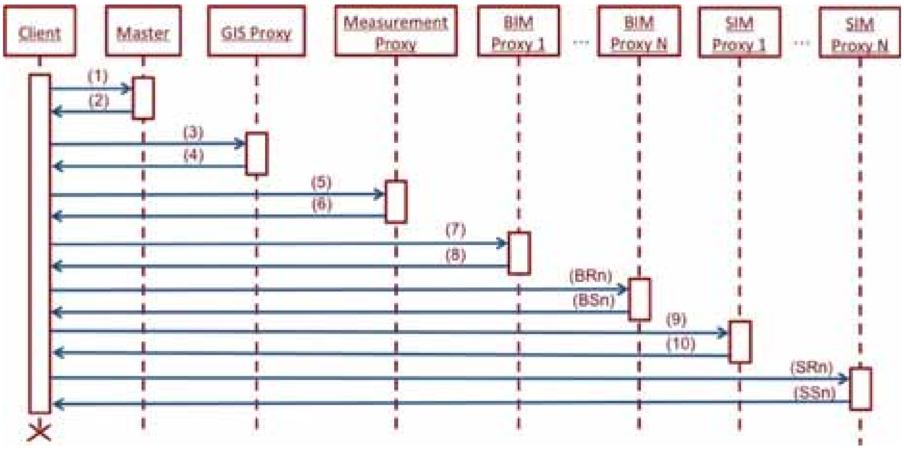


Fig. 3. District data query sequence diagram

4 Conclusions

The CDIM approach [17] showed that a district-based simulation can be beneficial to optimize energy consumption, with respect to BIM simulations. In our work, we introduced a different model for the district, i.e. DIMCloud, in which each data source is reachable by means of a Web Service proxy. The underlying hardware is available as a service, and the user can query in the same way heterogeneous sources, to monitor real-time energy consumption in the district.

We think that the proposed system can be of crucial importance to manage district energy data, in order to develop energy consumption awareness and sustainability in smart district scenarios.

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BIM e GIS per la metodologia DIMM(ER)

BIM and GIS for the DIMM(ER) methodology

Anna Osello, Giuseppe Moglia*, Matteo Del Giudice*, Cristina Boido**

Vi è una forte necessità di un nuovo apparato grafico urbano in grado di effettuare analisi di performance dei modelli focalizzati sugli sviluppi sostenibili delle città intelligenti. Questa ricerca esplora l'uso del BIM, del GIS e di altri strumenti per consentire agli stakeholders di gestire ed utilizzare grandi quantità di diversi tipi di dati per comprendere intuitivamente le caratteristiche di rendimento energetico a livello urbano. I risultati mostrano che il prototipo in fase di sviluppo consentirà (i) la manipolazione in tempo reale dei dati in vari strumenti grazie all'interoperabilità e (ii) la visualizzazione interattiva dei dati grazie alla realtà virtuale ed aumentata.

Parole chiave: BIM, GIS, interoperabilità, database, riduzione del consumo energetico.

There is a significant need for a new graphical urban apparatus able to carry out performance analyses of the models focused on the sustainable developments of the smart cities. This research explores the use of BIM, GIS and other tools to enable stakeholders to manage and use big quantities of different kind of data in order to intuitively understand the characteristics of the energy performance at urban level. The results show that the prototype under developing will enable (i) real-time manipulations of the data in different tools thanks interoperability and (ii) interactive visualization of the data thanks virtual and augmented reality.

Key words: BIM, GIS, interoperability, database, energy reduction.

Introduzione

Il Building Information Modelling (BIM) e il Geographic Information System (GIS) negli ultimi anni hanno ricevuto molta attenzione in relazione alla loro capacità di gestire una grande quantità di dati, che può offrire importanti benefici economici a livello edilizio ed urbano, grazie ad una ottimizzazione dei processi basata sull'interoperabilità.

Il BIM è un metodo che si basa su un modello digitale di un edificio (BIM) contenente qualsiasi/tutte le informazioni riguardanti la costruzione. Oltre ai contenuti del modello basati sugli oggetti 3D parametrici, il modello può contenere informazioni storiche (fasi), materiali, costi, parametri strutturali ed energetici e così via. Un GIS integra hardware, software e dati per l'acquisizione, la gestione, l'analisi e la visualizzazione di tutte le forme di informazioni geograficamente referenziate. L'interoperabilità individua la necessità di passare automaticamente i dati senza perdere informazioni tra applicazioni.

Il BIM, il GIS e l'interoperabilità hanno molti usi possibili a livello architettonico ed urbano per il risparmio energetico come dimostrato dalla letteratura internazionale. Tuttavia, essi risultano ancora troppo deboli per essere utilizzati correttamente e in maniera avanzata come strumenti comuni per una grande quantità di stakeholders (architetti, ingegneri e facility o energy managers, etc.). Un modo per risolvere questo problema è quello di utilizzare le Tecnologie dell'Informazione e della Comunicazione (ICT) per il settore della sostenibilità ambientale, in collaborazione con il settore delle costruzioni per promuovere l'interoperabilità tra gli strumenti di auditing ed i sistemi per la costruzione e la gestione dell'energia, con l'obiettivo di sviluppare una comprensione sistematica della prestazione energetica di un edificio/quartiere/città. Questo è proprio uno degli obiettivi principali del progetto District Information Modelling and Management for Energy Reduction (DIMMER).

Sulla base del progetto DIMMER vi è l'opportunità di sviluppare una modellazione 3D avanzata, come elemento di base per le tecnologie di visualizzazione e di interazione in grado di ottimizzare l'utilizzo dei dati a scala edilizia ed urbana per gestire e promuovere comportamenti di utilizzo efficiente dell'energia. Per sbloccare le potenzialità

Introduction

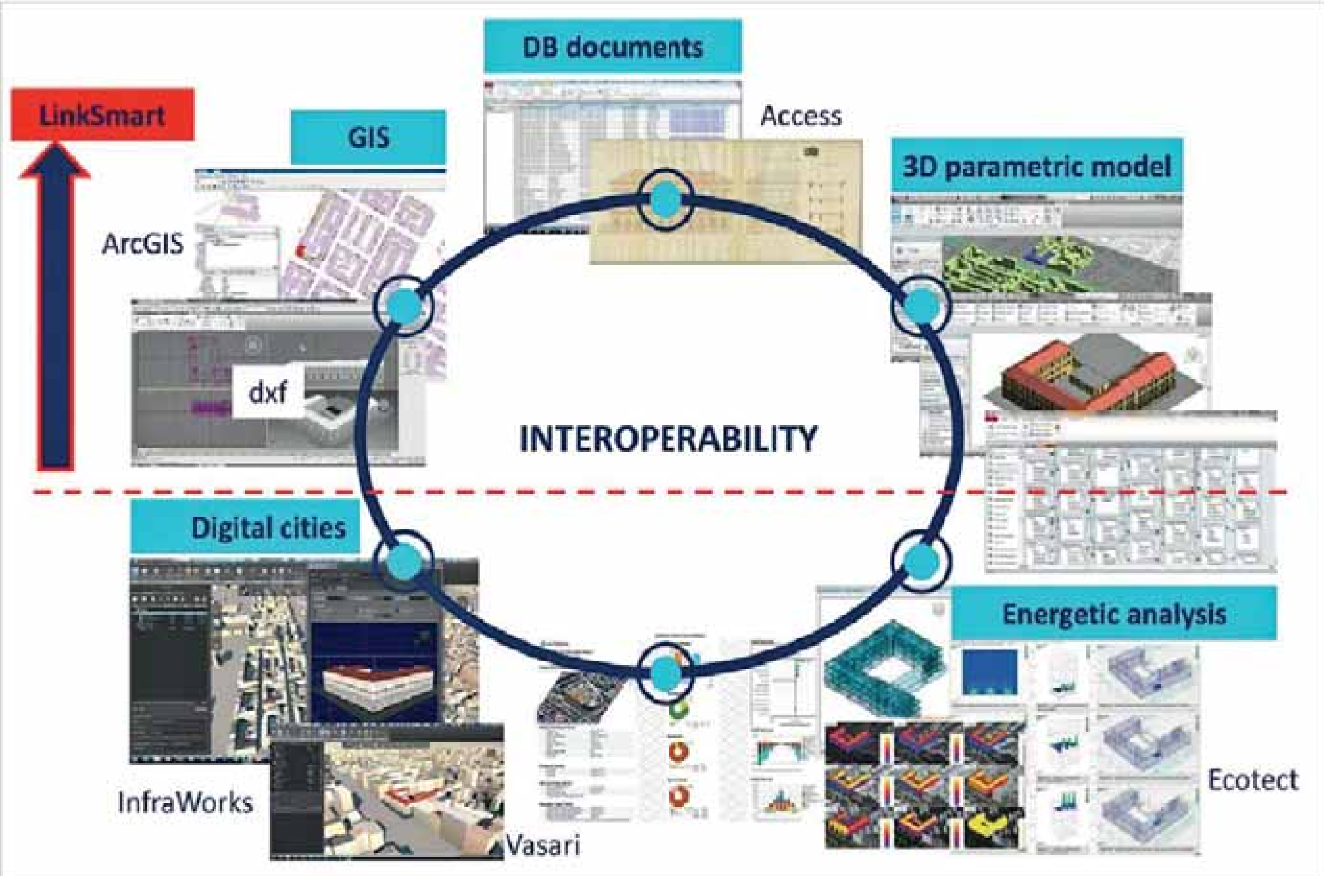
Building Information Modelling (BIM) and Geographic Information System (GIS) have received much attention in recent years due to their capability to manage a large amount of data, which can offer important economic benefits at building and urban level, thanks an optimization of the processes based on interoperability.

BIM is a method that is based on a Building Information Model (BIM) containing any/all information about the construction. In addition to the contents of the 3D parametric objects-based model, it may contains historical information (phases), materials, costs, structural and energetic parameters and so on. A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. Interoperability identifies the need to pass data automatically without losing information between applications.

BIM, GIS and interoperability have many possible use at architectural and urban levels for energy saving as demonstrated by the international literature. However, they are still too weak to be used correctly and in an advanced way as common tools for a large amount of stakeholders (architects, engineers and facility or energy managers, etc.). One way to solve this problem is to use Information and Communication Technologies (ICT) for environmental sustainability sector, working together with building and construction sector to promote interoperability between auditing tools and building and energy management systems, with a view to developing a systematic understanding of a building/district/city's energy performance. This is exactly one of the main goals of the District Information Modelling and Management for Energy Reduction (DIMMER) project.

On the basis of the DIMMER project there is the opportunity to develop an advanced 3D modeling, as basic element for visualization and interaction technologies able to optimize the use of the data at building and urban level to manage and to promote energy efficient behaviors. To unlock the potentiality of these technologies, the DIMMER project focuses on: (i) interoperability of district energy production and consumption, (ii) environmental conditions and user feedback data; (iii) exploitation of effective visual and web-based in-

1/ Tipologia dei dati e scambio delle informazioni sul base interoperabile. *Typology of the data and exchange of the information on interoperable basis.*



di queste tecnologie, il progetto DIMMER si concentra su: (i) interoperabilità di produzione e consumo energetica a livello di quartiere, (ii) condizioni ambientali e dati di feedback da parte degli utenti; (iii) utilizzo di interfacce visive basate sul web, efficaci per fornire un feedback pervasivo e in tempo reale in merito all'impatto energetico dei comportamenti degli utenti; (iv) integrazione dei Building Information Models (BIMs) con dati in tempo reale e loro estensione a livello di quartiere (DIM – District Information Model); (v) nuovi modelli di business per operatori energetici e prosumers, sfruttando l'utilizzo di diversi profili di utenti dell'energia.

Questo articolo presenta i risultati preliminari del progetto DIMMER[1] relativi alla modellazione parametrica 3D e allo scambio dei dati basato sull'interoperabilità tra BIM (Revit), GIS (ArcGIS) e software per le simulazioni energetiche (ad esempio Ecotect e Vasari), e per la visualizzazione dei dati alla scala urbana (Infraworks). Per essere in grado di gestire tutti i diversi tipi di dati, un insieme di databases (DB – Access) è in fase di implementazione e test.

terfaces to provide pervasive and real-time feedback about energy impact of user behaviors; (iv) integration of BIMs (as Building Information Models) with real-time data and their extension at the district level (DIM – District Information Model); (v) new business models for energy traders and prosumers exploiting different user energy profiling.

This paper presents the methodology under testing in DIMMER and preliminary[1] results on 3D parametric modeling and data exchange based on interoperability between BIM (Revit), GIS (ArcGIS) and software for energy simulations (e.g. Ecotect and Vasari) and for urban data visualization (Infraworks). In order to be able to manage all the different kind of data, a set of databases (DB – Microsoft Access) is under implementation and test.

At the moment, as results of the interdisciplinary activities, BIM and GIS are overlapped allowing users to manage architectural and urban data at the same time in order to be used as tools for energy management in real time at district level.

2/ Visualizzazione dei documenti d'archivio caricati sul sito web di Flikr.

Visualization of the district under study in ArcGIS.

Al momento, come risultato delle attività interdisciplinari, il BIM e il GIS sono sovrapposti, consentendo agli utenti di gestire contemporaneamente dati alla scala architettonica ed urbana, in modo tale da essere utilizzati come strumenti per la gestione dell'energia in tempo reale a livello di quartiere.

Metodologia

I modelli 3D delle città sono attualmente dispersi in diversi settori pubblici e privati in diversi sistemi, diversi modelli concettuali, diversi formati di dati, diversi schemi di dati, diversi livelli di dettaglio di diversa qualità. Inoltre, il potenziale dei modelli 3D va oltre la visualizzazione di oggetti 3D di scene virtuali di veri e propri modelli 3D della città, grazie al BIM. In tale contesto, l'integrazione di diverse fonti di dati per la costruzione di modelli 3D reali della città diventa più difficoltosa. Il progetto DIMMER utilizza un caso studio a Torino che è il quartiere adiacente al campus del Politecnico di Torino, caratterizzato da edifici omogenei, prevalentemente residenziali, costruiti a partire dal IX secolo.

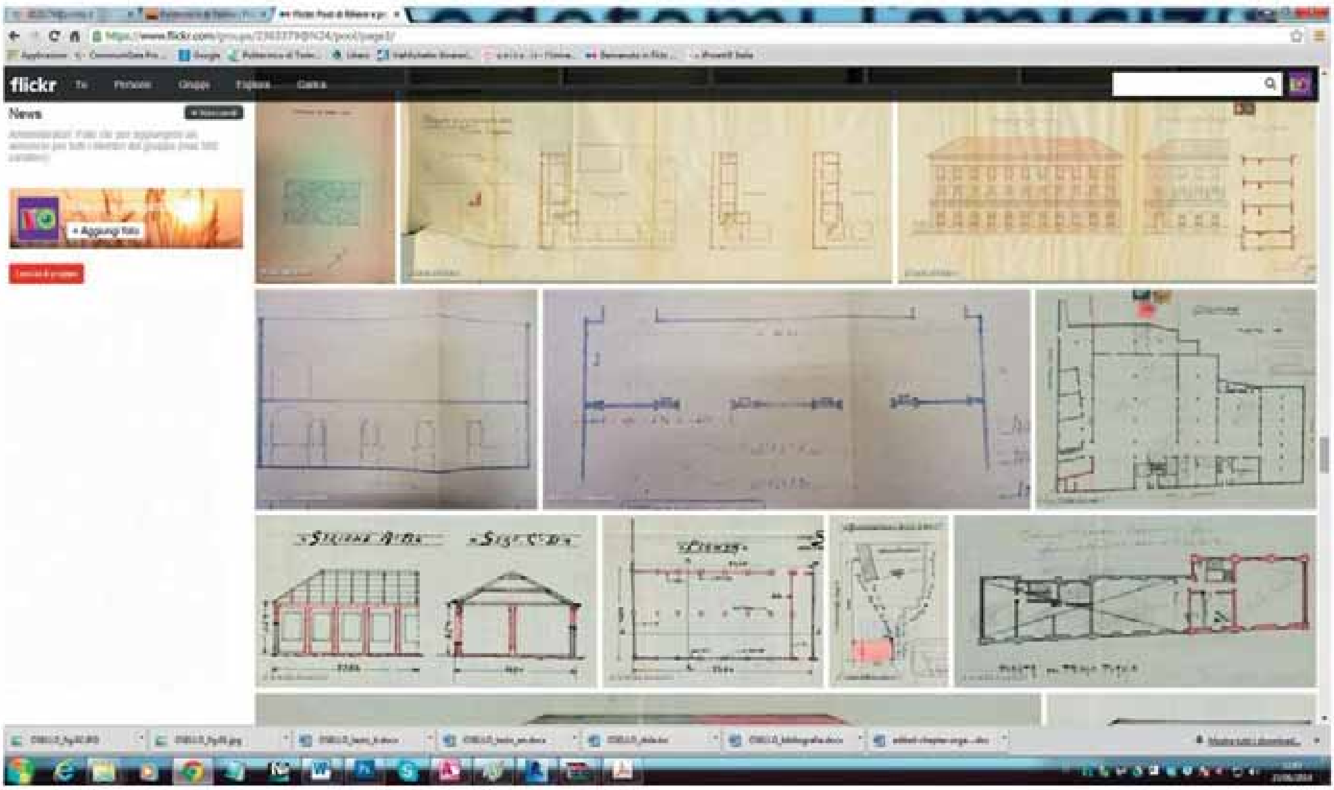
DIMMER, parte dal concetto che il BIM potrebbe contenere tutte le informazioni relative agli edifici, comprese le caratteristiche fisiche e funzionali e le informazioni relative al ciclo di vita, in una serie di

Methodology

3D city models are presently scattered over different public and private sectors in different systems, different conceptual models, different data formats, different data schemas, different levels of detail and different quality. In addition, the potential of 3D models goes beyond visualization of 3D objects of virtual scenes to real 3D city models, thanks BIM. In such an environment, integration of different sources of data for building real 3D city models becomes more difficult. The DIMMER project uses a case study in Turin that is a district near Politecnico di Torino main campus, characterized by homogenous constructions (mainly residential) built from IX century.

DIMEMR starts from the concept that BIM could carry all the information related to the buildings, including physical and functional characteristics, and project life cycle information in a series of 'smart objects'. So, by using BIM-based methods, stakeholders will be able to take more and better decisions earlier in the life cycle of a built facility thereby reducing costs, delivery time and environmental impact as well as improving communication, productivity and quality, both at building and urban level.

On this topic, the methodology of the DIMMER project provides several phases, each one characterized by specific tool as described below



"oggetti intelligenti". Pertanto, utilizzando metodi basati sul BIM, gli stakeholders saranno in grado di prendere maggiori e migliori decisioni nelle fasi iniziali del ciclo di vita di un edificio riducendo così i costi, i tempi e l'impatto ambientale e migliorando la comunicazione, la produttività e la qualità, sia a livello edilizio che urbano.
A questo proposito, la metodologia del progetto DIMMER fornisce diverse fasi caratterizzate ciascuna da uno strumento specifico come descritto di seguito e mostrato in Figura 1. Due sono i principali problemi che devono essere risolti: il primo è legato ai contenuti che devono essere definiti per ogni fase; il secondo è legato al sistema di comunicazione che deve essere basata sull'interoperabilità.

DBs dei documenti
Descrivere una realtà complessa come quella relativa ad un quartiere di una città necessita un sistema informativo in grado di gestire una grande quantità di dati di natura differente in grado di rappresentare e sintetizzare le caratteristiche del contesto.
Per il progetto DIMMER è stato impostato un DB con Microsoft Access partendo dalla creazione della tabella " Registry", contenente i dati generali di ogni edificio, localizzato in un isolato, che può essere composto da più volumi realizzati nella rappresentazione parametrica[2].
Successivamente, la completezza delle informazioni urbane ha comportato la catalogazione dei dati storici derivanti dai documenti d'archivio attraverso la tabella "Archival documents". Al fine di raccogliere e visualizzare alcune immagini rappresentative dei documenti storici è stato creato un campo specifico all'interno di questa tabella e ogni immagine è stata inserita sul sito web di Flickr[3] come visibile in Figura 2. Ovviamente, per ogni immagine è stato assegnato un codice univoco in grado di relazionarsi con l'edificio preso in considerazione.
Inoltre, sono state create ulteriori tabelle come "tab_streets type", "tab_streets" e "tab_city" per facilitare l'inserimento dei dati nella tabella "Registry" attraverso lo strumento casella combinata Combo.
La struttura su cui si è basato il DB è stata pensata per consentire una successiva implementazione attraverso l'aggiunta di un numero infinito di tabelle relative ad informazioni diverse a seconda dei possibili approfondimenti legati alla conoscenza del quartiere come ad esempio il tema del risparmio energetico o quello della sicurezza.
Attualmente il DB necessita di ulteriori sviluppi come ad esempio la realizzazione di maschere che possano aiutare il professionista a compilare agevolmente l'archivio; inoltre, la relazione tra le diverse tabelle dovrà essere ulteriormente testata e migliorata con tutti i dati necessari per il progetto DIMMER. Per questa ragione, l'elaborazione di codici in grado di individuare in modo univoco la cellula edilizia di riferimento, i volumi che la compongono, e i documenti che la caratterizzano è in fase di arricchimento, in vista del futuro collegamento con il modello parametrico realizzato con Autodesk Revit. L'obiettivo principale di questo lavoro è che il collegamento di diversi DBs consente ai professionisti coinvolti nel processo edilizio di testare la metodologia BIM relativa alla gestione degli edifici esistenti partendo dall'acquisizione dei dati, attraverso la ricerca dei documenti d'archivio e varie tecniche di rilievo.

and shown in figure 1. Two are the main problems that must be solved: the first one is related to the contents that have to be defined for each phase; the second one is related to the communication system that has to be based on interoperability.

DBs of the documents
Describing a complex reality such as a district in a city needs an information system able to manage a large quantity of different data, as the historical one, which have to represent and synthetize the area's characteristics.
For the DIMMER project a DB has been set with Microsoft Access starting from the creation of the "Registry" table, containing general data relating to any building that makes up the block and that can be composed of multiple volumes modeled with a parametric software[2].
Afterwards, the completeness of urban information involved the cataloging of historical data derived from the archival documents through the "Archival documents" table. To be able to collect and visualize the raster images of the historic documents a specific field was created and each image has been inserted on the Flickr web site[3] as visible in Figure 2. Of course, for each picture was assigned a unique code that can relate the image to reference building.
In addition to this, other tables such as "tab_streets type", "tab_streets," and "tab_city" have been created to facilitate the data entry in in the "Registry" table using the Combo box tool.
The structure of this DB has been designed for future implementations through the addition of an infinite number of tables relating to different kinds of information depending on the possible themes related to the knowledge of the neighborhood such as the issue of energy savings or security.
At present the DB requires some improvements such as the creation of forms that facilitate the fill of data into the archive; moreover, the relationship between the various tables should be further tested and improved with all data required for the DIMMER project. For this reason, the codes development that allows uniquely identification of the building unit, the volumes that compose it and the documents that characterize it are under enrichment for the future connection with the 3D parametric model created with Autodesk Revit. The main goal of this work is that the connection of different DBs allows the professionals involved in the building process to test the BIM methodology on the management of existing buildings starting from the data acquisition, through the archival documents research and various techniques of survey.

3D parametric model
Since the beginning of the DIMMER project a 3D parametric model able to explicit geometric and alphanumeric data has been done using Autodesk Revit. This model is required because when different professional (like architects and engineers) create objects in the parametric environment at the same time a relational database is automatically generated. In this case the model has been customized using shared parameters to give to each block a unique code extracted by information system of the city

3/ Modello parametrico del quartiere Crocetta realizzato con Autodesk Revit. *Parametric model of the Crocetta district made with the software Autodesk Revit.*

Modello parametrico 3D

Fin dall'inizio del progetto DIMMER un modello parametrico 3D in grado di esplicitare dati geometrici e alfanumerici è stato realizzato utilizzando il software parametrico Autodesk Revit. Lo sviluppo del modello è dovuto al fatto che quando diversi professionisti (come ad esempio architetti ed ingegneri) creano oggetti nell'ambiente parametrico, contemporaneamente viene popolato un DB relazionale. In questo caso il modello è stato personalizzato utilizzando i parametri condivisi per dare ad ogni volume un codice unico estratto dal sistema informativo della città di Torino. Ogni isolato è stato descritto da un'analisi volumetrica, visibile in Figura 3 attribuendo a ciascun piano un'altezza media di tre metri. Ogni edificio è stato modellato con lo strumento "massa"[4].

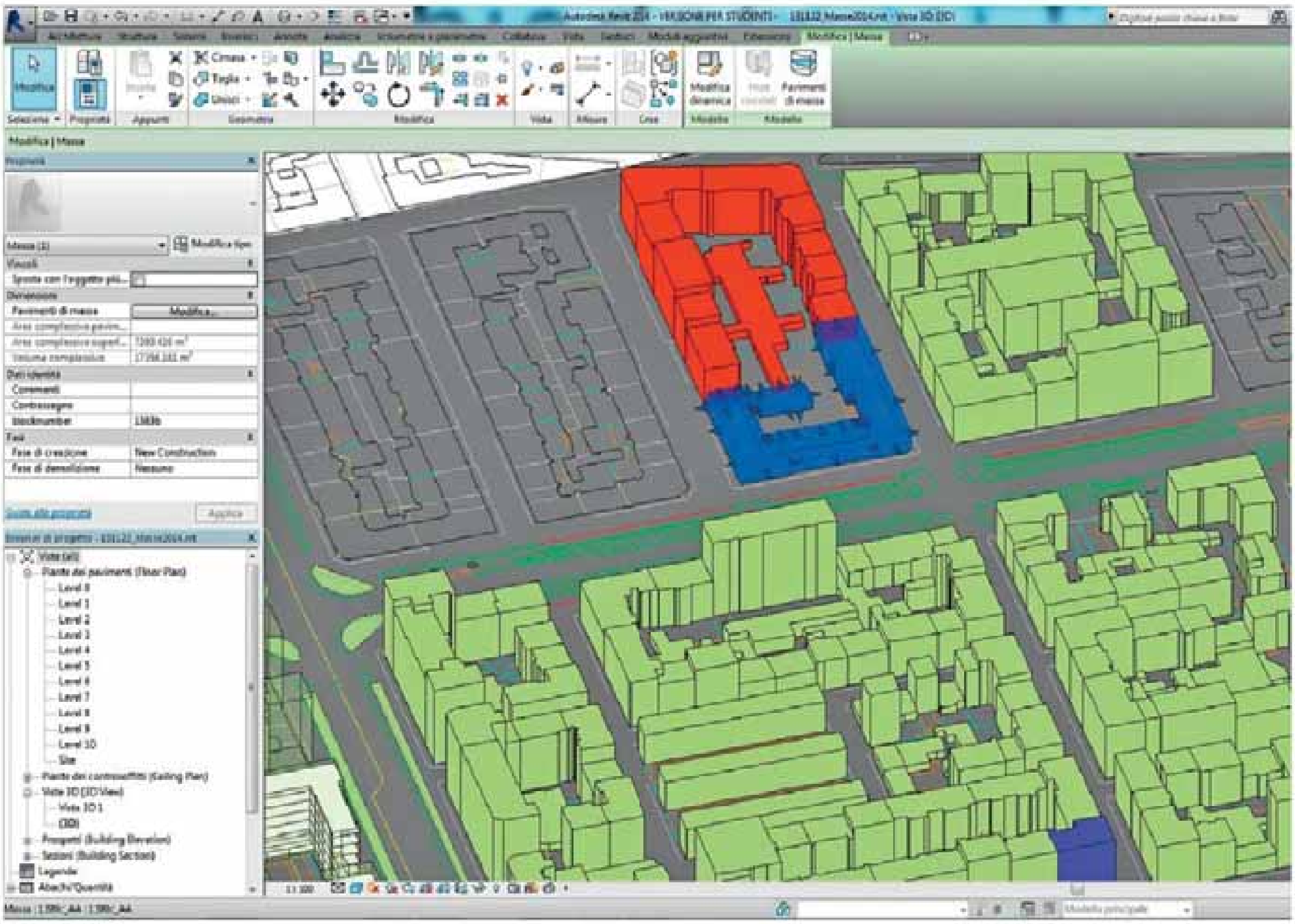
I parametri condivisi sono stati inseriti per collegare il DB grafico come modello parametrico 3D con gli altri DBs quali il DB storico ed il DB modello GIS che hanno gli stessi campi in comune.

of Turin. Each block has been described by a volumetric analysis as visible in Figure 3, attributing to each plan an average height of three meters and each building has been modelled using the "mass" tool[4].

The shared parameters were inserted to link the graphical database as the 3D parametric model with the other DBs such as the historic DB and the GIS model/DB which have the same fields in common.

Energetic analysis

The model described before has been used also to realize energetic simulations such as the lighting analysis of the internal and external part of some buildings of the district, like the primary school "Michele Coppino". Some test have been done using Autodesk Ecotect Analysis 2011 and Autodesk Vasari Beta 3. For this part of the work different interoperable processes have been followed using different standard exchange formats such as Industry Foundation Classes (IFC), dxf, green



4/ Esportazione da Revit in formato gbXML del Modello della scuola Coppino.
The model of Coppino School. Export file in gbXML format from Autodesk Revit.

Analisi energetiche

Il modello precedentemente descritto è stato utilizzato anche per sviluppare simulazioni energetiche come l'analisi illuminotecnica della parte interna ed esterna di alcuni edifici del quartiere, come ad esempio la scuola elementare "Michele Coppino". Alcune prove sono state sviluppate utilizzando Autodesk Ecotect Analysis 2011 e Autodesk Vasari Beta 3. Per questa parte del lavoro molti processi di interoperabilità sono stati eseguiti utilizzando formati standard diversi, come Industry Foundation Classes (IFC), dxf, green building XML (gbXML) visibile in Figura 4, etc. Questo è dovuto al fatto che in alcuni tipi di processi di importazione/esportazione molti dati vengono persi. Per questo motivo, risultava essenziale investigare il modo migliore per evitare la perdita delle informazioni.

GIS

Un modello urbano 3D può essere definito come la rappresentazione digitale della superficie terrestre e dell'ambiente costruito all'interno di una città. La realizzazione di questi modelli può essere ottenuta attraverso una varietà di applicazioni, considerando un modello generico urbano o un modello parametrico di un singolo edificio. L'aumento del livello di dettaglio dei modelli comporta un aumento delle relazioni spaziali tra oggetti e informazioni che sono contenute in ciascun modello. Attualmente, la realtà può essere rappresentata con due modalità diverse: il metodo BIM legato alla rappresentazione architettonica e il metodo GIS per le informazioni geografiche spaziali. Per questo progetto, contemporaneamente allo sviluppo del modello BIM, è stato sviluppato il modello GIS con la creazione di shapefile (.Shp) degli edifici, degli indirizzi relativi ad ogni edificio e della rete di distribuzione del teleriscaldamento del quartiere.
Allo stato attuale del progetto, è possibile visualizzare il modello del distretto usando differenti visualizzazioni interrogando il DB come mostrato in Figura 5.

Città digitale

Dopo lo sviluppo del modello BIM e GIS è sorta la necessità di collegare i due DBs. Utilizzando Autodesk Infraworks i due modelli parametrici sono stati sovrapposti per permettere agli utenti di visualizzare dati eterogenei con differenti livelli di dettaglio nello stesso ambiente. Questo dovrebbe diventare un utile strumento di gestione e pianificazione urbana.

Risultati e sviluppi futuri

Come mostrato in questo articolo, l'obiettivo di far interagire informazioni provenienti da raccolte finalizzate, organizzate secondo gerarchie interne, generate in epoche differenti, collegate a tradizioni documentarie basate su stratificazioni successive di novità e su progressiva implementazione dei dati, in funzione della evoluzione della realtà da documentare, impone di mettere in un sistema generale una serie di convenzioni già esecutive in organizzazioni amministrative locali. Tali informazioni sono eterogenee per fonte, per finalità, per elementi, per unità di misura, per precisione, per affidabilità.

building XML (gbXML) as visible in Figure 4, etc. This is due to the fact that in some types of import/export processes many data were lost, so it was essential to investigate the best way to avoid data loss.

GIS

A 3D city model can be defined as the digital representation of the earth's surface and of the built environment within a city. The realization of these models can be obtained through a variety of applications, considering the general city model or the parametric model of a single building. The increase in the level of detail of the models implies an implementation of the spatial relationships between objects and information that are contained in each of them. Currently, reality can be represented with two different systems: the BIM method tied to the architectural view and the GIS method for the spatial geographic information. For this project, simultaneously development of the BIM and the GIS models has been set with the creation of the shapefile (.shp) of the buildings, of the address of each building and the heating grids of the neighborhood.
At this stage of the project, it is possible to display the district model using different visualization querying the DB as shown in Figure 5.

Digital cities

After the development of the BIM and GIS models the need to link the two databases arose. Using Autodesk Infraworks the two parametric models have been overlapped to allow the visualization of heterogeneous data with different levels of detail in the same environment. This should become a useful tool for urban management and planning.

Results and future developments

As shown in this paper, the goal of interacting information from collections designed, arranged according to internal hierarchies, gener-

5/ Visualizzazione del quartiere oggetto di studio in ArcGIS. *Visualization of the studied district with the software ArcGIS.*

La formazione di un modello di livello (BIM per il livello edificio, DIM per il livello urbano, e così via a salire, e a scendere) può essere la strada per originare un prototipo valido per tutte le raccolte di informazioni finalizzate ad una utilizzazione particolare.

Per il DIM il riferimento per l'organizzazione della gestione dei dati va fatto alla definizione di distretto (che deve comprendere informazioni di significatività, di dimensione, di indipendenza) e a quella dell'unità che sommata *n* volte produce il distretto.

L'unità per l'organizzazione delle informazioni del DIM deve essere individuata al confine tra l'edificio (building), che si riconosce per la indivisibilità delle regole e dei servizi che lo fanno nascere e lo mantengono in vita, e tutto ciò che lo circonda, che lo contestualizza e che fa vivere la sua individualità di edificio. Il distretto si riconosce non solo come sommatoria di edifici ma come portatore di una nuova individualità, quella urbana, caratterizzata da un ordine di grandezza maggiore delle informazioni che lo definiscono.

Analogamente, il distretto è l'unità che deve essere individuata al confine tra quella parte di tessuto urbano che si riconosce per la indivisibilità delle regole e dei servizi che la fanno nascere e la mantengono in vita, e tutto ciò che lo circonda, che lo contestualizza e che fa vivere la sua individualità urbana. Il tessuto urbano si riconosce non

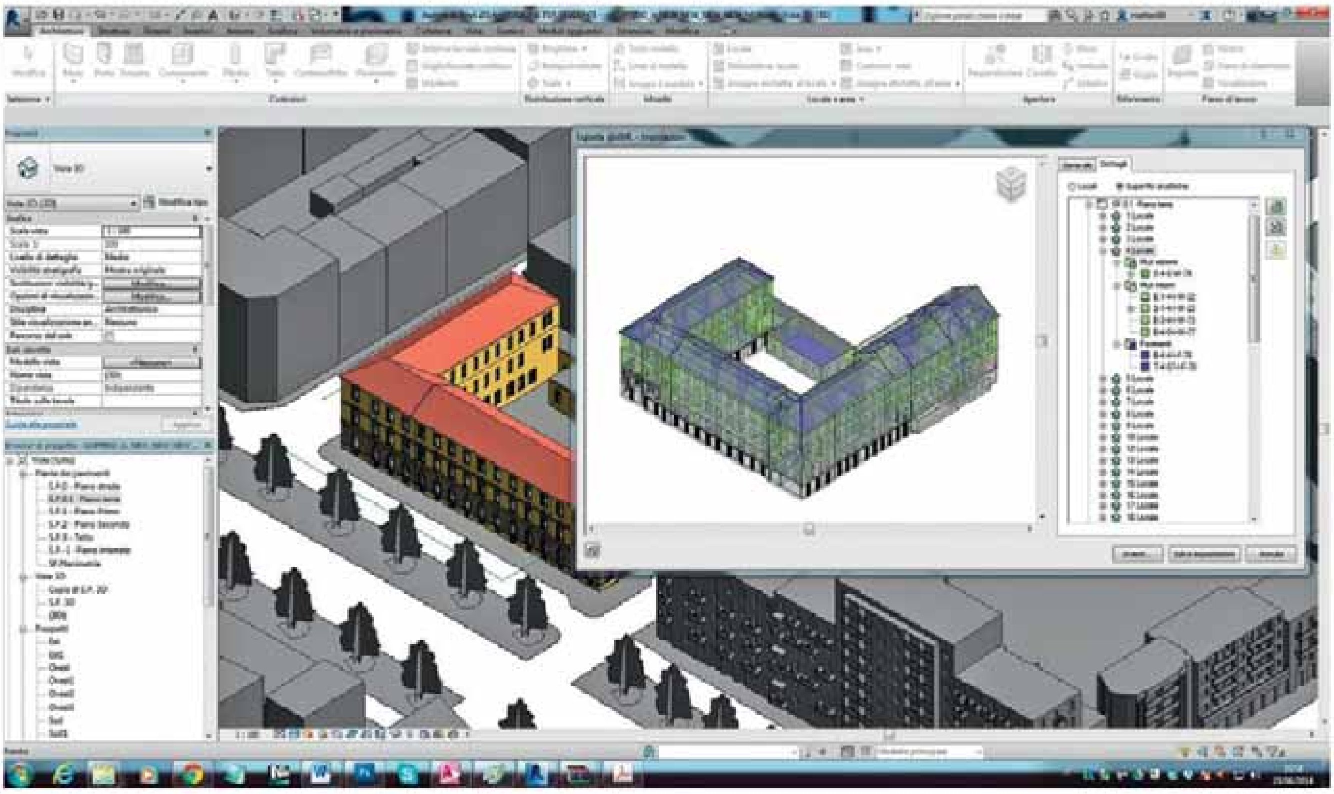
ated in different epochs, connected to documentary traditions based on successive layers of progressive news and data on implementation, depending on the evolution of reality to be documented, requires putting in a general system a series of conventions already enforceable in local administrative organizations. Such information is heterogeneous by source, for purpose, items, units of measure, accuracy, reliability.

The formation of a layer model (BIM for level building, DIM for level town, and so on up and down) may be the way to create a prototype for all collections of information aimed at a particular use.

To DIM the reference for the organization of data management is to the definition of district (which must include information of significance, size and independence) and to that of the unit that added *n* times yields the district.

The unit for the organization of information of the DIM must be identified at the boundary between the building, which is typified by the indivisibility of rules and services that arise it and keep it alive, and everything that surrounds it, that contextualizes it and that makes his individuality of building. The district can be seen not only as a sum of buildings but as the bearer of a new individuality, the urban one, characterized by a greater size of information that defines it.

Similarly, the district is the unit that must be located on the boundary



solo come sommatoria di distretti, e quindi dall'eliminazione dei confini tra i distretti, ma come portatore di una nuova individualità, quella territoriale, caratterizzata da un ordine di grandezza maggiore delle informazioni che lo costituiscono.

Alla fine del progetto il sistema DIMMER integrerà BIM e modelli 3D alla scala di quartiere con i dati provenienti dai sensori e dal feedback degli utenti per analizzare e correlare l'utilizzo degli edifici e fornire risultati in tempo reale sui comportamenti connessi al consumo energetico. Esso consentirà un accesso aperto con dispositivi quali tablet e smart phone attraverso la Realtà Aumentata (AR) alla visualizzazione delle informazioni relative all'energia agli utenti finali. Tali informazioni saranno relative ad analisi dei costi, pianificazione e valutazione delle tariffe, identificazione e manutenzione dei guasti e in generale, condivisione delle informazioni sul tema energetico. Tutte le seguenti tecnologie saranno incluse: (i) la raccolta in tempo reale dei dati, (ii) la tecnologia middleware avanzata per l'integrazione dei dati[5], (iii) la simulazione e la visualizzazione virtuale, (iv) il profilo utente/sociale con la visualizzazione e il feedback dei dati, (v) l'efficienza energetica e l'analisi dei costi del sistema, (vi) l'interfaccia web e l'interazione delle informazioni.

Riconoscimenti

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* Anna Osello, Dipartimento di Ingegneria Strutturale, Edile e Geotecnica – Politecnico di Torino, anna.osello@polito.it; Giuseppe Moglia, Dipartimento di Ingegneria Strutturale, Edile e Geotecnica – Politecnico di Torino, giuseppe.moglia@polito.it; Matteo Del Giudice, Dipartimento di Ingegneria Strutturale, Edile e Geotecnica – Politecnico di Torino, matteo.delgiudice@polito.it; Cristina Boido, Dipartimento di Architettura e Design – Politecnico di Torino, cristina.boido@polito.it.

[1] Periodo del progetto: dal 01.10.2013 al 30.09.2016.
[2] Questi dati possono essere visualizzati su una mappa locale di Google grazie all'utilizzo del sito web http: //batchgeo.com/it/
[3] Flickr è un sito per la condivisione di immagini.
[4] Questo strumento produce elementi con un numero ID che identifica l'elemento nel DB.
[5] Il middleware LinkSmart citato in figura 1.

of that part of the urban fabric which is typified by the indivisibility of rules and services that arise it and keep it alive, and everything that surrounds it, that contextualizes it and that makes his urban individuality. The urban fabric can be seen not only as a sum of districts, and then by elimination of boundaries between districts, but as the bearer of a new individuality, the territorial one, characterized by a greater size of constituent information.

At the end of the project, the DIMMER system will integrate BIM and district level 3D models with data from sensors and user feedback to analyze and correlate buildings utilization and will provide real-time feedback about energy-related behaviors. It will allow open access with personal devices as tablet and smart phone using Augmented Reality (AR) visualization of energy-related information to end users. These information will be about energy and cost-analysis, tariff planning and evaluation, failure identification and maintenance, and in general energy information sharing. All the following technologies will be included: (i) real-time data collection, (ii) advanced middleware technology for data integration[5], (iii) simulation and virtual visualization, (iv) user/social profiling, visualization and feedback, (v) energy efficiency and cost analysis engine, (vi) web interface and interaction of the information.

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* Anna Osello Department of Structural, Geotechnical and Building Engineering – Politecnico di Torino, anna.osello@polito.it; Giuseppe Moglia, Department of Structural, Geotechnical and Building Engineering – Politecnico di Torino, giuseppe.moglia@polito.it; Matteo Del Giudice, Department of Structural, Geotechnical and Building Engineering – Politecnico di Torino, matteo.delgiudice@polito.it; Cristina Boido, Department of Architecture and Design – Politecnico di Torino, cristina.boido@polito.it.

[1] Period covered: from 01.10.2013 to 30.09.2016.
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[3] Flickr is a site for image sharing.
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[5] The LinkSmart middleware evocated in figure 1.

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BIM and GIS for district modeling

M. Del Giudice, A. Osello, E. Patti
Politecnico di Torino, Turin, Italy

ABSTRACT: Many researchers are exploring Building Information Modeling and Geographical Information System to try to create a graphical database able to collect data about landscape, city, utilities, buildings, etc. This paper aims to investigate the way to link BIM and GIS to connect information belonging to different systems that characterize in a different way the same objects. So, interoperability between different environments, software and professionals plays a key role to provide a great contribution for the DIMMER project, where the development of a District Information Model is related to manage data about energy saving.

1 INTRODUCTION

Nowadays, the building industry is taking into account the development of 3D parametric models to optimize the construction process. This may be due to the current economic and environmental condition, which has underlined the need to reduce the energy waste in the Architecture Engineer and Construction (AEC) Industry. For this reason energy efficiency is becoming relevant for the existing buildings and it is receiving much attention in the research field.

Through the Horizon 2020 program, the European Commission is driving the member states to convert the existing cities into *Smart Cities* in order to reduce the energy consumption by actively involving the citizens. This raises the problem of how to handle large amounts of data from multiple buildings in order to perform energy simulations by environmental monitoring and its digital visualization. So, the creation of a digital parametric model that acquires information not only related to a single building but also to the power and thermal distribution networks connected to it becomes fundamental. From this point of view Building Information Modeling (BIM) and Geographic information system (GIS) offer 3D data models that provide information about buildings and the surrounding environment.

Many researchers are investigating on these fields, underlining the need to develop a urban model able to contain heterogeneous data, which can be exploited for many purposes including: i) the design or refurbishment of buildings; ii) maintenance and monitoring of energy consumption.

The parametric models created with both BIM and GIS have different characteristics because they are related to different information: BIM is usually used for the architectural scale while GIS is adopted for the urban and geographic scale. The connection of the both environments should be done in geometric and alphanumeric information level. Unfortunately, the data sharing between the two worlds is not easy and for this reason interoperability between BIM and GIS, nowadays, is one of the major challenges that face building information systems and practitioners.

So, the aim of this paper is to show one possible way to connect BIM and GIS models trying to preserve geometric and alphanumeric information, developing a District Information Model (DIM).

The idea to link BIM and GIS is followed in the District Information Modeling Management for Energy Reduction (DIMMER) European project which aims to develop a web-service oriented open platform with capabilities of real-time district level data processing and visualization. Thanks to the web-service interface, applications can be developed to monitor and control energy consumption and production also from renewable sources. This is showed in Figure 1. The DIMMER project schema.

The case study chosen for this work is "the Politecnico district" located in Turin (Italy), which is composed by both public and private buildings. For public buildings, such as schools, university campuses or municipal buildings, applications can be developed to visualize real-time energy consumption, which leads to a considerable educational impact for the citizens.

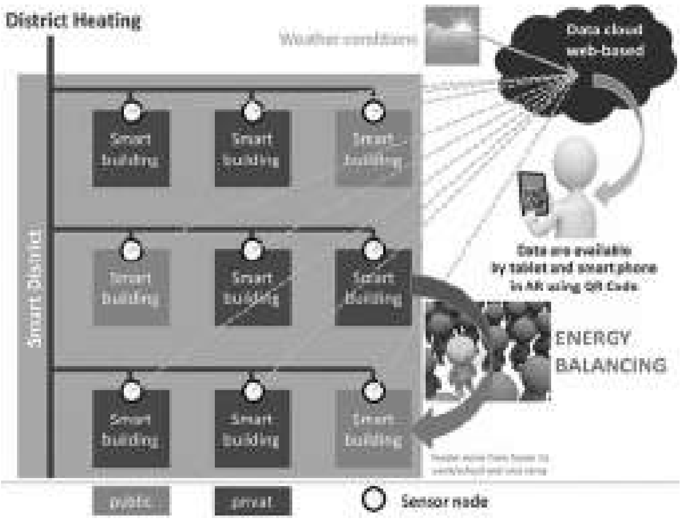

Figure 1. The DIMMER project schema.

For this paper, the attention is focused on the Coppino primary school that is one of the specific case studies of the DIMMER project. The building was originally built in 1902 and almost totally rebuilt, for the parts in elevation, at the end of the Second World War. At the beginning of 80s of last century was enlarged. At the present, despite the transformations, the unit features retains its formal aspect, of great interest, largely borrowed from the original project. For its transformations and for its function it considered important to investigate its energy behavior.

The work was started with an archival document research to better know the construction typology of the different buildings that are located in the "Politecnico district". To manage the historical data an historical database has been developed; this will be linked to the 3D parametric models. The basic concept of this work consists in considering the models generated in BIM and GIS as two different databases that are able to collect and share information considering different Levels of Development and different Levels of Detail (LOD). In order to optimize the data sharing, define the LODs and the range of parameters, useful for the urban or building visualization, is needed. To achieve this goal it was necessary to test the interoperability process between different applications. Two different ways were followed to link the two databases: the first concerned the use of the Revit DBLink; the second was the use of the Interoperability extension of ArcGIS 10.

The two 3D parametric models were developed without too many details of the buildings because the main purpose of this work is to merge the information stored into the two different databases. Using a third application called Autodesk Infraworks, both databases were imported with their native format; the resulting model contains both graphical and alphanumeric information. It appears as the overlaps of the two original.

2 METHODOLOGY

Starting with the district information modeling, the first step before the creation of the 3D model was the archival documents research to carried out to better know the construction typology of the different buildings. The most important documents are collected in order to create an historical database to link historical data with the 3D parametric models developed subsequently with Autodesk Revit, and ESRI ArcGIS 10. Before the modeling step, referring to the American Institute of Architects (A.I.A.), particular attention has been given to the choice of the Level of Development and the Level of Detail because the meaning of two types of levels are different:

- Level of Detail is essentially how much detail is included in the model element.
- Level of Development is the degree to which the element's geometry and attached information has been thought through the degree to which project team members may rely on the information when using the model.

Summarizing, Level of Detail can be thought as input to the element, while Level of Development is reliable output (LOD Specification 2013).

In this paper LOD refers to Level of Development. For this work the models are developed in LOD 100 for the GIS model and in LOD 100 and LOD 300 for the BIM model. Below the definitions of the chosen LOD are reported (AIA 2013):

- LOD 100: The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.
- LOD 300: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

After choosing the appropriate LODs the modeling phase on both ArcGIS and Revit began.

As visible in Figure 2, the general model of the interested area was developed in Revit using *Masses*, which are *In place* family able to describe the volume of the district. These items have been enriched by some architectural information coming from the website of the city of Turin through the use of shared parameters. So, this model was developed using LOD 100. Then the Coppino Primary school was modelled including more architectural information then the context's model.

Figure 2. The 3D model of the context and of the Coppino Primary School developed by Pamela Scaramozzi with Revit

In this model external and internal walls, floors, roof, windows, rooms are presented. It was developed in LOD 300.

Both 3D models were oriented and located in the right way.

Working on ArcGIS, first it was necessary to define the geographic coordinate system (in this case study the WGS84 ellipsoid was used), then shapesfiles (.shp) of the buildings and shapefiles of the addresses were made (Fig. 3). Shapefiles are able to stores non-topological geometry and attribute information for the spatial features in a data set (ESRI). These files have been developed to describe the GIS model. It was characterized by simple building blocks with several attributes, such as construction typology, construction date, building's function, etc.

In this model there are also points that characterize the address of each building. After the development of both BIM and GIS models, the testing phase of data sharing began. Regarding this step, interoperability between software becomes a key factor.

The use of a parametric models in different applications for specific analysis implies the presence of an export / import process, which aims to find the standard exchange format for better preserving information, avoiding the generation of errors.

Figure 3. The building's shapefile developed on ArcGIS (.shp developed by Enrico Osello and Stefano Dellarole)

Figure 4. the Coppino model and the Building's shapefile imported on Infraworks. (the model was developed by Paolo Marcia)

Several different format were analyzed: .ifc (Industry Foundation Classes), ODBC (Open DataBase Connectivity), CityGML (Geography Markup Language), .rvt, .fbx, .accdb, .mdb, .shp, etc. At present, referring to interoperability between software, IFC and CityGML are considered the two principal standard exchange format in the building industry.

In this case the idea of interoperability can interact with the concept of a common platform where different databases can share information. In this way, data can be extracted for a specific calculation in different applications.

For this reason, the presented work also aims to create a network of interconnected databases where data can be visualized in different ways on different applications according to the scale of representation.

Hence, the connection of both models followed different strategies. The two parametric models are graphical relational databases. Indeed it should be possible to connect them in a graphical way but also visualize them with tables, forms, etc.

At present we are trying to connect them to preserve graphical information. As visible in Figure 4, using Autodesk Infraworks the two models were graphically overlapped. The shapefiles coming from ArcGIS were imported easily, while the Revit model was exported firstly in .fbx and then imported into Infraworks. This is due to the fact that there is a possibility to import the file in .rvt format but this can occur, only using the Infraworks release.

Then, the BIM model was exported in Microsoft Access, using the Revit DBlink; in order to visualize the parametric model as tables.

3 RESULTS

In recent years, BIM and GIS are becoming more common in the AEC industry. Many researchers are investigating the theme of 3D city models that can be considered as digital representation of the Earth's surface with its related spatial objects.

Each object can be easily modeled as building blocks starting from GIS and then can be improved adding architectural and alphanumeric information in the BIM environment. So, the connection between BIM and GIS needs to be improved. With the presented work we tried to establish a connection between these two methodologies, which aims to create a district information model able to extend the BIM methodology at urban scale. Following this approach, it will be possible to make tests related to energy saving considering not only on the single building but also the neighborhood buildings.

A district information model could allow the end users to include data related to urban planning and power and thermal distribution networks in order to provide services to the citizens. These data should be discharged automatically in a more detailed parametric model able to increase information about a single building, such as the construction type, the energy consumption analysis for each room, the building's location and orientation, etc.

At present both 3D parametric models were developed separately in an easy way in order to find a link between the data stored in the two databases (Fig. 5).

Through this work the importance of the data sharing between different models was shown. The interoperability has to be improved because at present it is possible only overlap the two models without a database connection. With Infraworks the possibility to import the BIM and the GIS model with the .rvt, .fbx and .shp formats, displaying them in a single file, was verified. IFC and CityGML need to be investigated and tested in detail relating to the data sharing.

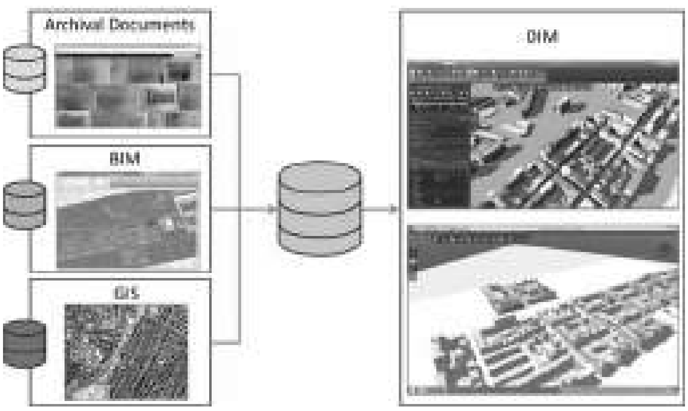

Figure 5. A possible way to display the District Information Model.

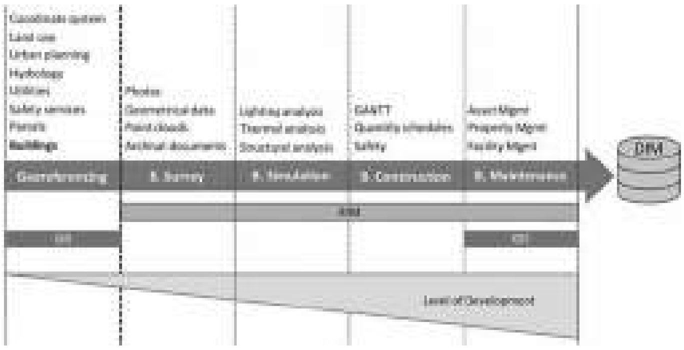

Figure 6. the schema of the BIM and GIS world in the DIM process.

4 FUTURE WORK

Following the interoperability idea, we will able to connect the two databases, adding and extracting data with the Structured Query Language (SQL). In this way the two parametric models will not be simply overlapped, but may communicate each other, sharing information related to the buildings' district. As future work, we will import the models into a relational database, which merges data, coming from heterogeneous sources to improve the data visualization from an urban representation to more detailed architectonical view of the building.

Finally, the aim of the DIMMER project is to improve the awareness of citizens about energy consumption through an open platform where the interested users can view and use data to save energy. These data will be taken also from the district information model. In this way citizens will have the possibility to display information about energy consumption for the buildings where they usually live, becoming active part in the energy saving process

5 CONCLUSION

In the last year, the need to share information is having a great success in the AEC industry. Professionals are realizing that the way of conceive the building process is changing. In order to achieve the energy saving policies, professionals should consider the building characteristics and the geographical information about the context where they are located.

Developing a district information model means to develop a process that starts from the urban and territorial scale, and arrive to the architectural scale (or viceversa), as the Figure 6 shows. Recreating different models with different levels of detail will not need, but enriching a single information model able to interact with the other buildings and with the urban utilities will be possible.

Obviously, the district information model will be improved adding urban and architectural information for better manage data useful for professionals.

6 ACKNOWLEDGMENT

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FROM THE ARCHITECTURAL MODEL TO THE ENERGYMODEL: THE USE OF BIM FOR THE EVALUATION OF THE ENERGY PERFORMANCE OF BUILDINGS

Davide Bavastro[1], Alfonso Capozzoli[1], Vincenzo Corrado[1], Matteo Del Giudice[2], Anna Osello[2], Laura Rietto[1] and Elisa Vigliani[1]

[1]DENERG - Department Energy, Politecnico di Torino, Torino, IT

[2] DISEG - Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Torino, IT

www.polito.it

ABSTRACT

Since about a decade the European policies are impelling researchers to find solutions to reduce the energy demand of buildings, for both new constructions and renovations. The first step towards energy consumption reduction is to carry out a reliable energy performance analysis of the building envelope.

At present, the Italian professionals are required to assess the energy demands of buildings according to the quasi-steady state method specified in the Italian Technical Specification UNI/TS 11300-1:2008 that follows the UNI EN ISO 13790:2008.

The paper aims to investigate the common professional practice in the assessment of the energy performance of an existing building. Thus, this study analyses a real building block situated in Turin (Italy) and develops a 3D parametric architectural model and an energy model by means of an Italian certified commercial software, commonly used for energy diagnosis and certificates.

This paper highlights the importance of the interoperability between the 3D parametric model and the energy model in speeding up the acquisition of precise data and making the work of a professional more accurate and more cost-effective. In particular, the paper focuses on the impact of the projections, due to the geometry of the building, on the energy demands for heating and cooling.

INTRODUCTION

Because of the current economic and environmental concerns, the energy efficiency of buildings is becoming a central issue not only in the research field but also in the Architecture Engineering and Construction(AEC) industry. In order to promote significant energy savings in the building sector, the European Commission issued the European Directive 2010/31/CE (EPBD recast) and supported it with the funding program 'Horizon 2020' that strongly incentivizes the renovation of buildings.

A detailed architectural and energy characterization of a building starts with the collection of geometric and thermal data from the available documents. This process can take a long time, depending on the geometric features of the buildings. In the last years, many researches focused their attention on an innovative methodology, defined as Building Information Modelling (BIM). The BIM method (Osello A., 2012) consists of building a 3D parametric model that contains information about the different features of construction elements, such as measures, materials, costs, physical data, manufacturer or any other data that the designer considers important for the project in addition to geometric data. The use of this method could speed up the data acquisition phase and improve the completeness and the accuracy of the energy model making it more similar to the real building.

Unfortunately, this methodology is not yet diffused among the professionals, thus energy performance calculations are usually carried out after the architect’s design phase. In this common case, the results of the energy analysis often makes it necessary to do architectural improvements and lead to more expensive design and construction. The BIM can improve the building process through the interoperability between software; in fact, sharing the information with other applications through the import/export process is one of the industry’s biggest challenges on the way to obtain a fully integrated and collaborative project team.

Many researches were performed on this field: Nevertheless, at present, the interoperable process is only effective for the acquisition of a part of the total available information of a BIM model (e.g. geometry and zones for energy simulations) and excludes several data necessary for the energy consumption analysis (Azhar S. et al.). This kind of analysis is usually carried out using commercial software that often lead the professional to simplify the input data because of the time-taking data acquisition phase. As consequence, the evaluation of the energy performance may be affected by the initial assumptions and simplifications. On the contrary, the BIM process gives the possibility to professionals to manage each step of the building life cycle, including the energy analysis (Cheng-Yuan Hsieh et al.), creating an iterative and interactive process able to achieve accurate and precise results with time and cost savings.

For what concerns the building energy simulation, many researchers (Asdrubali F. et al., 2009, Ballarini I. et al., 2009, and Tronchin L. et al., 2010) focused their attention on the comparison between dynamic and quasi-steady state methods (UNI/TS 11300-1 or UNI EN ISO 13790:2008) in order to calculate the thermal energy demands. Moreover, other researchers (Corrado V. et al., 2007 and Ballarini I. et al., 2009) deepened the impact of model simplifications on the accuracy of the results of the building energy simulation. These researches agree that the initial assumptions principally affect the accuracy of the results and they focus on the impact of simplifications, but no one investigates the impact of the projections on the energy performance of the buildings.

By applying the quasi-steady state method, which represents the common professional practice, this paper focuses on the advantages that the interoperable process could give to the input data acquisition.

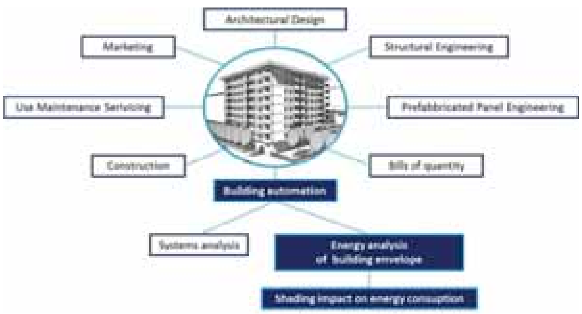

Figure 1 The Building Information Modelling process

According to the BIM process highlighted in Figure 1, the paper describes the operational potentiality of a parametric model for the acquisition of the data required by the regulations to run an energy diagnosis of an existing building with a common commercial tool. In this work, a real building situated in Italy was considered as the case study. In particular, its BIM model was developed using Autodesk Revit 2013 and an energy model was implemented according to the Italian Technical Specification UNI/TS 11300-1 using the commercial software Edilclima EC700, widely used in Italy for the energy performance analysis of buildings. The influence of possible geometrical simplification of projections on the energy needs of the building envelope was investigated in detail using the Edilclima model. In addition, the energy model was also implemented in an Excel datasheet in order to control the impact of each single input datum and the entire process of calculation. This tool was considered as a reference baseline to validate the reliability and the accuracy of the commercial software.

CASE STUDY DESCRIPTION

The residential multi-storey building analysed in this paper is situated in the centre of Turin (Figure 2). It was built in the '70s and it is considered representative of significant part of the real estate of the city. Figure 3 shows the 3D model of the building and its surroundings.

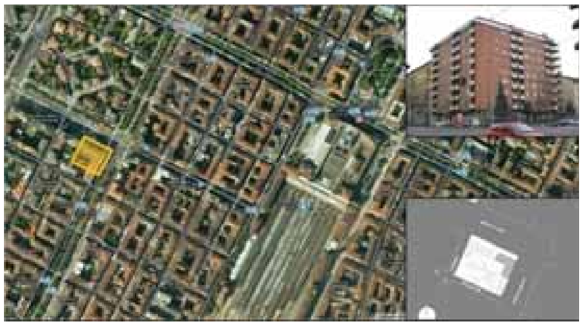

Figure 2 Image of the case study

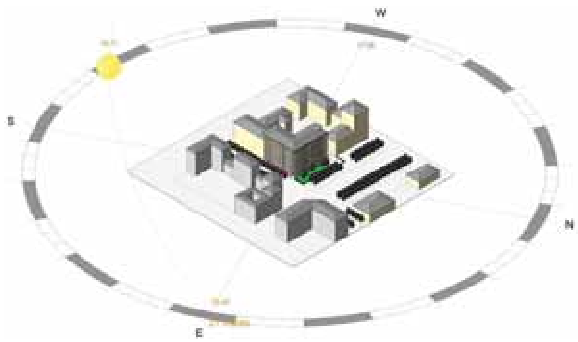

Figure 3 The model orientation using Revit

The building has an angular shape and only one of its sides is adjacent to another building. It includes nine floors, each one divided in four residential units. The vertical distribution consists of two unconditioned staircases. An archival research was carried out in order to collect the technical characteristics of the building. The frame of the building consists of a beams and columns concrete structure. The general data of the building are reported in Table 1.

Table 1

General data of the building

Floor number		9	
Clear height between floors		3.3	m
Conditioned gross volume	V_g	26628	m^3
Conditioned net volume	V_n	22968	m^3
Total net floor area	$A_{f,n}$	6960	m^2
Envelope surface	A_e	7982	m^2
Transparent surface	A_w	803	m^2
Perimeter		148	m
Total height		31.5	m
A_e/V_g		0.30	m^{-1}
A_w/A_e		0.10	
$A_w/A_{f,n}$		0.12	
Unconditioned zone			
Total volume		1968	m^3
Total area		62.5	m^2
Total perimeter		52.3	m

SIMULATION

The following paragraphs deal with the architectural and energy models of the case study. Firstly, the methodology for the extraction of data from the BIM model is presented, then the energy consumption assessment method is described.

Architectural model

The BIM methodology requires a 3D parametric model which is conceived as a graphical and relational database where professionals can add a lot of information which is useful not only during the design phase but also for the management of the building after its construction. For this reason the development of a good building information model is also essential to perform energy simulations. The 3D parametric model contains precise geometry and relevant data to support the construction or renovation of buildings, including energy retrofits. For this reason it can be a useful tool for professionals to control the energy performance of the building. In this way, the geometric and thermal characteristics of the building can be quickly acquired or modified, implementing an iterative process that allows a continuous improvement of the energy performance.

Concerning the sharing of information between different software, the interoperability process plays a key role. Today many standard exchange formats are available, such as Industry Foundation Classes (IFC), .gbXML, fbx and also Open DataBase Connectivity (ODBC) which can be used to open the 3Dmodel as a database. However, the interoperable process often does not exploit the total potentiality of the BIM methodology because of the lack in the communication protocol.

The traditional approaches of sharing project information are based on 2D models (using dwg, dwf, and pdf formats) which do not transfer the appropriate information from the architectural model to the energy model. On the other hand, new approaches aim to find a new format in order to exchange data in a correct and complete way.

The development of the 3D parametric model started from an archival research aiming to collect the technical data of the considered building. During this phase, the consistency between the documents and the actual building characteristics was verified through an on-site survey. Information about the elevations and the structural part was extracted through this validation and it was useful to correctly develop the model. The level of Development (LOD) of the model was decided before adding the objects in the Revit environment. For this work it was chosen a LOD 300 according to the LOD Specification of 22nd August 2013. The model built in Revit is shown in Figure 4.

Figure 4 3D parametric model

The objects that make up the model belong to different categories. For the nearest buildings the *In-place* families were used, while for the case study the *Loadable* families were used.

In order to calculate the shading factors related to the obstacles and the horizontal and vertical solar shadings, a *Loadable* family was created starting from the "Metric Generic Model face based" family (Figure 5). This family was associated to each external surface, transparent and opaque (Figure 6). Following this procedure, the architectural model maintains the same geometric characteristics of the real building which allows to correctly consider and calculate the shading angles.

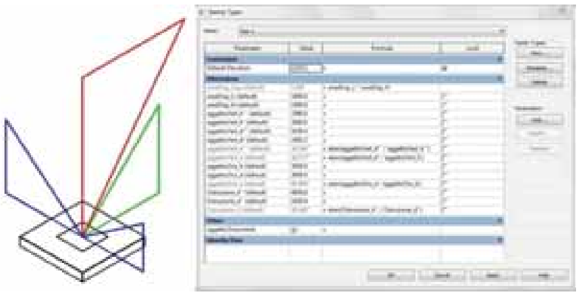

Figure 5 Loadable family for the shading parameter

Figure 6 The plan of the building

The input data needed to perform the energy assessment derive from the shape, the orientation and the envelope typology of the building. Therefore, the 3D parametric model was considered as the main source of the geometrical data. Querying the building information model, a great saving of time and a relevant reduction of errors were obtained avoiding multiple manual measurements.

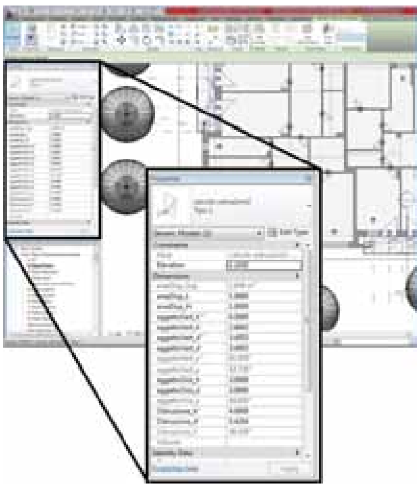

Figure 7 Shading angle visible in the project file

Some *Instance* parameters were created for the horizontal and vertical shading angles. In this way, it was possible to the generate a family able to query the model through the manipulation of certain geometric elements. Within the family, some simple trigonometric formulas were implemented in order to automate the reading of the angles needed for the calculation of the shading factors according to UNI TS 11300-1.

Moreover, the "room" tool was used to obtain information related to the area and the volume of the conditioned and unconditioned zones.

All the geometrical data extracted from the BIM model were used for the computation of the energy demand analysis following the method described in the next section.

Energy model of the building envelope

The energy balance of the building envelope was performed using the commercial software Edilclima certified by the Italian Thermo-technical Committee (CTI), according to the Italian Presidential Decree 2 Apr. 2009 no. 59. Therefore the energy model complies with UNI TS 11300-1:2008.

According to this standard, three different models can be built. In this paper the 'asset rating' energy performance assessment was performed. This implies that the calculation of the energy performance of an existing building was carried out under standard conditions, as defined by the legislation.

The UNI/TS 11300-1:2008 allows to evaluate the energy performance of existing buildings using a quasi-steady state model.

This model is simpler than a dynamic model because it takes into account the dynamic phenomena of a building through a simplified dynamic parameter, the utilization factor (η).

η is a monthly dimensionless factor depending on both the thermal inertia of the building and the heat gains-losses ratio.

The aim of the energy calculation was to assess the summer and winter thermal energy needs, only considering the building structure. For the heating period (subscript H), the energy need is calculated with the following equation:

$$Q_{H,nd} = Q_{L,H} - \eta_{g,H} Q_{G,H} \quad (1)$$

For the cooling period (subscript C), the energy need becomes:

$$Q_{C,nd} = Q_{G,C} - \eta_{l,C} Q_{L,C} \quad (2)$$

Where Q_L is the total energy losses, due to transmission, including the radiative infrared flux, and ventilation:

$$Q_L = Q_{tr} + Q_{ve} \quad (3)$$

Q_G represents the total energy gains summation of the internal and the solar gains:

$Q_G = Q_{int} + Q_{sol}$ (4)

$\eta_{g,H}$ represents the quota of the free energy gains exploited during the heating period while the $\eta_{l,C}$ is the quota of the energy losses useful to reduce the cooling need in the cooling period.

The thermal energy needs were divided by the conditioned area, in order to obtain an index easily comparable to the regulatory standard and benchmark values.

The input data that constitute the boundary conditions of the model derive from different sources: the climate data from the Italian Standard UNI 10349:1994 and the thermo-physical data of the construction materials from the UNI 10351:1994. The geometric data, as the length of the thermal bridges and the shading angles, were extracted from the BIM model as a relational database in a datasheet in order to have the possibility to manage the data with Excel.

As concerns the evaluation of the thermal bridges, the 'Atlas of thermal-bridges'(Capozzoli A. et al.) was used, identifying the technical and geometric configurations as corners, beams, columns and balconies. In relation to the projections of the case study, 58 different shading angle combinations were obtained considering both those on the transparent and on the opaque part of the envelope. Each combination may contain one or more of the following shading angles: horizontal, left vertical or right vertical. In addition, the 2 shading angles due to the buildings present to the East and the West of the building object of this study were considered.

Some assumptions were applied to the energy model. Firstly, the unconditioned zones (staircases) were considered to be completely included in the conditioned volume with no external walls. In addition, compared to the real building, the energy model does not consider the basement while the presence of an air space buffer between the ground floor slab and the ground was assumed.

Using the Excel datasheet, the real positioning of the building can be set while, in Edilclima, only few pre-defined angles can be chosen: 0°,45°, etc.. The considered case study has an actual orientation of 26° NE and only with the Excel datasheet the exact interpolation of the solar radiation was possible. Nevertheless, the gap between the results obtained with the Excel model oriented at 0° N and 26° NE was equal to 3,4% and, consequently, considered negligible. For this reason, the entire energy analysis presented below, was performed using the software Edilclima with the model oriented at North.

DISCUSSION AND RESULT ANALYSIS

Energy simulation results

The results obtained from the energy performance analysis of the building envelope are presented in this section. These results refer to the baseline scenario, defined Case A, which precisely considers all the geometric information recorded in the parametric model. In Figure 8 and 9 the pie charts show the share of the heat losses of the building in winter and summer seasons.

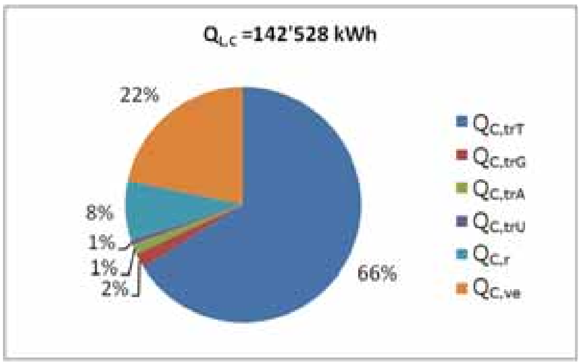

Figure 8 Building heat losses in summer

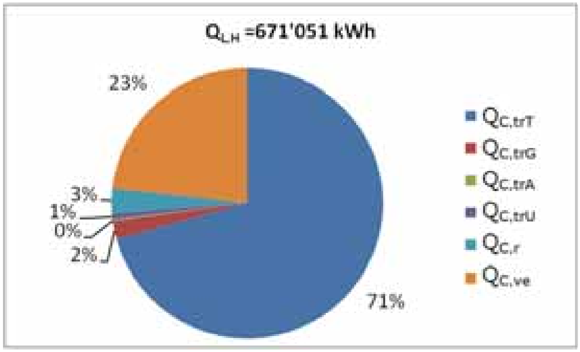

Figure 9 Building heat losses in winter

As can be noted from the previous graphs, it is clear that the main losses are due to the energy transmission through the envelope of the building both in winter and summer seasons and less than a quarter of the losses are due to the ventilation. It is interesting to observe that the impact of the radiative infrared energy loss vary from 3% to 8% considering respectively the heating season and the cooling season.

In Figure 10 the annual trends of the building energy need are shown. The high value of the $Q_{H,nd}$ (energy need for heating) is due the low insulation of the envelope. The building requires to be cooled only from June to August with a peak demand in July equal to 29136 kWh/month.

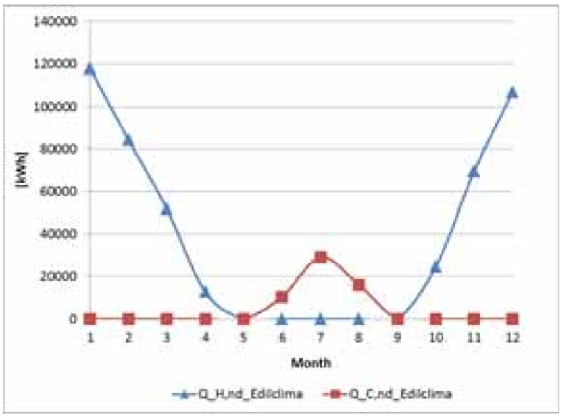

Figure 10 Building monthly energy need.

Starting from the annual energy need, presented in Figure 10, the calculation of the energy performance index was performed, as shown in Figure 11.

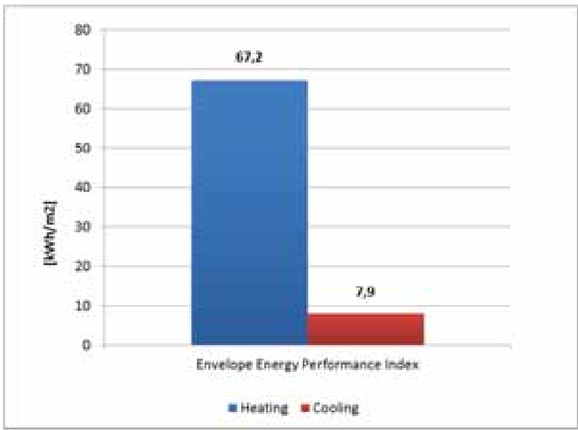

Figure 11 Envelope Energy performance index of the building

The contribution of the different terms of the annual thermal energy balance through the envelope are presented in the following table.

Table 2

Detail of the energy balance terms

Heating [kWh]			
Q_{tr}	Q_{ve}	Q_{sol}	Q_{int}
488123	154060	117171	79704
Cooling [kWh]			
Q_{tr}	Q_{ve}	Q_{sol}	Q_{int}
61148	16449	83110	32659

The previous results obtained with Edilclima were validated using the Excel datasheet; in fact, as can be seen in Figure 12, the trend of the building energy needs are very similar.

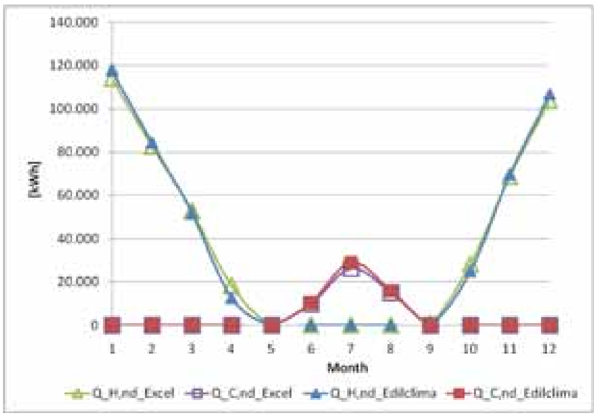

Figure 12 Comparison between annual envelope thermal energy needs for the two models

Sensitivity analysis

In this section, a sensitivity analysis showing the impact of shadows on the energy demands of the envelope is carried out. The shadows considered in this study are due to neighboring buildings and to the projections caused by the geometrical shape of the building itself.

The measurement of all the angles required for a complete energy analysis without the support of a detailed and accurate 3D BIM model would take a long time making the work non cost-effective. Since the diffused approach consists in simplifying the projections of the building, because of the large dimension and the complexity of the geometry, it is interesting to investigate the error on the energy demands due to the simplifications. In fact, this energy analysis highlights the influence of the projections on the energy performance indicators of the building analyzing the following case studies obtained by a regression of the model:

- Case A: All shadings are taken into account
- Case B: The vertical shadings are neglected
- Case C: Both horizontal and vertical shadings are neglected
- Case D: No shadings are taken into account

Case A represents the most accurate work that a professional can carry out. The Case B represents the most probable simplification that a professional can apply to the energy model given that the vertical projections may seem to be small and ignorable and moreover because they generate a significant quantity of angles (56 shading angles on windows and walls). These considerations probably lead the professional to exclude the vertical shadings from his calculations in order to achieve a cost-effective work. However, Case B still takes into consideration the presence of the two horizontal shadings, caused by the balconies, and the shadings due to the presence of buildings at the East and the West sides. Case C represents an energy simulation carried out so quickly that the professional ignored the presence of both the vertical and the horizontal projections. The last case, Case D, represents the case in which probably the professional never went on site for a direct evaluation.

In order to describe the influence of the shadows on the energy needs referred to the floor area, the values of the envelope energy performance indexes are shown in Figure 13-14.

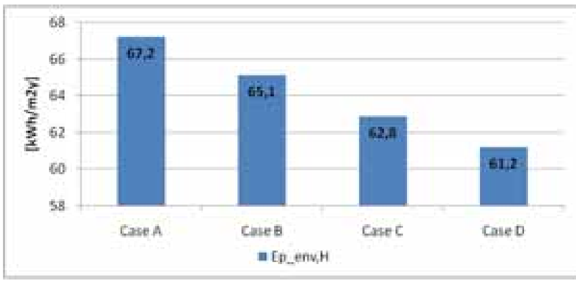

Figure 13 Heating Energy Performance Index

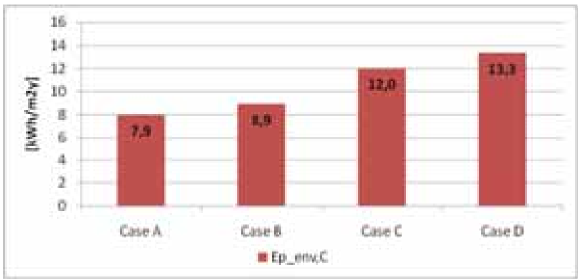

Figure 14 Cooling Energy Performance Index

Excluding the shading effect from the calculation, the heating energy demand decreases while the cooling one increases. Therefore the presence of shadings is relevant above all in the summer season in order to reduce the energy need for cooling while their presence worsen the performance during the winter season. In particular, the heating energy demand, with respect to Case A, decreases by 3% in Case B, by 6% in Case C, and by 9% in Case D. For the summer case the consumption increases respectively by 12% in Case B, by 51% in Case C, and by 68% in Case D.

The major impacts caused by the simplifications can be observed on the infrared radiative lost energy towards the sky (Q_r) and on the solar energy gains (Q_{sol}). In Figure 15 the shading effect of cases B, C and D is compared with the results obtained in case A.

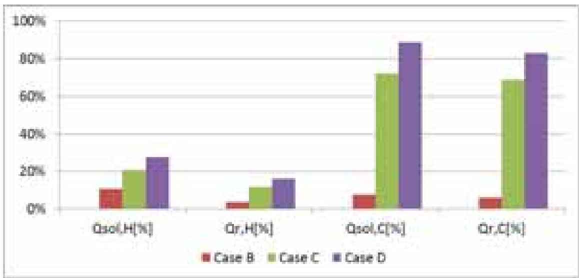

Figure 15 Q_{sol} and Q_r increase in percentage with respect to Case A

It is worth to note that excluding the shadings from the calculations, the radiative energy and the solar energy increase. Cases C and D, especially in the summer season, are markedly different from case A, both for the solar effect and the radiative energy losses.

CONCLUSION

The use of BIM is strictly founded on the setup of the 3D parametric model. Indeed, the development of a 3D model rich in information enables the professionals to query it many times obtaining data useful in the phases of building design, allowing time and cost savings.

In this paper, the potentiality of BIM for the building energy performance evaluation was tested and the model was used as a database to extract geometrical and technical data. Actually, the use of traditional Computer Aided Design (CAD) tools may lead a professional to employ a long time to acquire the data, in particular those of the shading angles, or to strongly simplify the geometrical model and subsequently the energy one.

In this paper, a particular family was created in order to speed up the reading of the angles of the shadings and a detailed impact assessment of shadings on energy performance results was carried out. As demonstrated in this work, the geometrical simplification impacts the envelope energy need, affecting above all the summer performance. The most influenced parameters are the solar gain and the lost radiative infrared energy.

In relation to the interoperability between BIM software and commercial software for the energy performance assessment of buildings, this study highlights that a gap still needs to be filled. Looking at the problem from the BIM software side, it would be useful to have a command that calculates the angles as the Revit *family* that was expressly built within this study. On the other hand, the common commercial software for the energy performance assessments should be able to acquire the geometrical information exported by a BIM software, including the shading angles as described in this paper.

Therefore, the interoperability process of this study could be further improved considering the BIM model as a relational database. This database could be used in other applications (e.g. Microsoft Access), in order to permit a direct link of the BIM model with other software, for the energy performance assessment, able to read and decode it.

It is desirable that the BIM methodology will soon constitute a common practice, improving the interoperability between software. This improvement will give the opportunity to professionals to use common commercial software to carry out reliable building energy assessments more practically, more precisely and with time and cost savings, especially considering the impelling necessity to renovate old buildings of our existing real estate.

NOMENCLATURE

$Q_{H,nd}$, building thermal energy need for space heating;

$Q_{C,nd}$, building thermal energy need for space cooling;

$Q_{L,H}$, total heat losses during the heating season;

$Q_{L,C}$, total heat losses during the cooling season;

$Q_{G,H}$, total heat gains during the heating season;

$Q_{G,C}$, total heat gains during the heating season;

$\eta_{g,H}$, utilization factor related to the energy gains during the heating season;

$\eta_{l,C}$, utilization factor related to the energy losses during the cooling season;

Q_{tr}, transmission heat losses;

Q_{ve}, ventilation heat losses;

Q_{int}, internal heat gains;

Q_{sol}, solar heat gains;

Q_r, extra heat flow due to thermal radiation to the sky;

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BIM FOR CULTURAL HERITAGE

Matteo Del Giudice[1], Anna Osello[1]

[1] Department of Structural, Geotechnical and Building Engineering (DISEG) – Politecnico di Torino, C.so Duca degli Abruzzi 24, 10100, Torino, Italy - matteo.delgiudice@polito.it, anna.osello@polito.it

KEY WORDS: BIM, Point Clouds, survey, interoperability

ABSTRACT:

When you think about the Architecture, Engineering and Construction (AEC) Industry people tend to refers to new buildings, but nowadays the recovery of existing ones is increasingly the subject of the research. The current historical context raises this issue at the center of numerous thought due both to economic and environmental conditions. So, the need to refurbish the cultural heritage is becoming more important than the construction of new buildings. Modern technologies allow professionals to do this to turn the buildings into structures capable to meet the users' confort with a considerable energy saving. Italy is trying to make a change to the construction industry through the national InnovANCE project, which aims to develop the first national database able to share information among professionals through the help of Building Information Modeling (BIM). In this way the subject involved in a construction process can update their way of working, with a consequent time and cost saving. This paper aims to present the way in which the InnovANCE project can be considered as the key for Italy to change the way to conceive the building industry, using a case study such as the old thermal power of Politecnico di Torino, starting from the survey step. The methodology followed to obtain the 3D model will be described, starting from the data of a topographic and a laser scanner survey and from an archival documents research.

1. INTRODUCTION

The world environmental and economic conditions, focusing on Europe and specially on Italy, require a change of the development strategies of the society starting from the built environment in which people live.
Usually the AEC Industry is focusing on new buildings without paying attention to the cultural building heritage. So, the need to refurbish existing buildings, transforming them into smart buildings, is an essential research field in Italy in the last years.
We know that the term 'smart buildings' describes a suite of technologies used to make the design, construction and operation of buildings more efficient, applicable to both existing and new-build properties. These might include Building Management Systems (BMS) that run lighting, heating and cooling systems according to occupants' needs or software that switches off all PCs and monitors after everyone has gone home. Of course, BMS data can be used to identify additional opportunities for efficiency improvements.
Adding to this, we can consider a smart building, as intelligent building, not only for a number of technologies that it contains, but also analyzing the method used to make the building, starting from the design phase arriving to management phase. This idea goes well with Building Information Modeling (BIM). Recently smart buildings has received much attention as well as BIM and interoperability as independent fields. To link these topics is an essential research target to help designers and stakeholders to run processes more efficiently. As a matter of fact, to work on a smart building requires the use of ICT to optimize design, construction and management. Nowadays, several technologies such as sensors for remote monitoring and control, building equipment, management software, etc. are available in the market. As BIM provides an enormous amount of information in its database and theoretically it is able to work with all kind of data sources using interoperability, it is essential to define standards for both data contents and format exchange. In this way, a possibility to align research activity with Horizon 2020 is the investigation of energy saving using ICT, and BIM and interoperability can play a key role to transform existing buildings into smart buildings. This idea was reflected in the InnovANCE project which aims to develop the first national database for the AEC Industry. This archive will be able to involve all professionals in the construction process, deleting misunderstandings that generate inefficiencies, optimizing each step of the process in term of energy saving and price performance. The use of this database is strictly related to the use of BIM which gives the possibility to manage all the construction process, reducing errors and costs. Although this project has many positive aspects there are still some difficulties related to the full creation of this idea.
First of all there is the need to change the way to concept the project because today professionals are used to work with CAD tools, secondly the BIM process is used for new building rather than for existing building. This is related to the fact that existing buildings have many constrains to respect, considering the will to preserve the correspondence between the parametric model and the existing structure. Adding to this the interoperability process is not error free.
To overcome these problems would be enough to train professionals according to this new methodology applied to existing building, using the InnovANCE database correctly. To solve problems related to sharing of data it is necessary to use the correct standard exchange formats and a correct modeling.
Other states such as the UK have proceeded with the development of national database of BIM objects, called National BIM Library (NBL), to streamline the building process, setting a common approach to quality standards throughout the AEC industry. The NBL has the task to promote greater consistency of information improving the collaboration

between professionals. At the end of the InnovANCE project (July 2015) all of this will be possible in Italy too.
The purpose of this database is to improve the sharing of information between different professionals within a project, solving the interferences between them, avoiding the creation of mistakes, decreasing costs, obtaining good results.

Relating to existing buildings, the design steps have been simulated with the BIM methodology in a traditional professional studio used to work CAD tools. Starting from an international bibliographic research and a more detailed plan for the state of the art of BIM in the most advanced countries, all the design steps have been set in the construction project to facilitate the transition from CAD to BIM.
At the beginning of the InnovANCE project, a case study has been selected: the old thermal power plant of the Politecnico di Torino. This is a building square shape built in the mid-50s: the structure will change its native function because four large classrooms reserved for teaching will be made inside it.

Figure 1. Location of the old thermal power(image extracted from Google Maps)

At present the database is continuously implemented and improved with a lot of tests using different case studies to find the easy way that will be followed by the professionals which want to use the InnovANCE database.

2. METHODOLOGY

During the first phase of the InnovANCE project time was spent to set properly the methodology that will be followed in the future of the project, beginning to develop the parametric model. More tests are needed to test the 3D model in specific applications, deepening the interoperability issue, arriving to define guidelines for the correct use of BIM for the refurbishment of the existing buildings. Existing building have a number of major difficulties than new buildings, but the use of new technologies mentioned above gives the opportunity for professionals to manage data, querying the 3Dmodel through a iterative and interactive steps that characterize the BIM process.
The case study analyzed consists of the refurbishment of the former thermal power plant of Politecnico di Torino. This choice joins the current need in which the issue of the recovery of buildings is also a priority in government policies. Adding to this, there is the need by the university to increase the numbers of rooms that can be used for educational purposes.

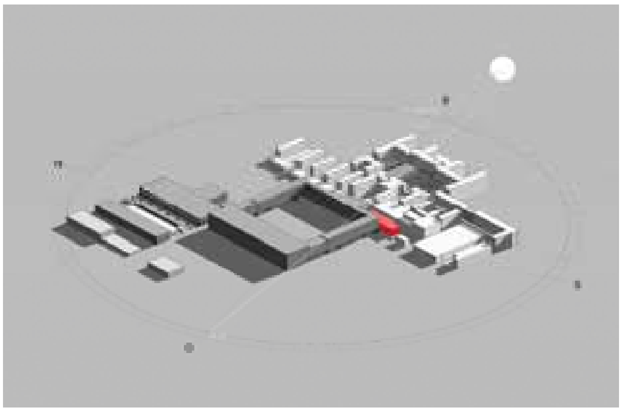

Figure 2. 3D Massing Model of Politecnico di Torino for shading study

The building is located adjacent to the newly constructed building that forms a part of the Doubled of the university. It has the east-west orientation that can be exploited in the design phase for natural building. The structure will change its native function because four large classrooms reserved for teaching will be made inside it.
Based on what we just said before the research has been organized and developed considering three essential elements:

- The working methodology based on the data exchange following the interoperable way and the problems' solution related to it;
- The data hierarchy during the different phases of the design and the role of professionals in the filling's data steps in the 3D model;
- The existing rules and the need to update them.

So, in order to organize the work to be performed, possible areas concerning the project management, in which it is necessary share information to develop the full BIM, have been identified.

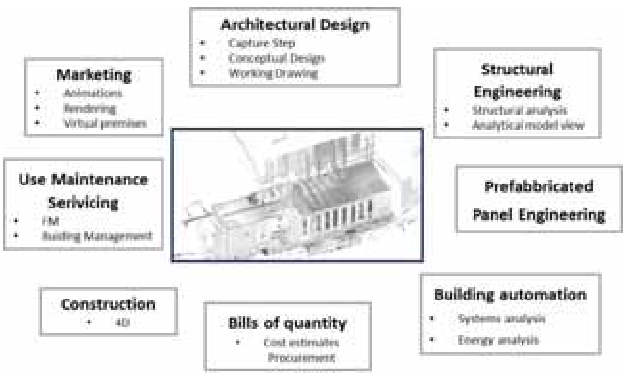

Figure 2. Organization of the building process

As seen from the above figure, eight areas have been identified; at present we have focused on the Architectural design step. First of all, due the importance of the context analysis, a research based on the archival documents (by our team) and a geometric survey (by an external team) have been done. The geometric data capture needed for the developing of the parametric model in Autodesk Revit. This step took place in two parallel and complementary ways: the first way was characterized by a topographic survey using a total station for the measurement of the essential elements of the external facades, while the second by the use of laser scanner for the external and internal part of the building.

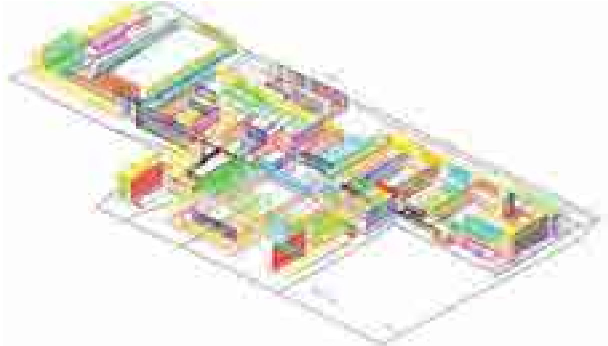

Figure 3. Survey of the Main Campus realized using a total station. (realized by Eraldo Mondino and Daniele Zaccaria)

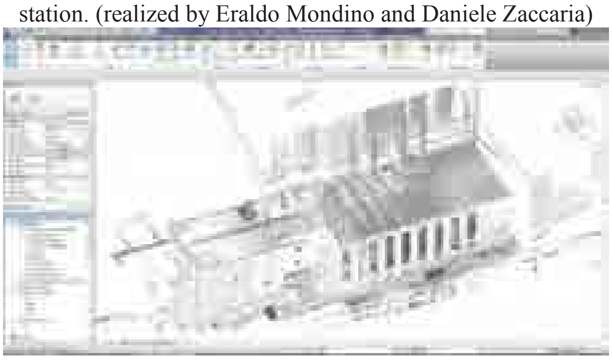

Figure 4. Point Clouds of the old thermal power. (realized by A.Lingua charge from the construction and logistic area of the Politecnico di Torino)

The reason of these two way is due to the fact that it was necessary to check data coming from different sources, using the BIM process. The use of laser scanner to obtain the point clouds was fundamental for the correct location and orientation of the model: this should facilitate the subsequent lighting simulations. Adding to this, the point clouds of the internal part of the building have helped us to observe inconsistencies between the design documents and the existing building.

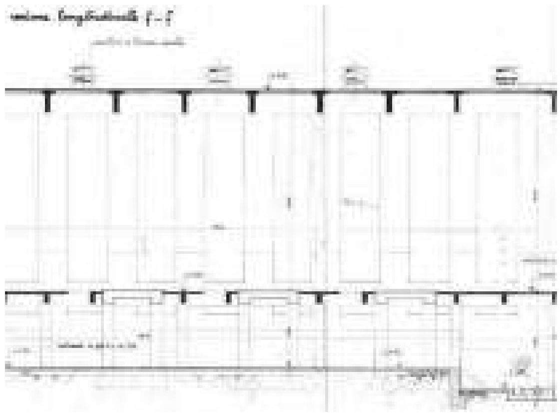

Figure 5. Longitudinal section of the old thermal power, coming from archival documents.

At the same time an historical research was conducted to find the original project which are essential to check the coherence with the building constructed.

This comparison showed some differences like for example the beam system of the principal floor modified to put the boilers inside of the structure. Following this procedure we obtained some information useful for the concrete reinforcement. In order to simulate a real situation and to optimize the information sharing between different professionals involved in a project worksets has been created, developing the information exchange idea. Worksharing is a design method that allows multiple team member to work on the same project model at the same time.

Figure 6. Image of the workset display.

Worksets are like boxes in which divide different parts of the project, like for example internal walls, external walls, roof, slabs and also the point clouds' survey; they give the possibility to the various subjects to work each on a local model tied to a central model that is updated constantly through the synchronization of files.

Before to start with the modeling step it was essential to organize all data available to us using them properly and smoothly, arriving to the development of the 3D model of the existing condition. We have not immediately started to model, but we have organized the building information model according to the discipline, that is according to the sector in which we went to work (Architectural, Structural, System, etc.) and according to the different phases of work of the refurbishment of the former thermal power plant. So, the Project Browser has been modified to view the information in the preferred way.

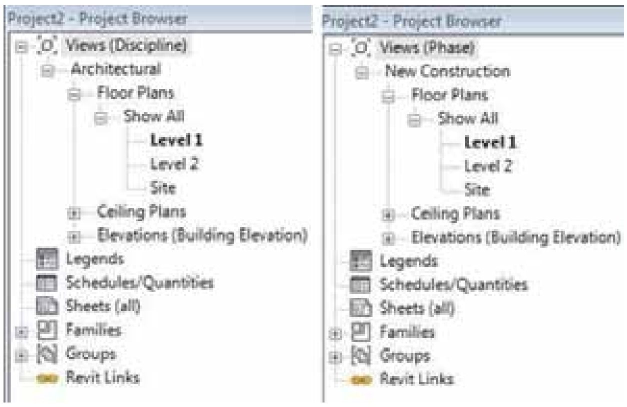

Figure 7. Browser organization of the 3D model.

Also we have assigned to each element the temporal phase related to the time when the element compare in the structure, and for this reason the database can be used for the construction phase of the project (BIM 4D). For this study we dedicated the first phase to the point clouds' survey and after that we created the existing phase, associating each element to the correct phase.

With such a large amount of data, the work organization and the data management have become very important: for this reason the parametric model was organized in the appropriate way, considering each discipline and each phase in the construction process.

In this way once filled data in the information model, professionals can visualize it and can use it for specific calculation, avoiding errors, reducing time costs, obtaining good results.

As said before, the first step was to check the consistency between laser scanner survey and archival documents. Therefore, we created the structural grids and, fortunately, from its overlap with the point cloud exists a good fidelity. The grids were created according to the type of element and the type of source that has allowed its localization.

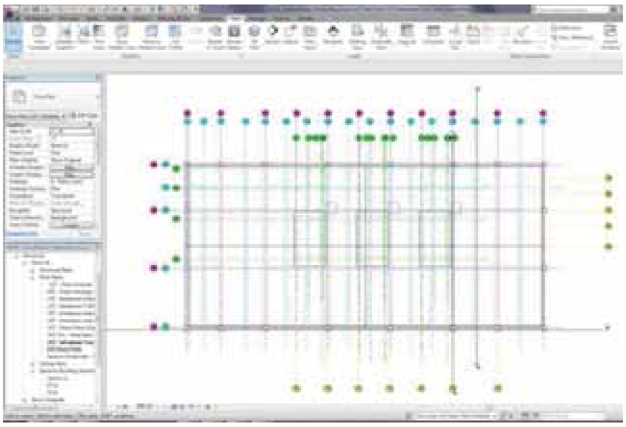

Figure 8. Image of the structural grids.

Since the model was populated with data from different source, some design parameters were created: these are useful to the designer because in this way he can assign to each element the source from which it is derived.

Although there are obvious advantages arising from the point clouds for the development of the architectural model, however there are also some disadvantages such as the need for use of PC able to manage large quantities of data in short time and the not error free interoperable process. The presence of the point clouds, the topographic survey and the design documents was crucial for the development of the parametric model because has greatly facilitated the data processing and their inclusion in the graphic database. The data management according to the BIM process will require the creation of a reference template to be used for the refurbishment of the existing buildings.

3. RESULTS

With this study it is clear how the BIM can give a great contribute to transform an existing building in a smart building and InnovANCE project is an opportunity for the AEC Industry to change the way of conceive the construction process.

During the first year of research the first results obtained is undoubtedly the organization among professionals to develop a shared model with Revit. In order to organize the work in a better way considering all the construction process identifying subjects which have to share information to better deliver the BIM process.

Analyzing the former thermal plant of Politecnico di Torino gave the possibility to test the BIM process on existing building, using data coming from different type of survey and archival documents. In this way we discovered how it is more difficult manage a large quantity of data to develop a parametric model related an existing building than a new building.

However, this study will allow us to develop this theme also to refurbish the cultural building heritage.

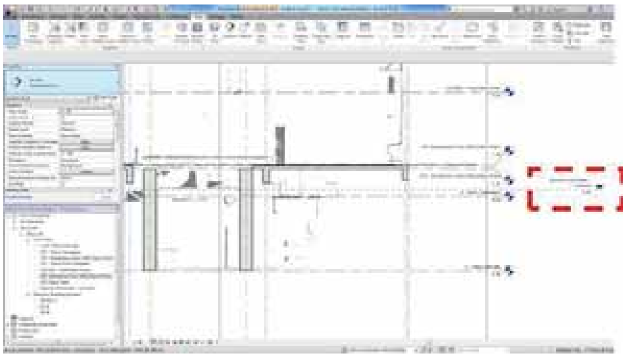

Figure 8. Image of the control level.

Analyzing the step of the point cloud management, we have inserted a level of control to correctly identify the spaces and the elements. We choose to use a level as a functional horizontal section to facilitate the display of elements that are visible from point cloud as previously anticipated. The implementation of these control levels has proved very useful because some components were difficult to detect and would be complex insert the object in the right space.

At present we have created the model of the existing building starting from survey data. We know how the organization of the information is important in a BIM process; this is also a goal of InnovANCE that aims to standardize alphanumeric codes that are able to identify building components and building materials. So by the end of the project, to each BIM object will be associated to an InnovANCE code able to identify one way the building component within the project, becoming part of the InnovANCE database. This will be possible with the Add-in which is in a beta phase in Autodesk Revit.

4. CONCLUSIONS

The need to create a database of free access containing all the information useful to the AEC Industry should be considered as the first step in the renewal of this sector in Italy.

The current traditional system fails to meet the increasingly demanding needs of performance capabilities in terms of energy reduction.

In the InnovANCE archive, for each phase of the process, will be encoded uniquely named and described all of procedures and products in the AEC Industry through systems for collecting shared information to all professionals. In this way will be possible to optimize the energy performance of the building and also the building process. Certainly, at present we spent a lot of time to analyze the method which allow to transform an existing building in a smart building and also we have tested the first step of a refurbishment; in the next year will be possible focus on the other phases. More tests are needed to test the 3D model in specific applications, deepening the interoperability issue, arriving to define guidelines for the correct use of BIM for the refurbishment of the existing buildings. As introduced before, existing buildings have a number of major difficulties than new buildings, but the use of new technologies mentioned above gives the opportunity for professionals to manage data, querying the 3Dmodel through a iterative and interactive steps that characterize the BIM process.

The elapsed time was essential to set the job properly and to achieve the objective of the project for subsequent research. Additional time is necessary to apply an iterative methodology essential for new and existing building, specially to translate the results into a first draft of standard BIM guideline valid for the Italian market.

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A DATABASE FOR THE ARCHITECTURAL HERITAGE RECOVERY BETWEEN ITALY AND SWITZERLAND

I. Bianco [a], M. Del Giudice [a], M. Zerbinatti [a]

[a] Dept. of Structural, Building and Geotechnical Engineering, Politecnico di Torino, Italy – isabella.bianco@polito.it, matteo.delgiudice@polito.it, marco.zerbinatti@polito.it

KEY WORDS: Cultural Heritage, BIM, Database, 3D model, Interoperability, GIS

ABSTRACT:

The purpose of this paper is to show some results coming from the international Interreg-AlpStone project, a research whose main aim is the protection and valorisation of a rural Cultural Heritage, theme of recent growing interest. In particular the background of this contribute is the traditional stone architecture placed in the territory between Italy and Switzerland, while into the foreground is put the method to right document, archive and analyse information about the objects of study. The response comes from BIM technologies (acronym of Building Information Modeling) which objective is the creation of a dynamical and interoperable system allowing the share of information through a unique database. If these methods have been largely employed on new constructions, they still haven't been enough tested on the field of historical architecture. In order to fill this gap, the paper suggest a method leading to the creation of a Cultural Heritage information system, which arise during the survey phase and continue through the detection of different building information, the proposal of recovery solutions, the asset georeferentiation on the territory and finally the moment of sharing information on a web platform. The creation of an architectural database is made possible by a survey based on point clouds. The latter constitute then the input data for the creation of a 3D model made with a parametric software allowing the increase of various kind of information. The future work plans will complete this project by locating the Cultural Heritage models on a webGIS.

1. INTRODUCTION

The field of rural architectural heritage protection and conservation is nowadays an issue of growing interest: a cultural awareness toward an endangered asset that finds its roots in traditions and customs characterising a certain area is increasingly drawing the attention of both professionals and local people.

This will of revitalising the past is well supported by the improvement of the nowadays technologies and ways of communication.

In particular, what is interesting is not just the practical tools employed for the protection and valorisation of the heritage, but, first of all, the methodology and the setting out of the work.

It is in this sense that thinking in terms of "database" should mean a great step forward concerning the efficiency of information exchange, work in team and continuous up-to-date. This approach is increasingly entrenching in the field of new constructions but it isn't yet enough developed in relation to the intervention on historical heritage.

Some researchers have however already effectively begun to explore, even if from different points of view, the way to make use of the advances in digital technologies in order to intervene on an "as-built" architecture.

A study developed by Tom Maver (Maver, T., 2001), whose main objective was the understanding and preservation of some Scottish assets, is the possibility to create virtual 3D models of the Cultural Heritage. In this way the important buildings can be explored and interrogated by tourists, professionals and students. Analogous researches (Kwon, Y-M. et al., 2001, Vlahakis, V. Et al., 2001) demonstrated how 3D models can be managed through a web service in order to permit a transcontinental exchange and to promote a cultural education (with a 3D cyber museum for example, as exposed byKwon, Y-M. et al., 2001). A little bit different approach is visible in researches made by the University of L'Aquila (Centofanti, M. et al., 2011; Centofanti, M. et al. 2012). Their studies mainly focus the attention on the management of different information in a database whose users won't necessarily be tourists, but, above all, professionals and technicians who plan processes of restoration, maintenance and management of the cultural heritage. With this aim they give a more global view, stressing the necessity of defining a geo-referenced information system integrated to digital 3D models of historical architecture.

However, it still doesn't exist a consolidated method that put together the different aspects raised by the authors mentioned with the intention of creating an interoperable and dynamic database of historical Heritage exploitable by both the professionals and people interested in such an architecture. This broad theme is at the moment fringe research and the purpose of the present paper is to explore, at least in part, some possible solutions by suggesting a methodological process. Our need of creating an interoperable archive of Cultural Heritage has its origins in the Interreg-AlpStone project, a research oriented to the protection and valorisation of the rural traditional architecture widespread in the area between Italy and Switzerland.

The first essential step has been the definition of a work methodology and a general scheme where the information will be placed. As the achievement of the objective requires the contribution of operators having different kind of knowledge, it needed a tool permitting a high level of interoperability. The response necessarily comes from the BIM process.

This approach permits a good management and data sharing too.

The present paper is consequently organised in way of showing the BIM methodology applied to the Cultural Heritage at the different scales required by the research: from definition of virtual 3D graphical models and related data tables till information about the territory (given by a GIS).
Since the research is still in progress, some items are just presented as future plans and will presumably be object of future publications.

2. METHODOLOGY

The current investigation has involved an important theoretical phase focused on the setting-out of the work and, at a later stage, a phase of practical experimentation of such a process.
The macro-objective of the Interreg-AlpStone research is the protection, valorisation and management of the traditional stone architecture placed in Ossola Valley (Italy) and Canton Ticino (Switzerland). The essential condition in order to achieve this aim is the availability of many documents and consequent elaborations. With the purpose of realising a functioning Cultural Heritage information system employable by several professionals, the best solution is to use just one meta-model able to manage data of different nature. The intermediate goal, the one investigated by the paper, is therefore the determination of the most efficient instrument able to collect, analyse and easily interrogate the huge quantity of data related to the buildings. In other words, it is necessary that the different tools employed during the research have a common denominator that permits them to easily communicate.
The project is therefore articulated in the following moments:

1. A knowledge moment, which aim is to have a first approach to the asset by both an historical documentation (archival documents, chronicles, etc.) and an accurate geometric survey (morphology, metrical data, etc.);
2. A critical study moment, when an analysis is required from several points of view, as for example the constructive building technologies (materials, structures, etc.), the conservation conditions (structural problems, signs of decay, pathologies, etc.) and the detection of characteristic components (finishing and decorative elements, frescos, etc.). During this step a possible way of taking advantage of the BIM technologies is given by working with 3D interrogable models;
3. A proposal moment, defining hypothesis for a restoration planning;
4. A sharing moment, when the information is made available to an extended number of people. This step, still in phase of development, will include the use of web platforms, easily interrogable and in some cases modifiable by different kind of users.

All this phases are thought with a background made up of territorial geo-referenced data in order to properly collocate every piece of information in its specific area.
The will is indeed to integrate the 3D digital models with webGIS: in this way the interoperability and exchange of data should be extended not just to different professionals working on the same area but also to people studying physically distant architectures.
Next paragraphs explain in a more detailed way the methodology used during each of the previously mentioned moments.

2.1 Knowledge moment

The tools employed during the knowledge phase have to be chosen with regard to the kind of object to be surveyed and the target of the study.
Since the paper focuses the attention on historical heritage (where every element is different from the others and possesses its own value) and the aim is to create a dynamic database (that find, as seen, a synergetic support in tridimensional models), the most efficient way to have geometrical data is to make a survey whose output is a point cloud.
This goal is nowadays achievable through different techniques and the choice is made in function of survey conditions, time, costs and expected precision.
In particular, we have tested the laser scanner and photo-modelling techniques.
The first one is expensive but, in a very short time (few minutes) is able to create very dense and precise point clouds (millions of points), which can be also geo-referenced (figure 1). On the other hand the photo-modelling, a technique based on multiview camera images, is cheap and more easily applicable in case of inaccessible buildings; it however requires longer time for the snapshots and the precision is a little bit lower.
Others techniques could anyway support and integrate these two methods.

Figure 1. Laser scanner survey of a Veglio (Piedmont, Italy) interior building

2.2 Critical study moment

This is a central phase, where probably the competences of more than a person will contribute to the collection of information about the Cultural Heritage object of study.
It is indeed in this phase that the use of BIM technologies becomes of fundamental importance in relation to the work methodology.
It has however been unavoidable the obstacle represented by the same philosophy of the BIM, which is expressively conceived for the architectonic projects. The parametric software belonging to BIM process do not refer anymore to basic object as lines, spline or geometric surfaces, but to complete components as windows, doors, walls, etc. Every element can be modelled so that it owns functional relationship and associated properties. These concepts make slightly problematic the use of BIM to historical architectures, where every element differs from the other and often has not sharp-

Figure 2. Typical Alpine stone building

cut geometries: it is sufficient to have a look to the irregular stone walls of Ossola Valley buildings (figure 2) to understand how a parametrisation for every single component would be clearly unthinkable.

The challenge is therefore to find the way to best fit the potentialities of BIM to the necessities of the Cultural Heritage.

This paper wants to suggest a possible compromise over the issue, letting however opened the dialog with others researchers in order to perfect always more the techniques.

Since the inputs coming from the building survey are, as stated before, either data from laser scanner or photos, the first step is to manage a point cloud that, for its nature, is well inscribed on the BIM methodology in reason of the possibility to easily communicate with some parametric software.

For both the survey tools there are appropriate information technologies permitting the visualisation, the management and the post-process of data. The tools experimented by the research are in particular the following ones:

- Faro Scene and MeshLab for laser scanner data
- Autodesk 123D Catch, Agisoft Photoscan and MeshLab for models created from multiple snapshots.

Point clouds can besides be transformed into meshes, which means surfaces having the geometry of the real object.

At this point, the choice of our study has been to import both the point clouds and the meshes on Autodesk Revit software. It is important to keep in mind that while the point cloud can't have any parametric properties, the related modelled surfaces can be increased with other kind of information (and therefore become part of BIM). Well conscious of Revit limits (concerning in particular the difficulty of this program to think in terms of "as-build", as underlined also by the University of L'Aquila in Centofanti, M. et al. 2012), we have judged this parametric tool a good compromise if looking to the finalities of the research. Indeed, if it is true that creating a model on Autodesk Revit, will necessarily decrease the precision and fidelity to the reality, it is also true that the mesh and the point

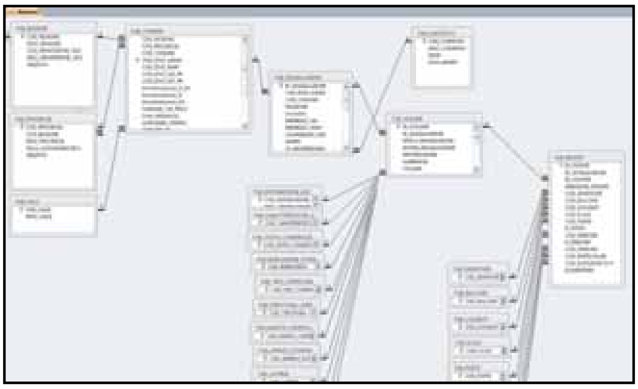

Figure 3. Access relationships

clouds are still present in the same file. In other words, with the awareness that the recreated model will necessarily be an idealisation and won't include information about the irregularity, for example, of openings and fallen walls, the users will however have the possibility, in every moment, of switching on the mesh in order to visualise and measure it.

Accepted this compromise, it is now possible to take advantage of the potentialities of the software: different kind of information about the building analysis can be associated to the objects in a dynamic and interoperable way by different people. The 3D model will become even more "interrogable" by associating table data to graphical information. For this reason the research has focused the attention also on the development of Microsoft Access tables that step by step support the user starting from the survey moment till the database interrogation.

At this point of the research two types of Access tables have been developed:

- A general database concerning the surrounding where the Cultural Heritage is located. The professional has to give information about the kind of environment (mountain, hill, lacustrine, etc.), the geographical localisation, the basic cartographical documentation, etc.
- A more specific database containing information about the building (classification of every door, window, wall, roof, etc.)

Figure 3 shows Access relationships determining the connection between different kind of information of a same building.

Access tables are dynamically integrated in the Autodesk Revit model, so that the user who needs to extrapolate information can utilise, according to his necessities, either the graphical model or the table data.

In addition to the Access tables, each professional who increases the 3D model will automatically create a series of alphanumerical data dynamically joined with the graphical visualisation.

As a consequence this unique database will progressively become richer in heterogenic information ranging from the materials to the structures, from the pathologies to the finishing elements. Moreover, the user can decide what to visualise, add or modify at every moment.

2.3 Proposal moment

At this stage of the study, the Cultural Heritage is therefore well defined and analysed from different points of view. It is so possible to project the protection and valorisation of the building.

For example the Interreg-AlpStone research has focalised on the standards update (structural improvement, thermal insulation, intervention on *piode* roofs, balconies and modillions reinforce) without compromising the traditional values.
The utilisation of BIM technologies becomes now the natural continuation of the previous step: people who work at this stage will intervene on the same database created before, adding layers that increase the state-of-the-art information with data concerning the intervention moment.
In this case the BIM tools are therefore employed a bit more in their classical way, that means as a project instrument.

2.4 Sharing moment

The last step is the sharing of information in a web platform. This point is, at the current state of the research, still in progress of development. The objective is the creation of an extensive Cultural Heritage information system which provides different levels of accessibility according to the kind of user. That means that people who are effectively working on historical buildings will have some credentials letting them the possibility of increasing the platform by adding, integrating or modifying the data. On the other hand, people who don't have the competences or the needed authorisations will just be able to consult the information collected in the web platform.
This platform will therefore be studied in line with the BIM principles of interoperability, letting the users move from the tridimensional model to the data tables.
In order to make this plan feasible it is necessary to integrate the platform with territorial information, meaning the creation of a 3D geo-referenced GIS where the building models can be right and easily collocated.
The Interreg-AlpStone research will focus on the area between Italy and Switzerland, but the base idea is to extend this concept to a much wider zone, in way of maximising the interoperability and exchange of information. In other words the project wants to create an architectural information system where the user can surf on the territory and progressively come closer to the Cultural Heritage just varying the scale of visualisation till the reaching of the modelled building, containing the information of the database.

3. RESULTS

Since the main aim of the research is the definition of solutions able to valorise and protect the spontaneous architecture located between Italy and Switzerland, it has firstly been necessary to find and choose some significant villages to study.
Veglio, hamlet of Montecrestese (Italy), is one of them and is the place hosting the examples showed in this paper. It is indeed a little village abandoned from its habitants about 60 years ago in reason of an avalanche risk: its typical stone buildings lie now in a state of degradation due to the lack of maintenance.

3.1 Veglio castle

The first case study has been the castle of Veglio, made up of a XIII century square tower and a XV-XVI century rectangular construction (Osello, E., 2012). Unfortunately the gable *piode* roofs have fallen down and the building presents clear signs of decay.

The study has been a chance for thinking in terms of BIM, starting from the first phases of knowledge till the 3D modelling.
Similarly to the procedure followed by Lo Turco M., 2012, the survey has been carried out with a laser scanner: 12 scansions, 9 outside and 3 at the interior of the building, allowed an exhaustive definition of the asset geometry. In order to successively join the point clouds and in view of the implementation of the survey on a GIS system, it has been necessary to predispose the georeferentiation of the building. For these reasons it has been created an internal planimetric network connected with a GPS sampler, which is able to supply the exact geographic position and altitude. It has firstly been necessary to place the GPS, which, connected to the Domodossola station, has furnished the benchmark useful to link the point cloud and the scansions. In order to allow the connection between scansions and planimetric network it is necessary to place some visible markers on the building and close objects that will be scanned. After that, the vertexes of the planimetric network (where the total station will be placed) have been located in way of surrounding the castle.
A step of data elaboration has then been necessary in order to get the correct coordinates of the planimetric network vertexes: this operation utilises the Bessel rule, which takes into account the right and left readings of the total station. These coordinates constitute the input information for the net compensation executed by Starnet software, which also permits the exportation of a local network image consisting of vertexes and markers (the markers coordinates will be fundamental for the point clouds georeferentiation).
The scansions are then opened in Scene software, where the georeferentiation is proceeded through the association of the coordinates -coming from Starnet compensation- to each of the marker before placed on the building and close trees (as showed in Figure 4).

Figure **4**. Point cloud georeferentiation through the markers (Osello, E., 2012)

The georeferenced point cloud is at this stage exported in .PTS file, the unique available format compatible with Autodesk Revit software. It is now possible to start with the tridimensional modelling, that, as stated before will forcedly be a simplification of the scansion (Figure 5).
In Autodesk Revit every professional is enable to associate properties to the objects: the Veglio Castle Revit file owns indeed information about materials, structures, pathologies and data linked to Access tables easily interrogable.

Figure 5. Creation of a parametric 3d model of the castle from the laser scanner point cloud (Osello, E., 2012)

3.2 Residential and rural buildings in Veglio

Besides the castle, Veglio is a village made up of simple stone buildings, which original destination was either residential or rural (e.g. barns, mangers, etc.).

Since a goal of the Interreg-AlpStone project is to study and valorise this local traditional Cultural Heritage, a survey of the village is in progress. At this moment of the research this work is still a step behind if compared with the castle one because it lacks the georeferentiation.

However, 20 scansions with laser scanner provided the model of 15 interiors and 5 external sights.

Moreover, it has been the occasion to test the photo-modelling technique as a cheaper alternative method to be eventually exploited for other already planned surveys.

It consists in taking a series of photos with some criteria allowing the software to right model the object. Indeed, the images have to be shoot with a digital camera in good conditions of light, few contrasts, no shining or moving objects and have to be taken always with the same focal length and approximately orthogonal to the facade. Respecting these rules and comparing the 3D output of photo-modelling with the analogous laser scanner point cloud, we have proved that the precision decreases of 2-3 cm in a wall of about 50 m^2 if compared with the laser scanner model (Figure 6).

This is a satisfactory result if we take into account the irregularity of the stone elements and low costs of the technique. The software employed for the creation of the 3D model and its post-processing are AgisoftPhotoscan, Autodesk 123D Catch and MeshLab.

Once the 3D point cloud has been obtained, the following goal concerned the modelling of the room. Since the strong irregularity of the walls will affect several aspect of the future recovery (e.g. thermal insulation, positioning of hydraulic lines, structural behaviour), it was necessary to model the walls with a discrete level of precision: in this case, indeed, the approximation with vertical walls would not have been functional. The challenge has been to find a way to draw irregular 3D walls capable of storing parametrical information. This objective has been achieved in Revit by drawing (with 4-5 points) some vertical profiles of the wall as "local mass"; they have then been jointed with the command "create form", obtaining in this way a surface that can be transformed in wall and consequently become a parametric object. Figure 7 illustrate the model of the irregular walls.

3.3 Future work plans

The study conducted till now is projected to the realisation of a GIS system where placing the georeferenced tridimensional models of the Cultural Heritage.

The idea is to test the importation of the database coming from Autodesk Revit and Microsoft Access in software as ArcGIS or City Engine, both of ESRI.

A particular attention will be probably necessary in order to guarantee a right transfer of information and communication between different software. As find in the literature (Centofanti, M. et al., 2011), it will probably be necessary to add an intermediate step with another software (e.g. 3D Studio Max), being careful not to have data losses.

Once the GIS will be operative the following step is the creation of a web platform permitting a dynamic sharing of information. This Cultural Heritage information system could indeed be increased by professionals studying assets localised in areas different from the one between Italy and Switzerland (thinking for example at the work made by the University of L'Aquila).

At the same time another important goal of the research is the definition of solutions for a good intervention on the Cultural Heritage object of study. These aim will involve knowledge of technical architecture and will necessarily talks the BIM language.

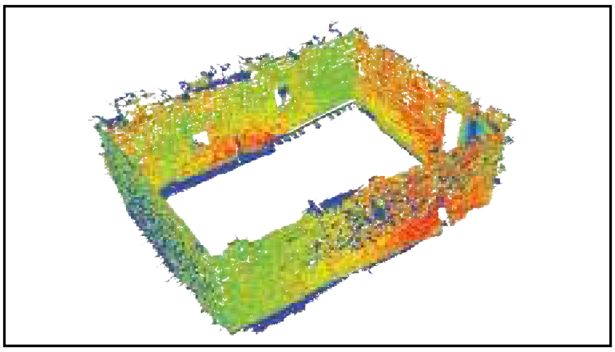

Figure 6. Comparison between laser scanner and photo-modelling 3D models: from red (indicating a minimal distance) to blue (maximum distance, set to 5 cm)

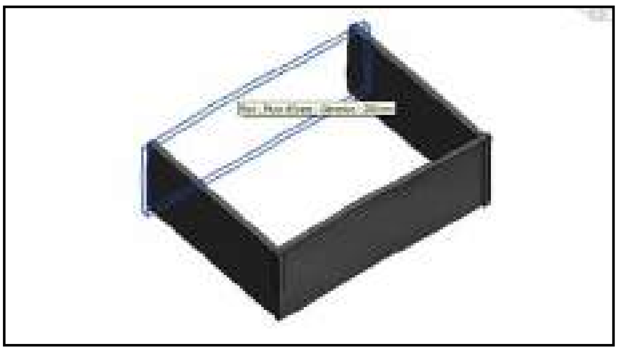

Figure 7. 3D Revit model of irregular stone walls

4. CONCLUSIONS

Prior researches have documented a new effort and attention in the field of Cultural Heritage. Indeed, new techniques are born in order to document, archive and preserve historical buildings.The technology improvement is going in the direction of 3D virtual models (Vlahakis, V. et al., 2001,Maver, T., 2001, Kwon, Y-M. et al., 2001) and GIS implementation (Centofanti, M. et al., 2012, D'Andrea, A., 2000), with the aim of permitting an easy dialogue between several operators. However, these studies often consider just some steps of the work and a global and interoperable methodology is still missing.
This paper follows the goal of suggesting a methodological approach involving all the phases, from the moment of survey till the sharing of information and begins to furnish some practical possible solutions.
The employment of BIM technologies in the field of Cultural Heritage is indeed possible and desirable: the interoperability will facilitate works in team, support the exchange of information and limit errors of transfer (there won't be transfers because the information is stored in a unique database). Moreover, the sharing of data on a web platform will allow an easy documentation about the historical heritage.
The phases analysed in this paper show how a step toward the interoperability is offered by the possibility of shaping the Cultural Heritage with a point cloud, which can then be imported in a parametric software allowing the integration of different kind of information. These tools could be utilised for any object of cultural importance from different people and in different areas.
Nevertheless, some improvements are still possible: a limitation lies for example in the inevitably process of simplification from the point cloud to the 3D model and in the communication between software. Future research should therefore follow-up work designed to find a solution to these issues and improve even more the interoperability and sharing of data.

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Figure 7. 3D Revit model of irregular stone walls

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6. ACKNOWLEDGMENTS

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Calcoli strutturali ed energetici per la riqualificazione degli edifici esistenti

Structural and energy calculations for the redevelopment of existing buildings

Anna Osello, Carlo Caldera, Bernardino Chiaia, Daniele Dalmasso, Sanaz Davardoust, Matteo Del Giudice, Anna Pellegrino, Pablo Ruffino

NEGLI ULTIMI ANNI I TEMI DELL'EFFICIENZA ENERGETICA E DELLA SICUREZZA STRUTTURALE DEGLI EDIFICI ESISTENTI SONO STATI OGGETTO DI MOLTEPLICI RICERCHE IN AMBITO NAZIONALE ED INTERNAZIONALE IN MODO ESTREMAMENTE SPECIALISTICO E SETTORIALE. IL PRESENTE CONTRIBUTO RAPPRESENTA I PRIMI RISULTATI DI UN'ATTIVITÀ INTERDISCIPLINARE CHE SI PONE L'OBIETTIVO DI DEFINIRE UNA MODALITÀ DI INTERVENTO FACILMENTE REPLICABILE A LIVELLO LOCALE E NAZIONALE, IN GRADO DI DEFINIRE CON CHIAREZZA METODOLOGICA QUALI DEVONO ESSERE GLI INTERVENTI DA EFFETTUARE, IL LORO COSTO E QUALI SONO I BENEFICI CHE SE NE POSSONO TRARRE.

PAROLE CHIAVE: EDILIZIA SCOLASTICA, BIM, INTEROPERABILITÀ, VALUTAZIONE ENERGETICA, ANALISI STRUTTURALE.

IN RECENT YEARS, THE THEMES OF ENERGY EFFICIENCY AND STRUCTURAL SAFETY OF EXISTING BUILDINGS WERE BEEN THE SUBJECT OF MUCH RESEARCH IN THE NATIONAL AND INTERNATIONAL LEVEL IN AN EXTREMELY SPECIALIZED AND SECTORIAL METHOD. THIS PAPER REPRESENTS THE FIRST RESULTS OF AN INTERDISCIPLINARY ACTIVITY THAT AIMS TO DEFINE A WAY OF INTERVENTION EASILY REPLICABLE AT THE LOCAL AND NATIONAL LEVEL, ABLE TO DEFINE WITH CLARITY METHODOLOGY WHICH OPERATION WILL BE PERFORMED, THEIR COST AND WHAT ARE THE BENEFITS THAT CAN BE DRAWN.

KEY WORDS: SCHOOL BUILDING, BIM, INTEROPERABILITY, ENERGY ASSESSMENT, STRUCTURAL ANALYSIS.

Gli eventi sismici che si sono verificati in Emilia-Romagna, Veneto e Lombardia nel maggio del 2012 e in Abruzzo nel 2009 hanno messo in evidenza le carenze strutturali degli edifici a struttura prefabbricata non progettati con criteri antisismici. La quasi totalità degli edifici prefabbricati crollati o che hanno subito danni irreversibili sono stati infatti costruiti quando le aree non erano soggette a normative che prevedessero una progettazione antisismica restrittiva come quelle entrate in vigore nel 2008. Purtroppo anche una grande quantità di edifici scolastici realizzati sull'intero territorio nazionale hanno caratteristiche analoghe. In questo contesto si inserisce l'attività di ricerca che viene presentata in questo contributo.

Uno degli elementi cruciali per tutte le attività di questo lavoro è risultato l'identificazione del caso studio esemplificativo di una tipologia ricorrente sul territorio nazionale che presentasse tre caratteristiche essenziali: i) si trattasse di un edificio pubblico facilmente accessibile; ii) fosse replicabile; iii) coinvolgesse degli utenti sensibilizzabili con attività specifiche. A partire da questi tre elementi, dopo una serie di valutazioni di carattere generale, si è deciso di concentrare l'attenzione sull'edilizia scolastica, anche in relazione al nuovo "Piano nazionale di edilizia scolastica" che dovrà essere approvato dal Cipe (Comitato Interministeriale per la Programmazione Economica), e che dovrà prevedere interventi di ammodernamento e recupero del patrimonio esistente, anche ai fini della messa in sicurezza degli edifici, e di costruzione e completamento di nuovi edifici scolastici, da realizzare nel rispetto dei criteri di efficienza energetica e di riduzione delle emissioni inquinanti, favorendo il coinvolgimento di capitali pubblici e privati.

Lo schema iniziale del lavoro (fig. 1) evidenzia chiaramente quali devono essere i criteri di scelta dell'edificio (quelli nei riquadri di sinistra), quali le fasi del lavoro da effettuare (i sei punti elencati) e quali le opportunità offerte da questo tipo di attività una volta definito il caso studio (quelle nei riquadri di destra).

Il caso studio selezionato, in grado di coniugare i tre criteri richiesti, è il Primo Liceo Artistico Statale di Torino (fig. 2). Si tratta di un edificio scolastico costituito da una struttura

The seismic events occurred in Emilia-Romagna, Veneto and Lombardia in May 2012 and in Abruzzo in 2009 have highlighted the structural shortage of the prefabricated structures. In fact, these buildings are not designed with seismic criteria. Nearly all of the precast buildings that had irreversible damage or collapsed during these events were built in areas not subjected to the 2008 seismic regulations laws. Unfortunately, in Italy a lot of school buildings are built with similar characteristics: this is the context of the research presented in this paper. One of the essential elements for the activities of this work has been the identification of the case study, which has to exhibit three essential features, recurring on national territory: i) public building easily accessible ii) replicability iii) the possibility of involving users sensitized through specific activity. From these three elements, and after a series of general evaluations, has been decided to focus on building schools. Another motivation of this selection was the new 'National Plan for school construction' which must be approved by the Cipe (Interministerial Committee for Economic Planning). The plan will include funds for the modernization and rehabilitation of existing assets (also for the implementation of safety of buildings) and for construction and completion of new school buildings, which must to be made in accordance with criteria of energy efficiency and reduction of pollutant emissions, encouraging the involvement of public and private capital.

The initial scheme of work (fig. 1) shows the selection criteria of the building (in the left box), the phases of the work to be done (the six points listed) and the opportunities offered by this kind of activity (in the right box).

The First Art School of Turin (fig. 2) has been selected as case study, because it fulfill all the three criteria described above. It is a school built in 80s of the twentieth century with a precast structure which requires significant energy efficiency improvement and an interior and exterior modernization. In addition, this school represent a well-defined and recurrent structural type, so it can be used for structural verification, simulating its behavior in different seismic areas of the national territory. Finally, the building is an art school, so it will be possible to work with students on specific proj-

1/ Schema metodologico di scelta del caso studio e delle attività da svolgere.
Methodological scheme about the choice of the case study and the activities to be carried out.

in prefabbricato risalente agli anni Ottanta del Novecento che necessita di significativi interventi di efficientamento energetico e di ammodernamento degli ambienti interni ed esterni. Inoltre, trattandosi di una tipologia ricorrente, può essere utilizzata per le verifiche strutturali, simulando il posizionamento in diverse aree sismiche del territorio nazionale. Infine, poiché l'edificio ospita un liceo artistico sarà possibile lavorare con gli studenti su progetti specifici (workshop, mostre, spettacoli teatrali, etc.) per la sensibilizzazione degli studenti stessi (oltre che dei parenti e degli amici) ai temi del risparmio energetico e della sicurezza, utilizzando anche strumenti di comunicazione innovativi come la realtà aumentata.

La metodologia adottata per lo svolgimento delle attività di indagine, di modellazione e di calcolo è definita nel Programma di Ricerca di Interesse Nazionale (PRIN[1]) 2013, Building Heritage Information Modeling Management (BHIMM), in cui il Building Information Modeling (BIM) viene utilizzato per creare una banca dati unica, da cui estrarre le informazioni necessarie per l'esecuzione di calcoli specifici come quelli strutturali, illuminotecnici, termici, etc. Ovviamente in quest'ottica l'interoperabilità tra i programmi utilizzati assume un ruolo fondamentale ed è oggetto di riflessione nel seguito di questo contributo.

A ragione di quanto accennato in precedenza, il primo passo per l'elaborazione di un modello parametrico ricco di informazioni è stato il rilievo della struttura esistente e un'attenta ricerca dei documenti d'archivio (fig. 3); questa prima fase è sfociata nell'elaborazione del modello parametrico che ha permesso di effettuare calcoli strutturali e in seguito anche energetici, consentendo di definire alcune ipotesi di messa in sicurezza antisismica e introducendo misure di risparmio energetico. Tutto questo verrà approfondito in futuro, considerando il rapporto costi/qualità.

ects (workshops, exhibitions, theater performances, etc.) to raise their awareness (as well as relatives and friends) to the issues of energy saving and security, using also innovative communication tools such as augmented reality.

The methodology adopted for the investigation activities, for the modeling and for the analysis is defined in the Programma di Ricerca di Interesse Nazionale (PRIN[1]) 2013, Building Heritage Information Modeling Management (BHIMM). This approach use the Building Information Modeling (BIM) to create a single database to export the information necessary for the implementation of specific calculation such as structural, lighting, heating, etc. Obviously, in this context, the interoperability between software is essential, and it will be developed later in this paper.

For these reasons, the first step in the development of a parametric model full of useful data was surveying of the existing structure and carefully research of archival documents (fig. 3); in this first phase a parametric model has been created. It allows to carry out structural and energy calculations, in order to define a series of improvement for the seismic safety and energy saving. These will be analyzed in the future, after a tradeoff between costs and quality will have been made.

Methodology

With regards to the whole building process, the first step considered was the survey of the existing building and the acquisition of archival data. These data were essential to analyze the building in its entirety. From the sources analyzed and from the survey executed on site, information have been obtained concerning the type of construction used and the construction details. The structure is composed of precast elements such as columns and beams. The floor is made with TT beams, conversely, the plinths and the connecting beams are cast in situ.

Naturally, numerous inspections have been carried out in order to perform a geometric survey which allowed to confirm or vary the assumptions obtained from the analysis of the archival documents.

The second phase has been the realization of the parametric model (Autodesk Revit 2013). The development of the database was carried out at the architectural and structural level. Particular attention has been given to the definition of each element: from the standard families contained in the software each element has been modified to make an accurate model of the existing building.

After the modeling stage, the model has been exported into a specific calculation software (Autodesk Robot Structural Analysis Professional) for the static and seismic calculation (more trials are underway with the software CSI ETABS) and Autodesk Ecotect Analysis for preliminary lighting tests (for further investigation will be used Daysim and Radiance). In order to perform specific calculations, the interoperability between programs and formats used to exchange files among them was crucial. To avoid the loss of data a lot of test have been carried out through the following formats: .ifc, .RTD, .gbXML, .fbx.

2/ Inquadramento generale del caso studio: il Primo Liceo Artistico Statale di Torino.
General overview of the case study: the First Art School of Turin.

Metodologia

Considerando l'intero processo edilizio, la prima fase affrontata ha riguardato il rilievo dell'edificio esistente e l'acquisizione dei dati d'archivio. I dati ottenuti sono stati di fondamentale importanza in quanto hanno permesso di analizzare il fabbricato nella sua interezza. Dalle fonti analizzate e dal rilievo eseguito in loco sono state ricavate le informazioni relative alla tipologia costruttiva utilizzata e ai particolari costruttivi. La struttura è caratterizzata da elementi prefabbricati relativamente ai pilastri, alle travi e ai solai, realizzati in tegoli TT; diversamente, i plinti di fondazione risultano essere gettati in opera e collegati unidirezionalmente tra loro attraverso travi ugualmente gettate in opera.

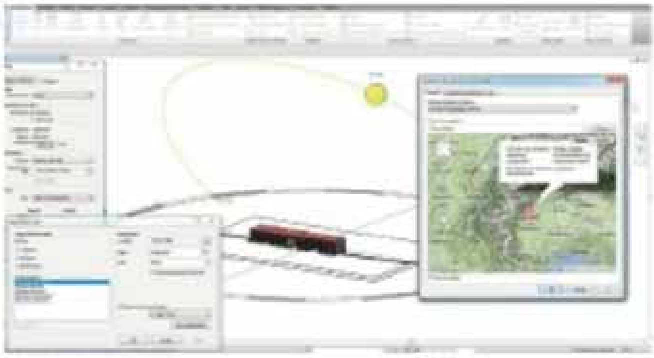
Naturalmente, sono stati effettuati numerosi sopralluoghi al fine di svolgere un rilievo geometrico che ha consentito di confermare o

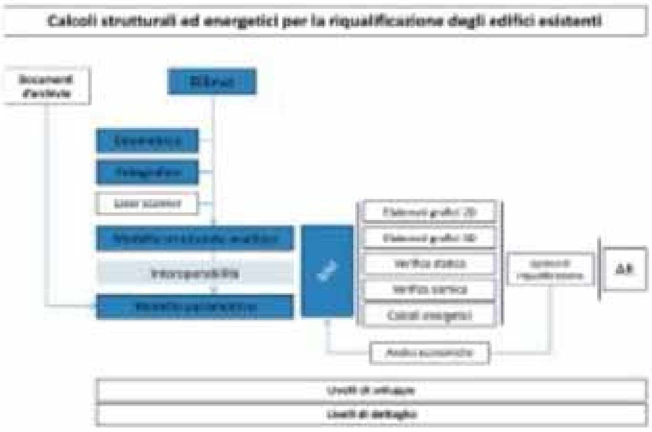
The IFC (Industry Foundation Classes) is the only interchange format recognized by IAI (International Alliance of Interoperability) based on the ISO/PAS 16739; however, it still has some limitations as it does not always allow the smooth passage of information between software. This causes a loss of important data.

In tests it has been tried to use the .ifc format. However, best results were obtained with the other formats mentioned above. In these cases has been used some software as 'bridge' between the different software in order to preserve the model information included in Revit.

Later, it has been built a 3D model containing all useful information for the lighting analysis, omitting the thermal and structural data. For example, in order to optimize the procedure, it has been focused only on a classroom, delimiting rooms through the 'Room' command. More-

3/ Schema metodologico relativo alle fasi di acquisizione dati per la modellazione parametrica.
Methodological scheme about the stages of data acquisition for the parametric modeling.
4/ Fase di inquadramento e orientazione del modello.
Stage of framing and orientation of the model.

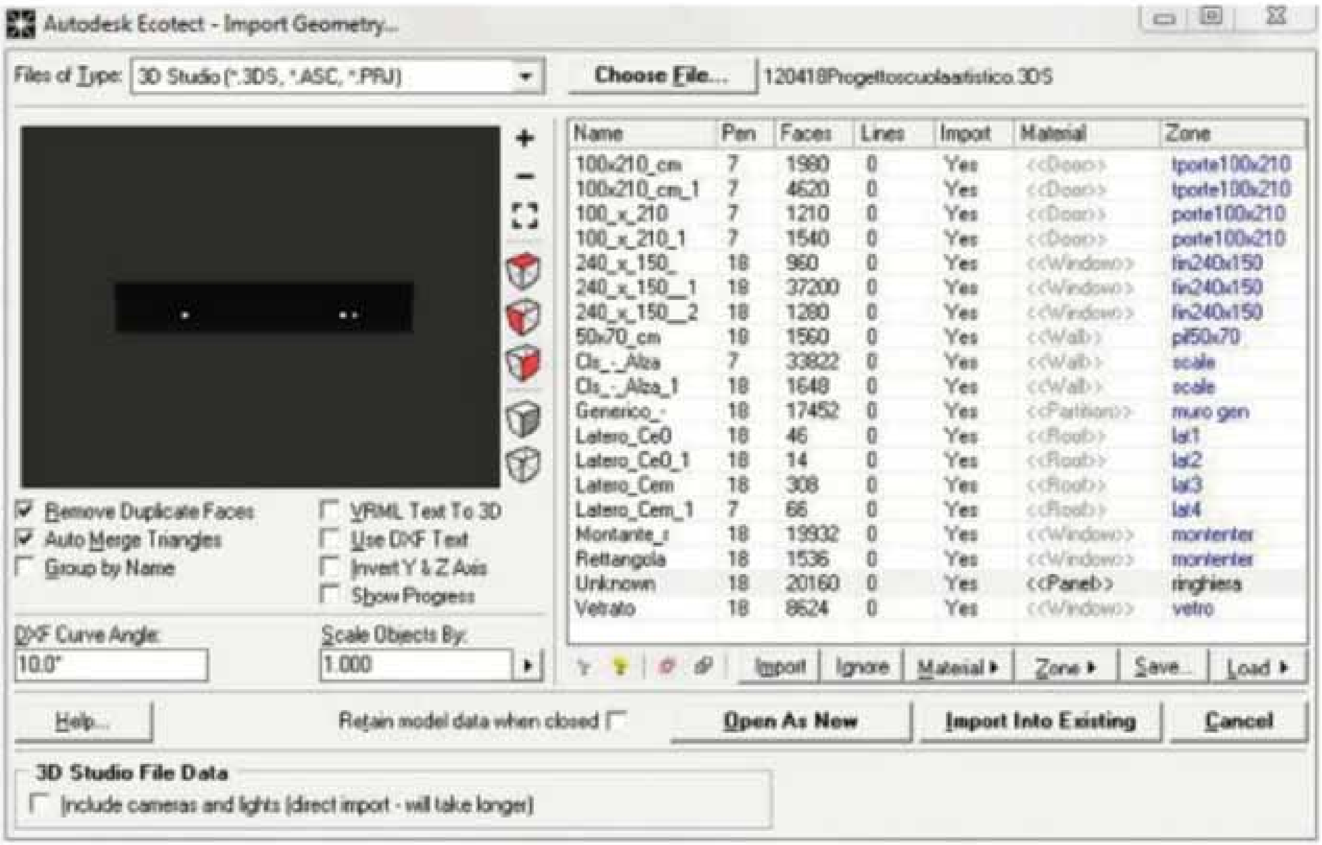




variare le ipotesi poste in sede di analisi dei documenti di archivio. Si è passati quindi alla realizzazione del modello parametrico (Autodesk Revit 2013). L'elaborazione della banca dati è avvenuta sia a livello architettonico, sia a livello strutturale. Particolare attenzione è stata posta nella definizione di ogni elemento che, a partire dalle famiglie standard presenti nella libreria del software, è stato personalizzato per rendere il modello corrispondente al fabbricato esistente.
Completata la fase di modellazione, il modello è stato esportato nei software di calcolo specifico Autodesk Robot Structural Analysis Professional per la verifica statica e il calcolo sismico (ulteriori prove sono in corso con il software CSI ETABS) e in Autodesk Ecotect Analysis per i test illuminotecnici preliminari (per successivi approfondimenti verranno utilizzati Daysim e Radiance). Per poter effettuare i calcoli specifici ha assunto grande importanza l'interoperabilità tra i programmi presi in considerazione e quindi i formati di scambio utilizzati per procedere in modo operativo. Per consentire la minor perdita di dati possibile sono stati effettuati vari test utilizzando i formati .ifc, .RTD,.gbXML, .fbx.
L'unico formato di scambio ad oggi riconosciuto a livello internazionale dall'IAI (International Alliance of Interoperability) è l'IFC (Industry Foundation Classes) sulla base della norma ISO/PAS 16739; tuttavia esso presenta ancora alcuni limiti poiché non consente sempre il corretto passaggio di informazioni tra un programma e l'altro causando talvolta una perdita di dati non trascurabile.
Nei test effettuati si è sempre cercato di dare priorità a questo formato, tuttavia si sono ottenuti risultati migliori con gli altri sopra citati, utilizzando anche diversi applicativi come "ponte" per arrivare a quello desiderato, perseguendo l'obiettivo di conservare la maggiore fedeltà possibile al modello sorgente creato in Revit.
Procedendo per passi successivi, si è partiti dall'analisi illuminotecnica decidendo di costruire un modello 3D in grado di contenere tutte le informazioni per il calcolo specifico, tralasciando i dati relativi alla parte termica e strutturale. Ad esempio al fine di ottimizzare la procedura, focalizzando l'attenzione solo su un'aula, gli ambienti sono stati delimitati grazie all'utilizzo del comando "Locali". Inoltre, il modello è stato correttamente orientato secondo le coordinate geografiche e gli assi cardinali (fig. 4), modellando anche gli elementi ombreggianti in grado di influenzare il test.
Per poter procedere con l'esportazione corretta il modello è stato dapprima importato in 3DStudioMax, utilizzando il formato .fbx, successivamente esportato in formato .3ds e quindi aperto con Ecotect. Si sottolinea che l'esportazione del modello da Revit in formato .fbx è potuta avvenire solo trovandosi in una visualizzazione prospettica o assonometrica dello stesso; altrimenti il comando non risulta attivo. Al momento dell'importazione del modello in Ecotect è stato necessario riassociare a ciascun componente le proprie caratteristiche funzionali e ricreare le "Zone" per ottimizzare la gestione dei dati all'interno del programma (fig. 5).
Si è notato che i vari elementi importati in Ecotect compaiono trasformati in superfici che risultano essere comunque ben accostate tra

over, the model has been correctly oriented in accordance with the geographical coordinates and the cardinal axes (fig. 4), modeling the shading elements able to influence the test.
To be able to proceed with the export of the model, it has been imported into 3DStudioMax, using the format .fbx. Then the model has been exported in .3ds format and opened in Ecotect. It should be noticed that the export of the model in Revit format .fbx has been possible through a perspective or isometric view of the model; otherwise the command is not active. During the import stage of the model into Ecotect, it has been necessary to re-associate the functional characteristics to each component and recreate the 'Zone' to optimize the management of data within the selected software (fig. 5).
Many elements imported into Ecotect has been converted in surfaces during the import phase: however these elements are still perfectly coincident and coherent. After the import phase, it has been possible to carry out the individual lighting analysis (fig. 6) relative the selected classroom.
With regards to the structural model creation, families of analytical components has been used in order to obtain the correct static calcula-

5/ Creazione delle "Zone" durante la fase di importazione su Ecotect Analisis.
Stage of creation of the 'Zone' during the import into Ecotect Analysis.



loro e perfettamente coincidenti. Terminata la fase di importazione si è potuti passare alle singole analisi illuminotecniche (fig. 6) relative all'aula considerata.

Per quanto riguarda la creazione del modello strutturale invece, si è fatto uso delle famiglie di componenti analitici al fine di poterle utilizzare in modo corretto durante la verifica statica. Per prima cosa è stata creata la griglia strutturale, su cui sono stati inseriti i plinti, i pilastri e le travi. La struttura è di per sé molto regolare sebbene talvolta si siano riscontrate delle difformità tra gli elementi: ad esempio, per alcuni pilastri si riscontrano le mensole di sostegno delle travi mentre in altri la sezione si riduce per consentire un piano d'appoggio (fig. 7).

Conclusa la modellazione della struttura, il modello analitico è stato importato in Robot seguendo due percorsi distinti.

Per il primo si è utilizzato il formato .ifc che purtroppo ha manifestato problemi: sebbene il programma considerasse conclusa l'importazione, nessun elemento risultava visibile.

tion. Initially, the structural grid has been created in order to insert the plinths, the columns and the beams. The structure is very regular, however it presents a few dissimilarity among the elements: for example, some columns have the support shelves of the beams, while in others, the section is reduced in order to create a support surface (fig. 7).

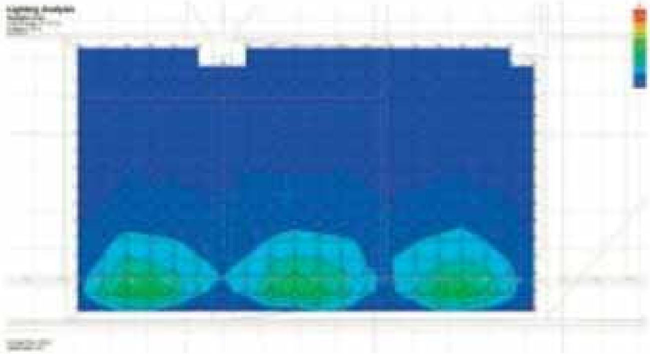
After the modeling of the structure, the analytical model has been imported into Robot through two different methods.

The first method used the .ifc format, which, unfortunately, had some problems: in fact, the software considered the import completed, but nothing was visible.

The second approach has been done through a plug-in within Revit, which allowed the connection with Robot without indirect procedures. The model obtained has been saved in .RTD format (fig. 8).

Certainly the second way was optimal in terms of data retention. However, it must emphasize that, in this case, we cannot speak of real interoperability; in fact two programs belonging to the same software house has been used: this verified what the author Finith E. Jernigan

6/ Analisi del Fattore di Luce Diurna (FLD) di un'aula.
Daylight Factor analysis (FLD) of one classroom.



Per il secondo, l'importazione è stata effettuata attraverso un plug-in all'interno di Revit che ha consentito il collegamento con Robot senza procedure indirette. Il modello, una volta importato è stato salvato in formato .RTD (fig. 8).
Certamente questa strada è risultata ottimale in termini di conservazione dei dati, tuttavia è d'obbligo sottolineare che in questo caso non si può parlare di reale interoperabilità trattandosi di due programmi appartenenti alla stessa software house: si è verificato quello che l'autore Finith E. Jernigan AIA in "BIG BIM little bim" ha definito come little *bim,* (strumenti che si limitano all'agevolazione della metodologia progettuale BIM).
Andando nel dettaglio della metodologia utilizzata per la modellazione, è utile osservare che analizzando ad esempio i tegoli TT, questi rientrano nella famiglia di Revit delle travi prefabbricate, tuttavia questa tipologia di elemento viene utilizzata per realizzare i solai. Questa duplice lettura viene interpretata in modo incoerente poiché dopo l'importazione del modello in Robot i tegoli TT sono considerati come delle travi semplici e quindi non utili ai fini del calcolo dei solai.
Inoltre, il peso proprio Q di ogni elemento è stato calcolato correttamente in Revit, impostando la densità del materiale pari a 25 kN/m³. È possibile mantenere questi valori in Robot o reimpostarli, calcolando "manualmente" i vari dati necessari (fig. 9).
Infine, si è verificata manualmente la veridicità dei risultati ottenuti dal calcolo dello sforzo normale N, taglio T, e Momento flettente M effettuato dal programma (fig. 10).
Ovviamente il modello è ancora in fase di implementazione per cui in futuro sarà possibile effettuare il calcolo statico generale di tutta la struttura e considerare anche quello dinamico.

Risultati e sviluppi futuri

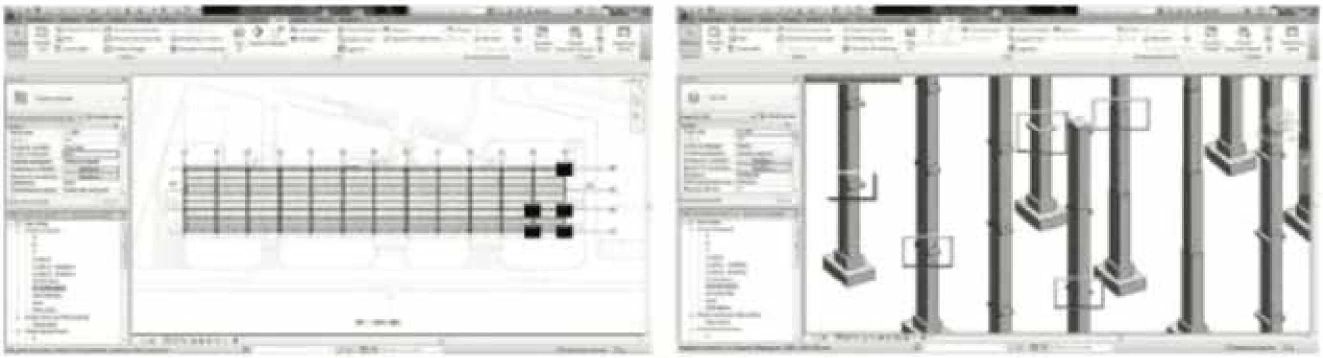
Il modello importato in Ecotect e Robot (rispettivamente per l'analisi energetica e strutturale) consente di effettuare un primo test traendo considerazioni sullo stato di fatto dell'edificio. Conclusa la prima analisi, è possibile ricercare diverse ipotesi di riqualificazione attraverso un procedimento iterativo dei calcoli. Naturalmente, gli esiti risulteranno essere il miglior compromesso considerando i costi di intervento e i benefici ottenibili.
Altro importante risultato perseguibile con sviluppi futuri della ricerca, è la possibilità di usufruire dei nuovi strumenti ICT come ad esempio la realtà aumentata per la visualizzazione rapida in loco degli elementi strutturali ed impiantistici dell'edificio.
La rappresentazione utilizzata in questo modo non si limita ad una semplice raffigurazione dei diversi elementi, ma diventa uno strumento attivo da utilizzare nelle fasi di manutenzione ed eventuale riqualificazione strutturale e/o energetica del manufatto.
L'intento massimo a cui si aspira nel prossimo futuro è che tale metodologia possa essere adottata con sufficiente semplicità, definendo i criteri di intervento per la riqualificazione del patrimonio edilizio esistente dal punto di vista energetico, impiantistico, strutturale ed architettonico.

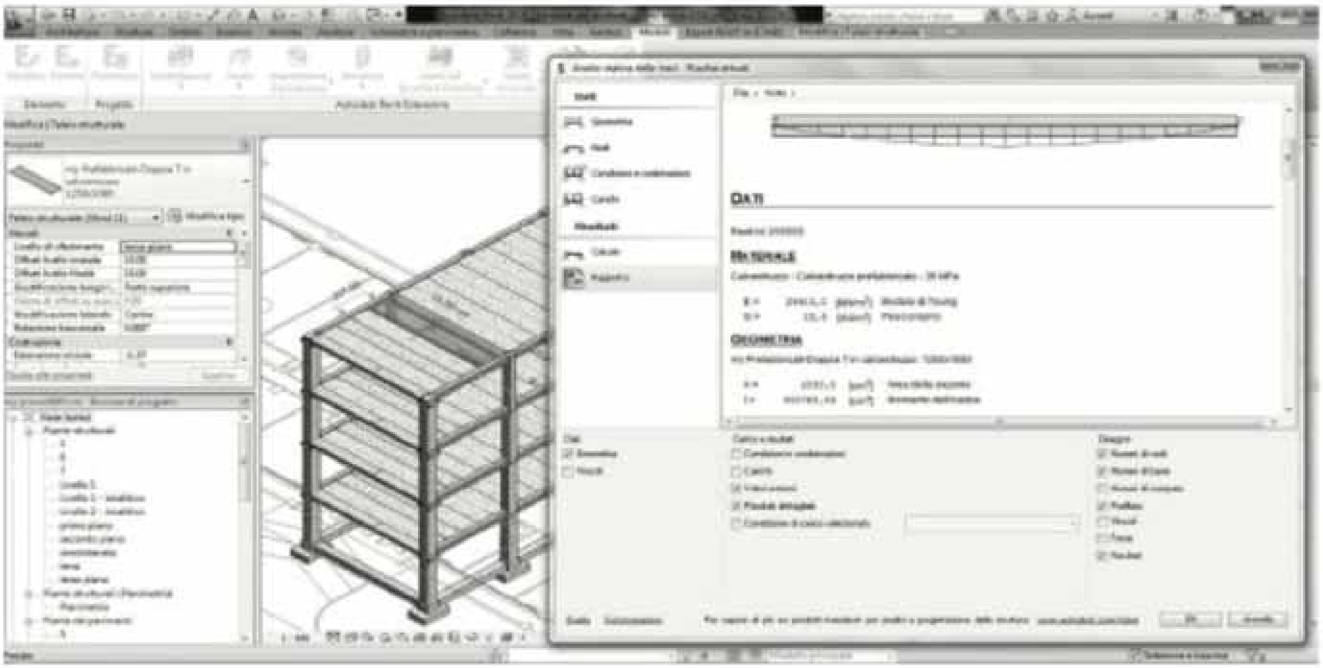
AIA in 'BIG BIM little bim' defined as little *bim*, (tools to facilitate the design methodology BIM).
To detail the methodology used for modeling, it is useful to observe that the beams TT belong to the Revit family of precast beams, but this type of element was used to make the floors in the model. This double feature is interpreted as incoherent: in fact, when the model is imported into Robot, the beams TT are considered as simple beams, not as floors elements, so they are not useful in the calculation of the floors.
Moreover, the weight Q of each element has been calculated correctly on Revit, setting the density of the material equal to 25 kN/m³. It is possible to keep these values in Robot or reset them, calculating 'manually' the necessary details (fig. 9).
Finally, it has been manually verified the accuracy of the results obtained from the calculation of the normal force N, T cutting, and bending moment M carried out by the program (fig. 10).
Obviously, the model is still in the implementation phase, thus it will be possible to make a static calculation of the whole structure and consider also the dynamic test during a future phase.

Results and future developments

The imported model into Ecotect and Robot (respectively for energy and structural analysis) allows to make a first test to obtain data about the actual status of the building. Concluded the first analysis, it is possible to search various hypotheses of redevelopment through an iterative process of calculations. Of course, the results will prove to be the best tradeoff between the intervention costs and the obtained benefits.
Another important result that can be achieved during future development of research is the possibility to use of new ICT tools, such as the augmented reality, for quickening the view of the structural and system elements of the building on site using a portable device.
The augmented representation is not only a mere picture of the system but it could be used as an active tool in the maintenance stage and in the structural, and energetic, redevelopment of the building.
The final goal is that this methodology can be adopted with sufficient easiness, defining the intervention criteria for the redevelopment of existing buildings in terms of energy, systems, structural and architectural.

7/ Individuazione della griglia strutturale e indicazione dei pilastri.
Locating of the structural grid and indication of the columns.
8/ Importazione del modello in Robot mediante Plug-in.
Importing the model into Robot using Plug-in.
9/ Fase di ottenimento del peso proprio.
Step of obtaining the Q weight.





10/ Calcolo strutturale dello sforzo normale e del momento flettente in Robot.
Structural calculation of the normal force and bending moment in Robot.

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[1] PRIN-BHIMM - Programma di Ricerca di Interesse Nazionale sulla Modellazione e Gestione del Patrimonio Edilizio Esistente (Built Heritage Information Modeling/Management), co-finanziato dal Ministero dell'Istruzione, Università e Ricerca (MIUR).

[1] PRIN-BHIMM - Programma di Ricerca di Interesse Nazionale about the Built Heritage Information Modeling / Management, funded by the Ministero dell'Istruzione, Università e Ricerca (MIUR).

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Rilievo e modellazione parametrica del patrimonio storico architettonico
Survey and parametric modelling for historic architectural heritage

Marco Zerbinatti, Isabella Bianco, Cristina Boido, Matteo Del Giudice, Paolo Piumatti, Pablo Ruffino

L'attenzione rivolta verso la conservazione e la tutela del patrimonio architettonico di importanza storica riveste da sempre un ruolo di cruciale importanza per la cultura e la personalità di ogni paese. Il presente contributo si pone l'obiettivo di mostrare come il rilievo e la rappresentazione si stiano plasmando in modo tale da sfruttare i vantaggi delle nuove tecniche digitali a favore di un processo efficientemente gestibile da più operatori che lavorano in fasi differenti del processo edilizio.

Parole chiave: patrimonio edilizio, BIM, interoperabilità, fotomodellazione, nuvola di punti.

The attention toward the Building Heritage preservation and protection assumes all along a role of fundamental importance for the culture and personality of every country. The present paper wants to show how survey and representation are being shaped in way of taking advantage of the new digital techniques so that the building process is more efficiently managed from several professionals working in different moments.

Key words: building heritage, BIM, interoperability, photo-modeling, point cloud.

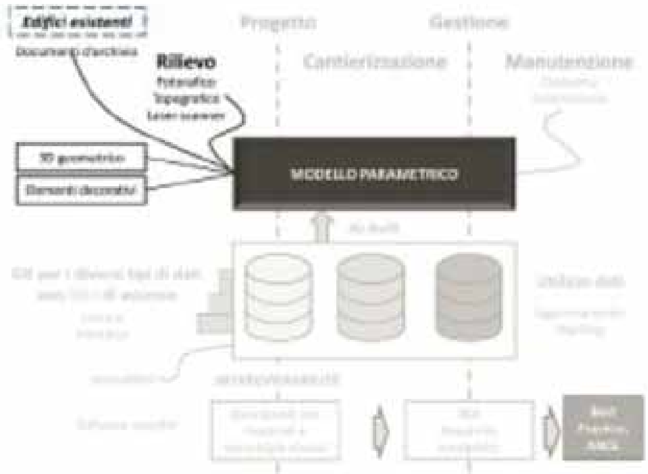
La sensibilità verso il patrimonio storico architettonico è ormai consolidata, ma da un tempo relativamente breve stanno cambiando gli strumenti attraverso cui è possibile analizzare e comprendere tali beni. In particolare, il valore aggiunto rispetto alle tradizionali tecniche di lavoro è l'approccio interdisciplinare e sistemico con cui saperi diversi vengono integrati in modo dinamico e interoperabile. Sebbene il processo sia rimasto immutato - e costituito dunque dalle fasi di rilievo, rappresentazione ed elaborazione dei dati - esso può contare adesso sui vantaggi offerti da una metodologia progettuale basata sul Building Information Modeling (BIM).
Due ricerche, ancora in itinere e di cui il Politecnico di Torino è partner, sono l'occasione per approfondire tali tematiche; esse affrontano, seppur con obiettivi molto diversi, problematiche di rilievo e rappresentazione analoghe. Il progetto PRIN-BHIMM[1] è incentrato sulla gestione dei dati per il restauro/recupero dei beni esistenti attraverso tecnologie BIM, mentre il progetto INTERRREG-Alpstone[2] focalizza l'attenzione sul recupero del tradizionale patrimonio architettonico in pietra diffuso in Val d'Ossola, Piemonte. Sebbene le applicazioni e i relativi casi studio siano dunque piuttosto differenti, una sinergia tra i due gruppi di ricerca permette di concorrere verso il comune obiettivo di adattare i principi e la filosofia del BIM - nato per edifici di nuova costruzione - anche nell'ambito del patrimonio edilizio esistente e, in particolare di un patrimonio a carattere storico.
Tale contributo si traduce dunque nell'impostazione di una metodologia di lavoro interoperabile che tocca le fasi del processo edilizio relative all'acquisizione dei dati e alla loro restituzione grafico-digitale. Il processo si basa su dati di rilievo prevalentemente tridimensionali che ben si adattano alle caratteristiche degli edifici storici e che possono comunicare più agevolmente con software di tipo parametrico.

Metodologia
Prendendo in considerazione le fasi dell'intero processo edilizio (fig. 1) è possibile affermare come la fase di rilievo sia essenziale per conoscere lo stato di fatto della struttura su cui si intende intervenire. Lo schema rappresentato in figura 2, invece, evidenzia come nel patrimonio edilizio esistente, la metodologia BIM possa essere collocata fra gli output originati dal rilievo, e gli input necessari alla generazio-

If this sensibility for the Building Heritage preservation is already far-back shared, the tools for analysing and understanding these assets are nowadays changing. In particular, the added value, if compared with the traditional techniques, is the interdisciplinary and systemic approach with whom different kinds of knowledge are integrated in a dynamic and interoperable way. Even if the process remains unchanged – and made up of survey, representation and data processing phases –, it becomes now coloured with the more up-to-date tones offered by the Building Information Modeling (BIM).
Two still in progress researches, of which Politecnico di Torino is partner, are the occasion to deepen these themes; they are involved, even if with very different aims, in analogous survey and representation issues. The BHIMM (Built Heritage Information Modeling and Management)[1] project focalises the attention on the existing real estate through BIM technologies (the Valentine Castle of Turin is one of the study cases taken into consideration), while the INTERREG-AlpStone[2] project treats the recovery of the traditional stone architectural heritage located in Ossola valley, Piedmont. Even if the applications are therefore rather different, a synergy between the two research groups allows to watch to the common goal of fitting the principles and philosophy of BIM – conceived for new constructions – to the 'as-build' field and in particular to an historical asset.
These challenge is therefore translatable in an interoperable methodology work planning that concerns the whole process, from the first phases of survey till the data processing. The process is based on mostly tridimensional survey data, which are adaptable to the historical building characteristics and which can easily communicate with parametric software.

Methodology
Taking into account the whole building process (fig. 1) it is possible to affirm that the survey phase is essential in order to know the original conditions of the asset to redevelop. In this phase it becomes really important to manage a big amount of data coming from different sources, as e.g. archive documents, geometrical, photographic and laser-scanner survey. The survey of an historic building and its

1/ Schema del processo edilizio con evidenziate le fasi trattate nel presente contributo.
Scheme of the building process, showing the steps discussed in this paper.



2/ Uso del BIM nel rilievo e modellazione per il patrimonio storico esistente.
Use of BIM in surveying and modeling for the historical heritage.

ne degli elaborati grafici (fig. 2). Risulta necessario, dunque, acquisire una serie di documenti che devono essere analizzati e ben interpretati al fine di diventare il veicolo per la realizzazione del modello parametrico, strumento di cui si farà uso non solo durante le prime fasi (relative al rilievo, progetto e cantierizzazione), ma anche in quelle finali di gestione e manutenzione del fabbricato.

Per questo motivo, ai fini dell'ottimizzazione dell'utilizzo dei dati, è utile stabilire una gerarchia delle informazioni che possano essere sfruttate al meglio all'interno del processo BIM: attraverso un'adeguata predisposizione sarà infatti possibile riuscire a estrarre facilmente e correttamente le informazioni e ottenere gli input necessari per determinate analisi specifiche come ad esempio i calcoli strutturali, illuminotecnici, la gestione dei locali, etc. In questa prospettiva acquisisce particolare rilevanza la rappresentazione dei dati inseriti nel modello parametrico in funzione del livello di sviluppo (*Level of Development*) e del livello di dettaglio (*Level of Detail*) del progetto. Diventa quindi importante sottolineare la differenza tra il rilievo, il modello parametrico e l'edificio reale.

Nella consapevolezza di quanto affermato, il contributo presenta diverse modalità di ottenimento del modello parametrico in funzione degli strumenti adottati in fase di rilievo.

Proprio per questo motivo, nel primo test, la definizione del modello è ottenuta mediante un rilievo di tipo tradizionale diretto del manufatto. Riscontrati i limiti di tale metodologia e coscienti del rapporto sinergico fra i software parametrici e i modelli tridimensionali, nei test successivi sono stati eseguiti rilievi il cui output fosse una nuvola di punti.

Tale obiettivo è perseguibile attraverso diverse tecniche, tra cui: il laser scanner e la fotomodellazione.

Il laser scanner è uno strumento ormai consolidato, in grado di acquisire una grande quantità di dati di elevata precisione in tempi molto ridot-

context could be considered as a necessary step of the building process of requalification because it allows to know all aspects of the building.

The diagram in figure 2 shows that in existing buildings, the BIM methodology is placed between the output arising from the survey, and the input necessary to the generation of drawings (fig. 2).

It is so necessary to obtain several documents that have to be analysed and interpreted in order to become the vehicle for the realisation of the parametric model, tool useful not just during the first phases, but also in the last ones of building management and maintenance. For these reasons and in order to optimise the data utilisation, it is better to establish a hierarchy of the information that will be take part in the BIM process: through an adequate predisposition it will be indeed possible to easily and accurately extract information and obtain the necessary inputs for specific analysis as e.g. structural and illuminating calculations, rooms management, etc.

In this perspective it becomes of particular relevance the representation of the parametric model data in relation to the project level of development and level of detail. It is so necessary to underline the difference between survey, parametric model and real building.

The paper presents different ways of obtaining the parametric model in function of the instruments adopted in the survey phase.

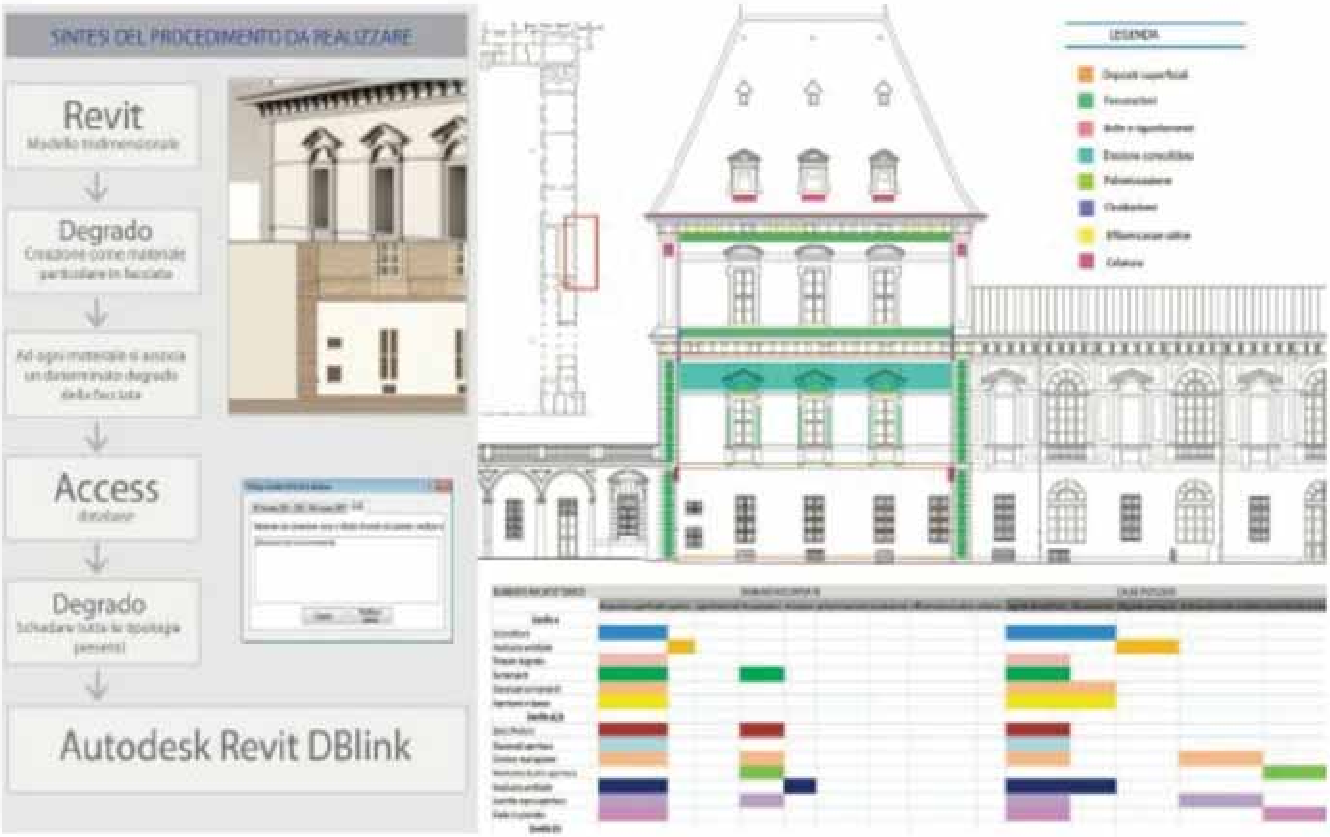
Since our researches present as cornerstone the historical heritage (that, for its nature is often made up of irregular elements or articulated geometries) and since the parametric software find a synergetic support on tridimensional models, the way that we have considered the most efficient in order to obtain geometrical data is the execution of a survey whose output is a point cloud.

This objective is achievable through different techniques, as laser scanner and photomodeling, which have been employed during our researches.

The laser scanner is an already well-established tool, able to acquire a huge quantity of data in a very short time. It is a high precision technique and it can be managed through software such as Faro Scene; the major inconvenient is the high price of the tool.

The photomodeling is instead a technique still in phase of development, based on the correlation of images shot with common digital ca-

3/ Modello parametrico del castello del Valentino.
BIM model of the Valentino Castle.



ti; il maggiore inconveniente è legato agli elevati costi dello strumento. La fotomodellazione è invece una tecnica ancora in fase di sviluppo basata sulla correlazione di molteplici immagini scattate con l'ausilio di comuni fotocamere digitali. Diversi software di elaborazione (Autodesk 123D Catch, Agisoft Photoscan, ESAT Arc3, etc.) permettono la costruzione 3D della superficie fotografata attraverso l'individuazione di punti omologhi in fotografie diverse e l'orientazione relativa delle immagini.

Le tecniche di rilievo basate sulle nuvole di punti non sono tuttavia da vedere in antitesi ai più tradizionali metodi di rilievo. Viceversa, il rilievo geometrico diretto (eseguito con strumenti semplici quali rotella metrica, filo a piombo, distanziometro, etc.) si pone in integrazione al rilievo digitalizzato. Esso può infatti essere utile per avere riferimenti, conferme dimensionali e rilievi di dettaglio di oggetti di dimensioni modeste.

Una volta conclusa la fase di rilievo, il successivo obiettivo è la rappresentazione dei dati raccolti tramite un modello d'informazioni.

meras. Several elaboration software (Autodesk 123D, Agisoft Photoscan, ESAT Arc3D, etc.) allow the 3D reconstruction of the photographed surface through the individuation of homologous points in different pictures and the relative orientation of the images.

Anyway, the survey techniques based on point clouds have not to be seen in contrast with the most traditional survey methods. Vice versa, the geometrical survey (carried out with simple tools as yardsticks, plumb lines, EDM, etc.) integrates the digitalised survey. It could in fact be useful in order to have references, dimensional confirmations and survey of detail of quite little-size objects.

Once the survey phase has been completed, the following aim is the representation of data obtained through a tri-dimensional parametric model.

Study cases

Today, several researches try to use the BIM methodology also for historical buildings. One of the means, for example, is the creation of li-

4/ Modellazione parametrica e nuvola di punti.
Parametric model and point cloud.

Nel caso di questo lavoro, per realizzare il modello tridimensionale parametrico dei diversi casi studio, è stato utilizzato il software Autodesk Revit.

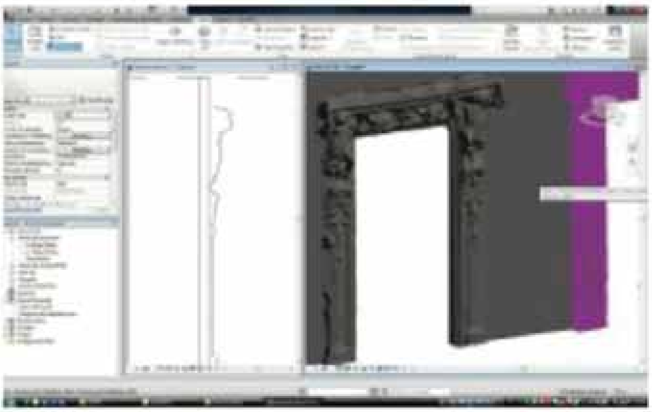
Casi studio

Oggi, diverse ricerche si sforzano di sfruttare la metodologia BIM anche nell'ambito del patrimonio storico edilizio. Uno dei mezzi, ad esempio, è la creazione di librerie interattive di oggetti architettonici parametrizzati. Tuttavia, spesso l'architettura storica presenta elementi decorativi caratteristici e irripetibili. Proprio per siffatto motivo, in questo contributo si è deciso di trattare casi studio (ad esclusione del test 1) che presentassero elementi architettonici unici, non facilmente archiviabili in una libreria di componenti.

Castello del Valentino, elementi di dettaglio - test 1

Il rilievo diretto, eseguito con distanziometro e rotella metrica, è stato utilizzato per studiare in modo accurato gli assi, i moduli e le proporzioni di una specifica zona del Castello del Valentino, analizzando nel dettaglio la geometria di elementi quali finestre e capitelli di particolare rilevanza architettonica. I dati raccolti in situ hanno costituito l'input per la successiva modellazione in Revit (fig. 3). In questo caso, tali documenti sono risultati utili ai fini della modellazione parametrica ad alto dettaglio di alcuni particolari architettonici quali ad esempio, i cornicioni, i capitelli, le lesene, le paraste bugnate, etc. È evidente come in questo caso la modellazione abbia ri-

5/ Sezione e inserimento nel muro della nuova famiglia.
Section and inserting in the wall of the new family.



braries of parameterized and interactive architectural objects. However, very often the historic architecture features decorative elements that are characteristic and unique. For this reason, in this paper the case studies (with the exception of test 1) have unique architectural elements, not easily storable in a component library.

Valentine Castle of Turin - 1st test

The direct survey, performed with electronic distance meter and measuring tape, was used for accurate study of the axes, the forms and proportions of a specific area of the *Castello del Valentino*, analyzing in detail the geometry of elements such as windows and capitals of particular relevance. The on-site data are the input for the next modeling in Revit (fig. 3). In this case, these documents were relevant to the parametric modeling high detail of some architectural details such as, for example, cornices, capitals, pilasters, the rusticated pilasters, etc.
It is evident that in this case the BIM modeling has requested many resources (especially in terms of time), obtaining a product that is close to reality without avoid some discrepancies.

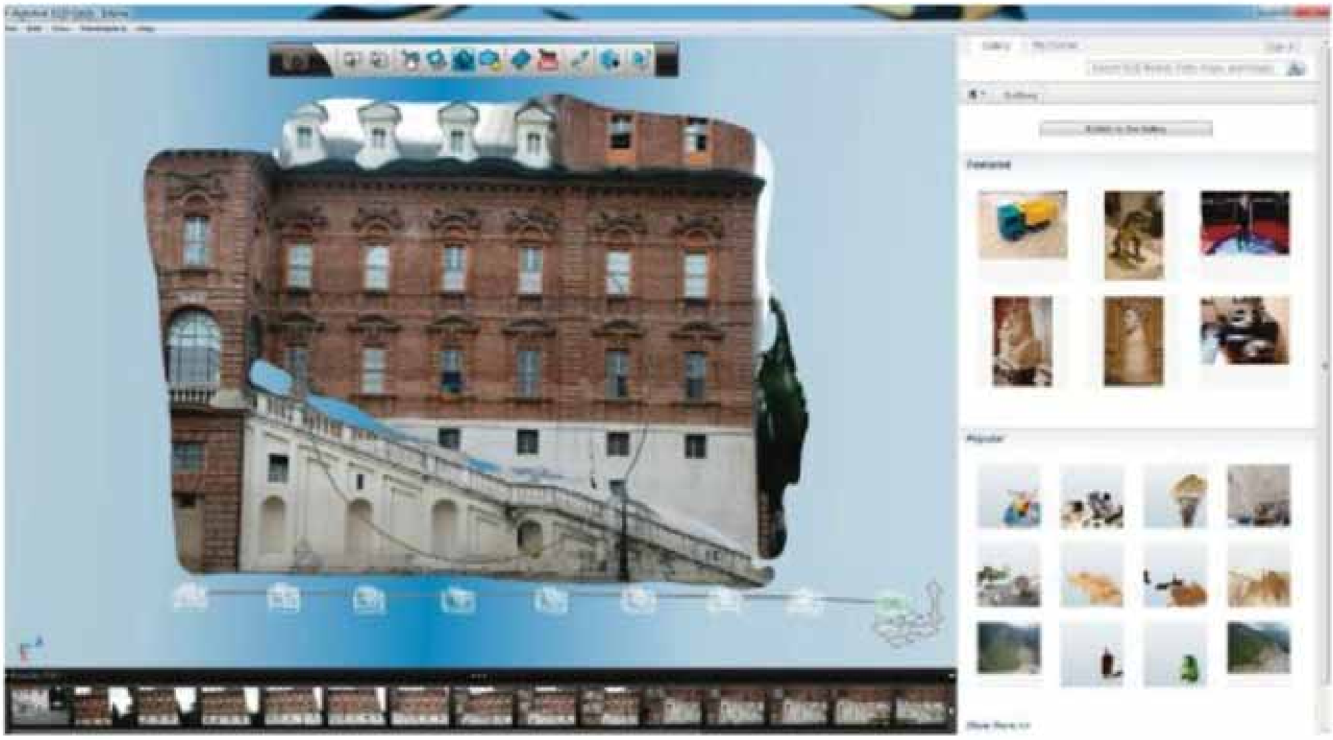
Veglio Castle - 2nd test

One of the Interreg-Alpstone research study case is the Castle of Veglio (hamlet of Montecrestese, Piedmont), made up of a XIII century square tower and a XV-XVI century rectangular construction. This study has been a chance for obtaining a representation in terms of BIM, starting from the first phases of knowledge till the 3D modeling.
The georeferenced point cloud is then exported with Faro Scene software in a.pts file, Revit compatible format. In this way it has been possible to start with the tridimensional modelling, that is forcedly a simplification of the scansion. In Revit every professional is enable to associate properties to the object: the Revit file of the Veglio Castle owns indeed information about materials, structures, pathologies, etc.

Valentine Castle of Turin, Door with decorations - 3rd test

In the last two tests, a survey based on the photo-modeling was carried

6/ Modello di superficie ottenuto con il software 123D Catch.
Mesh model obtained with the software 123D Catch.



chiesto non poche risorse (soprattutto in termini di tempo), ottenendo un prodotto che si avvicina alla realtà senza però evitarne alcune difformità.

Castello di Veglio - test 2
Uno dei casi studio della ricerca Interreg-AlpStone riguarda il castello di Veglio (frazione di Montecrestese, Piemonte), costituito da una torre quadrata del XIII secolo e da una costruzione a pianta rettangolare risalente al XV-XVI secolo. Tale caso studio è stato l'occasione per ottenere una rappresentazione in termini di BIM a partire dalla fase di rilievo fino alla modellazione tridimensionale.
Il rilievo, avente come scopo quello di ottenere una nuvola di punti dell'intero manufatto, è stato eseguito per mezzo di un laser scanner. Le singole scansioni effettuate, hanno generato nuvole di punti successivamente allineate e georeferenziate. L'insieme delle scansioni è stato elaborato con il software Faro Scene ed esportato in file.pts, formato compatibile con Revit. A questo punto è stato possibile iniziare la modellazione tridimensionale, che risulta necessariamente una semplificazione della nuvola di punti (fig. 4). In Revit ogni professionista che collabora alla restituzione e analisi del modello può associare proprietà di diversa natura all'oggetto: il file Revit del castel-

out. In this first case the object is a major port of considerable architectural interest located inside the Valentino Castle. Photo-modeling was accurate and there was no need to integrate it with survey data directly. 16 photos were included in the program 123D Catch for an output consisting of 6150 vertices. Obtained the photographic model, was required before importing into MeshLab in order to be able to export the mesh to a file.dxf format that can be opened in the parametric software. So, it was imported to Autodesk Revit creating a system family (fig. 5).

Valentine Castle of Turin, Staircase toward Po river - 4th test
The staircase survey has been carried out with the photomodeling technique: 20 photos have been shot from different points of view and being careful of taking clear pictures, without contrasts, over-or underexposed. Pictures have been the input data for the Autodesk 123D Catch software (fig. 6), which furnished a staircase model made up of 16781 vertexes.
Nevertheless, since in reason of the large staircase dimensions and the difficulty in shooting optimal pictures, the photographical model presents some uncertainties, the knowledge moment has been completed with a geometrical direct survey. The modelling phase is still in pro-

lo di Veglio possiede infatti informazioni circa i materiali, la struttura, le patologie, etc.

Castello del Valentino, cornice decorata di una porta - test 3

Negli ultimi due test, è stato eseguito un rilievo basato sulla foto-modellazione. In questo primo caso l'oggetto di rilievo è una porta di rilevante interesse architettonico situata all'interno del castello del Valentino (Sala del Negozio). Date le dimensioni notevolmente ridotte dell'oggetto, la fotomodellazione è risultata precisa e non c'è stato bisogno di integrarla con dati di rilievo diretto. Sono state inserite 16 foto nel programma 123D Catch per un output costituito da 6.150 vertici.

Ottenuto il modello fotografico, è stata necessaria una prima importazione in MeshLab al fine di poter esportare la mesh in un file .dxf, formato apribile nei software parametrici. Quindi, è stato importato in Autodesk Revit creando una famiglia di sistema (fig. 5).

In questo caso si evidenzia il problema del compromesso fra precisione della fotomodellazione ed elaborazione del modello nei software. Infatti, per ottenere una maggiore accuratezza del modello non sono trascurabili le prestazioni del computer.

Castello del Valentino, scalone verso il fiume Po - test 4

Nell'ultimo test si è effettuato il rilievo di uno scalone esterno al castello mediante fotomodellazione: 20 foto sono state scattate da punti di vista diversi facendo attenzione ad avere immagini nitide e senza contrasti, zone sovra o sottoesposte. Le fotografie hanno costituito il dato di input per il software Autodesk 123D Catch (fig. 6), il quale ha fornito un modello dello scalone composto da 16.781 vertici.

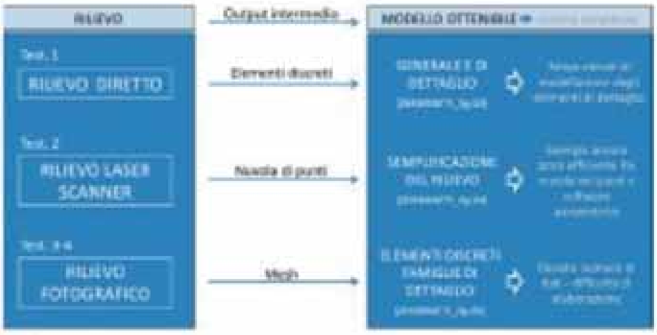
Date le grandi dimensioni dello scalone e la difficoltà nello scattare foto ottimali, il modello fotografico generato dal software non restituisce il manufatto nella sua interezza; il momento conoscitivo è stato dunque completato con un rilievo di tipo geometrico.

Infine, la fase di modellazione è ancora in elaborazione in quanto le informazioni provenienti dalla diverse fonti devono ancora essere analizzate e interpretate nel modo corretto.

Conclusioni

Il processo di rappresentazione degli edifici storici ha recentemente subito progressivi mutamenti che hanno migliorato le tradizionali potenzialità del disegno e del rilievo. Non in contrasto, bensì in armonica continuazione, le tecniche da secoli consolidate hanno lasciato spazio a quelle digitalizzate di rilievo e restituzione che bene si adattano alla morfologia irregolare degli edifici storici e alla necessità di lavorare a più mani su uno stesso oggetto edilizio. Si stanno dunque sviluppando sempre più tecniche di rilievo basate su informazioni tridimensionali (laser scanner e fotomodellazione) che vanno ad alimentare restituzioni parametriche più facilmente gestibili che parlano il linguaggio del BIM. È quindi d'obbligo riflettere su come la metodologia BIM possa essere in grado di abbattere alcune barriere relative alla restituzione grafica degli edifici storici che talvolta possono creare alcune difficoltà in chi deve realizzare il modello parametrico; si

7/ Schema riassuntivo dei test effettuati.
Schematic summary of the tests performed.



gress because information coming from different sources have still to be analysed and interpreted.

During our study cases, in order to obtain a parametric model, it has been employed the software Autodesk Revit 2013. Considering for example the laser scanner point cloud importation, it is possible to have some problems related to the management of a so large quantity of data; for this reason the entire point cloud has been divided into different parts that have then been reassembled in a unique file which contains all the links: the model realisation has been accelerated thanks to these external references. Moreover, once that the importation phase has been concluded, the following step is the modeling phase; levels of reference and horizontal and vertical sections have been created in order to test the accordance between model and point cloud.

Conclusions

The historic building representation process has recently experienced progressively changing that have improved the traditional potentialities of drawing and survey. Not in contrast, but in harmonic continuation, centenary techniques have let the place to digital techniques of survey and elaboration that rightly adapt themselves to the irregular morphology of historic building and to the necessity of working in team on a same building object. They have therefore developed survey techniques based on tridimensional information (laser scanner and photomodelling) which nourish parametrical results speaking in terms of BIM and more easily manageable.

To obtain the parametric model of a historic building, several types of survey were tried, analyzing subsequently the different benefits, limitations and weaknesses of each method (fig. 7).

The BIM methodology is therefore able to tear down some barriers connected to the graphical restitution of an historic heritage, which is often not easy to study with parametrical tools. Some criticalities are however present when a big amount of data has to be managed. Our researches have to be considered as a starting point leading to the still in progress elaboration of guide lines for the correct use of the BIM methodology for 'as built' assets.

presentano tuttavia alcune criticità relative alla gestione complessa di una grande quantità di dati.

Per ottenere il modello parametrico di un bene architettonico esistente, sono state sperimentate più tipologie di rilievo e modalità di acquisizione dei dati, analizzando, in un secondo momento, i diversi benefici, limiti e criticità che i singoli test ammettevano (fig. 7).

Il lavoro prodotto è da considerarsi come base di partenza per l'elaborazione di linee guida finalizzate ad un corretto uso della metodologia BIM negli edifici esistenti, soprattutto storici, oggi ancora in fase di ricerca a livello nazionale e internazionale.

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Interoperability between building information models and software for lighting analysis

Chiara Aghemo – Politecnico di Torino - DENERG, Turin, Italy
Laura Blaso – Politecnico di Torino - DENERG, Turin, Italy
Daniele Dalmasso – Politecnico, di Torino - DISEG, Turin, Italy
David Erba Politecnico – Politecnico, di Torino - DISEG, Turin, Italy
Matteo Del Giudice – Politecnico, di Torino - DISEG, Turin, Italy
Anna Osello – Politecnico, di Torino - DISEG, Turin, Italy
Giovanni Fracastoro – Politecnico di Torino - DENERG, Turin, Italy
Anna Pellegrino – Politecnico di Torino - DENERG, Turin, Italy
Pablo Ruffino – Politecnico, di Torino - DISEG, Turin, Italy

Abstract

Lighting analysis models are being integrated into building information models (BIM) quickly. The BIM of the Politecnico di Torino (Polito) campus used in the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) project is an integrated representation of each building to merge architectural, structural, electrical and HVAC elements and components. In the Polito campus there are three types of buildings: historical, modern and contemporary. A special approach has been adopted to model and to exchange data between software about historical buildings because they are characterized by paints, stuccos, etc.

The aim of this research was to set a parametric model able to share information without data loss, testing the interoperability between architectural software like Revit Architecture and lighting analysis software like Daysim and Radiance. As the process of exchanging data from Revit to Daysim and Radiance is not direct, Ecotect Analysis was used as an "interoperable bridge" with good results. Three different formats were tested: IFC, gbXML and FBX and for each one problems and possible solutions were analysed. Up to now, Ecotect was used in two different ways: to define material parameters before the export phase and to visualize analytical data obtained from Daysim and Radiance. In our tests some errors have occurred referring to data retention like material properties, but at present the main problems have been solved. Indications about performance of daylighting and energy consumption have been obtained, although a lot of work should still be done. The correct data exchange that we obtained enabled the optimization of the building simulation process by avoiding the need to remodel the same building in the lighting applications.

1. Introduction

Building information modelling (BIM) has received much attention in recent years due to its possibility of developing a new methodology of design, construction and facility management based on information exchange. This process is achieved through the interoperability of software that is defined as "the need to pass data between applications, and for multiple applications to jointly contribute to the work at hand" (Eastman C. et al., 2008). In this way a single building model can be used to perform all the simulations needed for its design and operation like lighting and thermal analysis, without the necessity to remodel it in any applications. On the other hand, this process is still not easy on account of the shortage of complete technical standards.

"Detailed technical standards are required to unambiguosly define the requirements of specific information exchanges as user of the exchange standards will do so with various types of software."

"At present, data exchanges between two application are typically carried out in four ways: direct; proprietary links between specific BIM tools; proprietary file exchange formats, primarily dealing with geometry; public product data model exchange formats like IFC, or XML – based exchange format" (Osello A., 2012). However, although the possibilities of exchange may appear numerous, there are cases which still require the use of an "interoperable bridge" to complete the procedure.

The present paper presents a set of criteria for the creation of a suitable parametric model. On the basis of these criteria, it describes the related tests aimed at data exchange between architectural and lighting analysis software carried out during the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) project. The project in fact is aimed at implementing a Building Management System based on the integration of both building information modelling and advanced ICT based control and monitoring system to increase the energy efficicency of public buildings. Actually, energy efficiency was, in the design phase of the project, mainly assessed through lighting and HVAC dynamic simulations.

The tests on data exchange between architectural and energy software have come to the definition of a procedure that allows interoperability by avoiding the need for external input from users for the exchange of information related to the model.

2. Simulation

All tests were conducted on six couples of rooms, selected for the SEEMPubS project, on the campus of the Polito. In these rooms, the new control and monitoring solutions for lighting, heating/cooling and electrical appliances were deployed to demonstrate the efficacy of the planned BMS. For these rooms lighting and thermal simulations were needed to assess the effectivness, in terms of comfort and energy savings, of possible different control strategies. The choice of the rooms was conducted according to the following criteria: representativeness with respect to the campus and other public buildings; energy saving potential, estimated according to their architecture, orientation, system and occupancy characteristics. The selected spaces are divided as follows:

- Four offices at the Valentino Castle, premises of the School of Architecture
- Two offices and two classrooms at the Main Campus in Corso Duca degli Abruzzi
- Four offices at Cittadella Politecnica, recently built next to the Main Campus, Politecnico's research centre

Building information model of each room was realized through Autodesk Revit, merging the architectural model with structural, mechanical, electrical and HVAC models. Methodologically, the model setup followed five phases which were functional to the type of activity for which the model itself is built.

The first phase provided for the definition of standards necessary to enable the collaborative work. The model was organized by dividing the various elements, according to their specific function, thanks to the use of WORKSETS in order to facilitate the sharing of work.

The second phase, related to a preliminary site inspection and starting from achieved documents, concerned modelling quickly the existing structure in an urban scale. This model includes building location, typology, size, volume, construction period and is used to analyze the main aspects of the building's performance, with a particular emphasis on energy efficient and sustainable design and management.

The third phase enabled the realization of a preliminary model that, at any time, can be enriched with all the specific information such as doors and windows, materials and walls stratigraphy. A survey was carried out in two different and complementary ways:

- Using a total station and a GPS receiver in order to establish precise GPS coordinates of the essential exterior and interior building elements

Fig. 1 – Survey of the Main Campus realized through a total station

- Using Electronic Distance Meter (EDM laser) to take quickly the measurements of the rooms

The fourth phase concerned the choice of the software tools that may be used in an interoperable way like Revit Architecture, Revit MEP, 3dStudioMax, Ecotect Analysis, Daysim, Radiance, Sketch Up and AutoCAD.

With the fifth phase began the setting of a method of continuous cross-checking and updating of data, with the intention to create an integrated model which is as correct as possible for each use. This phase was closely related to the previous one and it is continuously evolving. In fact, the exact knowledge of what type of data and from which software they can be successfully exchanged requires interesting considerations on the standards to be used in the integrated model to optimize the BIM process.

Fig. 2 – Example of final model of the Main Campus

Subsequently to the setting of the model, in the SEEMPubS project, thermal and daylighting simulations were required to estimate the rooms' energy performance.

In this paper the tests and procedures adopted to exchange data between architectural model and software for daylighting analysis are described. In the project lighting simulation was necessary to estimate the availability of daylight in the rooms, in order to define the control strategy of electric lighting based on daylight availability and on the rooms' utilization schedules. Furthermore, after the definition of the possible electric lighting control rules, the lighting simulation was used to estimate the consequent energy performance of the lighting systems (Fracastoro G.V. et al., 2012).

To proceed with the lighting analysis it was necessary to correctly characterize all construction components of the model (walls, floors, false celling, windows, window's frame, doors, internal obstruction and forniture etc.). This process occurred utilizing the Revit embedded logical division, thus reaching the Typology detail level (Family type). Therefore, in each family of homogeneous elements different types have been created for each object according to the materials that constitute them. As far as the modeling of the external environment surrounding the study object is concerned, which might influence the daylighting calculation, it has also been modeled with different typologies of building elements. To speed up the analysis process, the spaces were modelled using simplified furniture and external obstruction. Then, to obtain a correct lighting analysis, it was necessary to proceed with the optical characterization of all surfaces that may be involved in terms of interaction with light inside the room.

The characterization of materials' optical properties is an essential phase of 3D model preparation for the subsequent lighting simulation. Therefore, the reflection and/or transmission properties of each material and its mode of reflection (specular, diffused, mixed, etc.) must be defined. In this project the optical properties of the room and furniture surfaces were defined measuring, with a spectrophotometer, the chromatic characteristics and the visible reflectance. Transparent materials were characterized measuring the visible transmittance with a luminance meter. Moreover, by using software that in addition to numerical results also provides a rendering of the lighting environment, it is also necessary to define the materials' chromatic characteristics. The general rule consists therefore in diversifying volumes in relation to material, so that it is possible to associate their light reflection, light transmission and the chosen material's rugosity.

Several applications are available to perform daylighting analysis, characterized by different calculation approaches, accuracy and type of achievable results (Pellegrino A., 2012). Some of them are based on the concept of daylight factor, which assesses a room's daylight availability through the calculation of the ratio between indoor and outdoor illuminance under a reference sky condition (Dialux, Ecotect Analysis, etc.), others

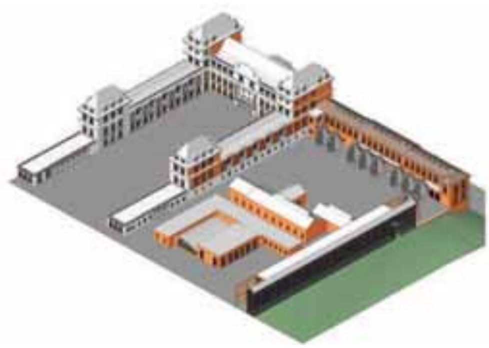

Fig. 3 – Final model of the Valentino castle Campus

calculate the illuminances within a room taking into account more detailed sky luminance distribution, which could vary from clear to intermediate to overcast, depending on the designer's input or on the climate of the considered site (Radiance, Daysim, Lightsolve, etc.). The two groups of software usually differ also for the accuracy of the algorithms used to calculate both direct and reflected components of daylight. Among the second group of applications some can be used to calculate time varying illuminances profile, for instance to assess Dynamic Daylighting Performance Metrics such as Daylight Availability or Useful Daylight Illuminances. This analysis, based on climate data and, usually, on a yearly basis, is the premise for a more detailed calculation of the electric energy consumption of the lighting systems, in particular when automatic control systems are used.

For the SEEMPubS project, daylighting simulations and consequent electric lighting energy calculations were performend using the climate-based dynamic application called Daysim (Reinahart C.F., 2001). From the operating point of view, to start the simulations it was necessary to import a 3D model of the room under study and its external obstructions. The 3D model, in this case, was realized with the Revit applications, which allow a complete modeling from the architectural and systems point of view, compared to other software such as SketchUp, AutoCAD, Ecotect Analysis. Hence, Ecotect Analysis has been used for the following three purposes:

- Like an "interoperable bridge", because, unlike Revit, one of Ecotect Analysis' functions allows model exportation to lighting application such as Daysim or Radiance, automatically creating the files required for the subsequent lighting calculation. These contain the geometric characterization and material assignment (.rad extension), viewport definition (.vf extension), coordinates and orientation of points in the calculation grid (.pts extension), climatic file (.wea) and finally the complete Daysim file (.hea)
- In order to define materials' optical properties and the calculation plan to be used in Radiance or Daysim simulation
- In order to graphically process the numerical data obteined with Daysim / Radiance, which are imported in the .dat format (coming from Radiance) and .da (coming from Daysim) and therefore their 3D visualization.

It must be specified that, despite Ecotect being developed as a simulation program aimed at evaluating buildings' performance, with particular attention to energy aspects from the point of view of sustainable design, in this case it was not used directly to perform the lighting analysis because higher accuracy and more detailed results were required. Moreover, this software does not directly allow a dynamic climate-based simulation.

In order to proceed with model exportation from Revit into Ecotect Analisys, and later to Daysim, three different procedures are defined and tested. Different results are analyzed and the most appropriate procedure from the point of view of lighting simulation is chosen.

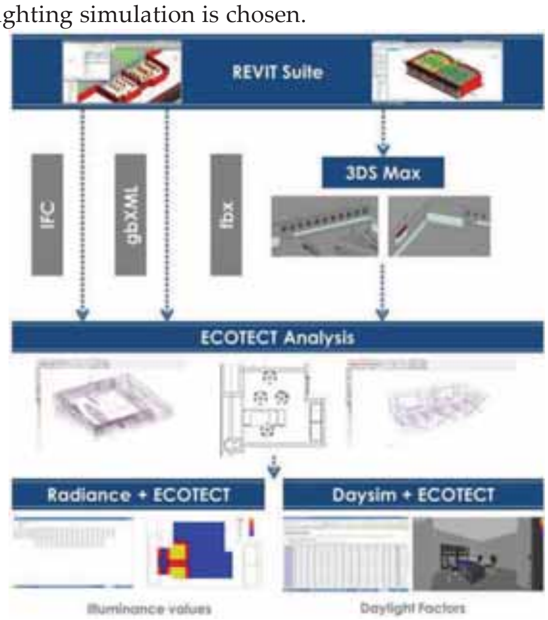

Fig. 4 – Layout of the procedures followed

The first export procedure consisted in following the traditional approach suggested by literature: exporting the file in Industry Foundation Classes (IFC) format. IFC is the main buildingSMART data model standard and it is an open format; therefore it can be used to exchange and share BIM data between applications developed by different software vendors without having to support numerous native formats. IFC is registered by ISO as ISO/PAS 16739 and is in the process of becoming official International Standard ISO/IS 16739. File importation occurs through the MODEL/ANALYSIS DATA modality because is the only one of the two available importation modes to be compatible with .ifc files, and it can directly import the .ifc files in the Ecotect Analysis application. During the procedure, the imported elements are listed in the importation window, including surface and single elements, as well as elements realized in Revit that are being imported in Ecotect Analysis.

The second procedure analyzed consists in exporting the 3D model through the creation of a Green Building schema XML file (gbXML). gbXML is an open scheme which facilitates data exchange of building properties stored in 3D building information models (BIM) to engineering analysis tools. In order to correctly export the data in the gbXML format it is essential to include in Revit model the ROOM entity. This consists in assigning to every closed space (delimited by a floor, walls, and ceiling) a label, precisely ROOM, identifying the room's volume; this operation allows thus to identify in advance the THERMAL ZONE used by Ecotect Analysis to the lighting simulations. If this operation is not performed, the gbXML file is not created. The gbXML standard enables the export of various types of information, in addition to ROOMS. In fact, it is possible to export the building's geographical location, its construction type, shading surfaces and any other architectural element that makes up the building. Trying to import the file in Ecotect Analysis, it is possible to verify that the ROOMS are imported as well as the building elements modeled with Revit.

Both the first two procedures presented problems during the importation phase in Ecotect Analysis. Therefore the third methodology was studied and tested.

The third procedure concerns exporting the model from Revit in the .fbx format. In this case exportation only occurs correctly in an elevation or axonometric view of the model, otherwise the command is not available. This operation has no control setting, because the command is closed and the operator cannot interact. Since Ecotect do not accept .fbx files, a third intermediate application has been introduced. This additional tool is 3dStudioMax. The use of this application has been necessary because it was not possible to export from Revit a file format compatible with Ecotect Analysis maintaining the model unaltered. Through 3dStudioMax, it is possible to export the file in a .3ds format fully compatible with the lighting simulation application used for the SEEMPubS project.

In the 3dStudioMax environment, the .fbx files are not directly imported, but a linkage operation must be performed through the command FILE LINK MANAGER. This instrument also allows the user to select among different link options, the one most appropriate for the creation modality of the Revit files. Among the available options, the importation of the elements composing the model was chosen grouping them based on the element TYPOLOGY. In this way, the parametric model realization logic in Revit was respected completely. In this phase, measurement unit setup operations are very important, in fact the right setting must be verified before linking the Revit file; in particular it is necessary that the 3dStudioMax units are consistent with those in which the parametric model has been realized.

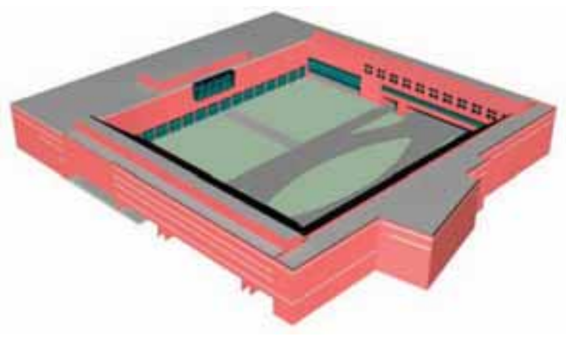

Fig. 5 – Model optimized in 3dStudioMax

Within the 3dStudioMax environment it is possible, as opposed to the previous procedures, to make changes to the model both from the architectural point of view and on the denomination of the element typologies in order to obtain a better uniformity. Another operation, recommended, though not essential, is to eliminate the camera and the light spot that the 3dStudioMax application automatically imports from .fbx file. This last operation is feasible reloading the .fbx file and unchecking the relative options in the dialog box. Moreover, these two specific objects are not useful for modelling and for subsequent simulation. At this point it is possible to export the file in the .3ds format and subsequentely to import in Ecotect Analysis.

The import mode, with respect to the previous procedures, is not MODEL/ANALYSIS DATA but the command denominated 3D CAD GEOMETRY, which allows for the listing of all model elements grouped by TYPOLOGY and to assign them the correct ZONE.

The materials, after importing the model in Ecotect Analysis, were characterized. Particular attention was paid to analysing each surface, consequently, reflection and/or transmission properties were defined. For the SEEMPubS models, field measurments of luminous reflectances and trasmittances of the different room and furniture surfaces were carried out and the data used to characterize the materials' optical properties of the models.

Finally, through the specific command the model can be exported to Daysim for the final lighting and energy simulations.

Before starting lighting simulations with Daysim, the models, built in Revit and exported in Ecotect, were validated using the Radiance application.

Radiance is an open-source, highly accurate, ray-tracing software system for UNIX computers and it predicts the light levels and appearance of a space (Larson G.W. et al.,1998). Its algorithms (Monte Carlo backwards raytracing) allow an accurate simulation of the phenomenon of interaction between light and surfaces; furthermore Radiance does not have any limitation on the geometry or the spaces that can be simulated. As for daylight sources, Radiance can take into account different sky luminance distributions, considering both direct and diffuse solar radiation.

From Ecotect, the model was then imported into Radiance and its validation was carried out by comparing the illuminances calculated with Radiance to the illuminance measured in the corresponding real room with same sun position and sky condition (Mardaljevic J., 1995).

As an example, table 1 presents some first results obtained for a clear and an overcast sky condition. The measurements were done in a single office (DAUIN office) in correspondence of two points on a horizontal plane: one near the window (point 1), one far from the window (point 2). The relative differences between calculated and measured values range from -12% to 29.4%, therefore confirming a good accuracy of the model used for the lighting simulation.

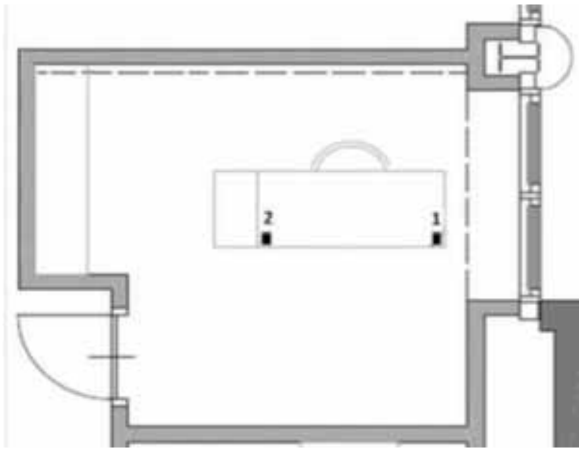

Fig. 6 – Detection point in DAUIN office

Sky condition	Point	Measured Illuminance (lx)	Calculated Illuminance (lx)	Relative difference (%)
Clear Sky	1	26618	31840	19.6
	2	1088	958	-12.0
Overcast sky	1	246	276	11.9
	2	74	96	29.4

Table 1 – Comparison between measured and calculated illuminances.

After validation, the models were used for lighting analysis with Daysim. Daysim in fact, calculates the annual daylight availability in arbitrary buildings based on the Radiance backward ray tracer, using external daylighting conditions derived from standard meteorological local datasets. It includes specific occupant behaviour model algorithms to mimic occupant use of personal controls such as light switches and venetian blinds and to predict the electric lighting use due to automated lighting controls such as occupancy sensors and photocell controlled dimming systems. In addition to daylighting metrics, among its outputs, the total annual energy demand for lighting [kWh] and the LENI value [kWh/m2year] are included (EN 15193, 2007).

Within the SEEMPubS project, Daysim was used to calculate the rooms' electric lighting energy demand for different proposed control strategies and to estimate the corresponding energy saving with respect to the manual lighting control usually adopted in the Politecnico rooms (Acquaviva A., et al., 2012).

In this paper an example of the achieved results is presented (figure 7; table 2). Results are referred to the DAUIN office, which is a single office, with an internal movable shading device, southwest oriented. Inputs for simulation are:

Occupancy profile: from 9:00 a.m. to 6:00 p.m., with lunch and intermediate breaks

User requirements and behaviour: target illuminance of 500 lx, mix of active and passive user's behaviour and active user behaviour for lighting; active behaviour depending on the user's need to avoid direct sunlight on work plan for blinds

Lighting control systems: different lighting control strategies were simulated to compare their effectiveness with respect to the manual control

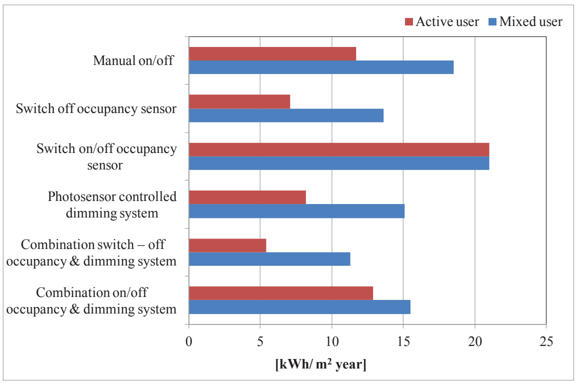

Fig. 7 – Energy demand for different control strategies

Control strategies	Energy savings with respect to manual control (%)
	Mixed user behaviour
Switch off occupancy sensor	-26%
Switch on/off occupancy sensor	+14%
Photosensor controlled dimming system	-18%
Combination switch off occupancy and dimming system	-39%
Combination on/off occupancy and dimming system	-16%

Table 2 – Calculated percentage of energy saving with different control strategies, respect to manual control

3. Discussion And Result Analysis

As outlined in the introduction, interoperability of software is the basic instrument for a successful Building Information Model process. In order to realize a complete parametric model, suitable for data exchange between architectural software and energy analysis software, three different procedures were investigated.

Each procedure has presented difficulties or errors. In the first two cases, data exchange was realized through open formats like IFC and gbXML that have proven not fully adaptable to the cases under study.

Among the errors encountered with the first procedure, which used the IFC standard, it is of particular importance the fact that window frames, which are fundamental for lighting analysis, are not imported. Besides, model representation turns out incomplete because it is imported with the constructive elements misaligned with respect to the original model. This suggests that the first procedure is not the best one and for these reasons a second way was analyzed.

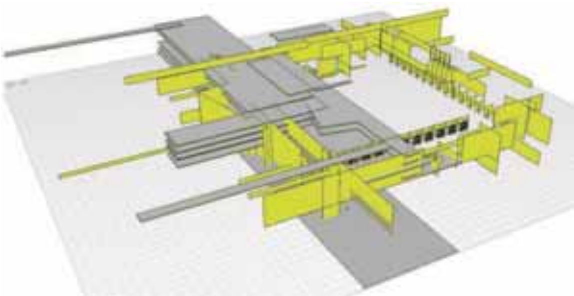

Fig. 8 – Errors encountered during the importation of IFC file in Ecotect Analysis

The second procedure consisted in the use of gbXML exchange format, which required that each space is defined by a ROOM. Even in this case several issues arose when opening the file in Ecotect Analysis.

Through this kind of exportation, the model is correctly regenerated and all elements maintain their reciprocal position, nevertheless the elements' volumetric characteristic is not maintained. Solids lose their connotation because they are transformed into surface, placed side by side but not exactly matching. The same problem occurred for the ROOMS that are represented by their surfaces. For instance, in the case of the window frames, they are broken down in two orthogonal planes composing the structure of the frame itself. A similar problem concerns vertical and horizontal surfaces, like walls, floor, ceiling, etc.

These transformations make lighting simulation unfeasible because, due to the excessive model simplification, there is a risk of destroying the real glass surface obstruction and of identifying daylight penetration points where surfaces do not perfectly match. Consequently, the model becomes unusable for lighting calculations.

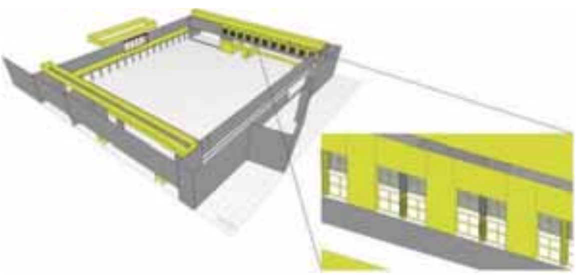

Fig. 9 – Elements exported by gbXML which do not maintain their volumetric characteristic

The third procedure, that concerns the use of an intermediate application (3dStudioMax), appears to be the most appropriate both for what concerns modeling in the Revit applications and for the analyses in Ecotect Analysis. However, it is necessary to highlight some basic steps for successful data exchange.

Firstly, the elements used for modelling in Revit environment (FAMILY TYPE) must be created in a suitable way in order to facilitate the subsequent operations of ZONE assignment in Ecotect Analysis. Besides, particular attention must be paid to the materials, which will concretely conform to their belonging ZONE. At the same time, the nomenclature of these elements (TYPE) must not exceed twelve characters, in fact, a longer denomination would be cut in the Ecotect Analysis environment with the risk of losing information useful for identification. For example, glass component modeling is very important because with Revit, it was not possible to export the component as 3DFACE. 3DFACE is the best typology of elements to import in Daysim and Radiance for the units characteristics association, like insulated glass or triple glazed, in order to avoid simulation errors due to the calculation complexity in terms of refraction of the light beam hitting the entire glass component. In this way, during the importation phase in Ecotect Analysis glass, being a solid, it is divided in its components' faces. However, materials' characteristic must be associated to one face only and other faces must be deleted. The following simulations could be influenced by the choice of characterizing inner or outer face and some errors can occur in the results (not very significant).

Afterwards, linking and file opening times are slightly longer than the two previous procedures. Obviously, the higher the simplification of the 3D model, the shorter the time is. Longer file opening times were found when the Revit model contained particularly elaborate windows and when the model included several objects. Moreover, particularly complex parametric elements (higher than 64K) are not automatically exported by 3dStudioMax. This implies that a MERGE operation on the model must be performed before the exportation in order to include these elements.

Particular problems arise while modeling a glass curtain wall, in a Revit environment. This family type differs from the importation rules in 3dStudioMax seen above; in fact, assigning two different names to two different curtain walls is not influential. In the importation into Ecotect Analysis they were recognized as one single element: the problem was solved temporarily by replacing the glass curtain walls with a WALL object to which trasparency characteristic was assigned.

Finally, whereas Daysim and Radiance require a reference surface against which lighting simulations perform, it is possible to define this surface directly in Revit through the creation of a specific solid exportable into Ecotect Analysis and employable without problems.

Unlike the two first procedures, also in this case solids are converted into surface, but these are well aligned with each other and are perfectly matched. The same happens for the window frames that guarantee the correct obstruction compared to the incoming daylight.

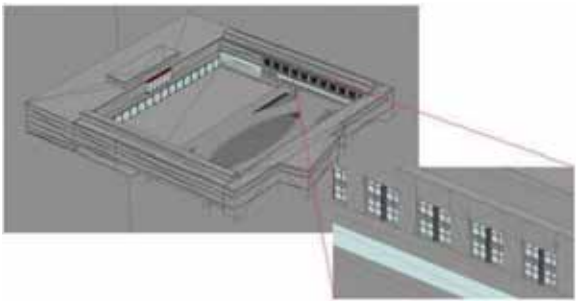

Fig. 10 – Ecotect Analysis view of the correct 3ds file exported through FBX

It could be concluded that this type of exportation allows to import the model in Ecotect Analysis correctly and appropriately with regard to the technical needs for lighting simulation.

The results of the validation phase of the model, carried out with Radiance, showed a difference between measured and simulated illuminances ranging from -12% to +30%, depending on the considered sky conditions (clear or overcast sky) and on the position of the verification point within the room. This discrepancy might be attributed to the interaction of the different aspects which are involved in the simulation process: 1) the correspondence of the sky model generated by Radiance starting from the measured outdoor illuminances (direct and diffuse horizontal illuminances) with the real sky condition; 2) the optical characterization of room with opaque and transparent surfaces; 3) the accuracy of the instruments which were used for the indoor and outdoor illuminance measures; 4) the accuracy of the geometrical model, with particular attention to the modeling of the glass surfaces.

As for the builbings' energy performance, simulations carried out with Daysim for the SEEMPubS project were very useful in defining the most effective control strategy to reduce energy consumption for lighting, based on both the annual daylighting conditions and the use of the space (type of activity, user behavior, etc.). From the data presented in the paper a combination of manual and automatic control turned out to be the most effective solution (39% of saving with respect to totally manual on/off control). The control strategy provides for turning on lights manually, and for automatic dimming and switching off. The control strategy based on switching on/off light through the occupancy sensor was more expensive than the others, manual control included. This result can be explained by the presence of daylight in the room during the year. When daylight is sufficient for the occupants' needs, users, with not a completely passive behavior, can switch lights off, while occupancy sensors, detecting the users' presence, always keeps them on. Furthermore, occupancy sensors have a stand-by power consumption during the year which increases the overall energy demand for lighting.

4. Conclusion

In the last few years, interoperability has become a crucial topic to develop Building Information Modeling. Our study focused on interoperability between architectural software and lighting analysis software. Three different procedures were studied and tested many times to guarantee correct data exchange that allowed lighting simulations.

Firstly, a Building Information Model was realized for each couple of rooms in order to enable correct energy analysis, then the exportation phase started. In all procedures difficulties or errors related to the definition of the elements' geometry and their mutual spatial arrangement were found; only in the third procedure this did not happen, due to the introduction of addictional software like 3dStudioMax.

Ecotect Analysis has played a key role in our tests, becoming an "interoperable bridge" that allowed us to exchange the information required from Revit to Daysim or Radiance and vice versa. At the end, the goal of interoperability is clear, but many unsolved issues still exist to turn this idea into reality. However, with this study we have tried to overcome the difficulties explained above allowing for a better sharing of information between the different subjects involved in the design process.

This interoperable bridge allowed the lighting simulation to run, both with Radiance and Daysim, thanks to the development of 3D models complete with all the information needed.

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Multidisciplinary team activity using BIM and interoperability. A PhD course experience at Politecnico di Torino.

Anna OSELLO, Andrea ACQUAVIVA, Anna PELLEGRINO, Elena CANDELARI, Giacomo CHIESA, Daniele DALMASSO, Matteo DEL GIUDICE, David ERBA, Kamila MANNANOVA, Iasef MD RIAN, Michel NOUSSAN, Edoardo PATTI, Marco PIPPIONE, Alessandro SERRA, Rajabzadeh SHAGHAYEGH, Riccardo TOMASI

Politecnico di Torino, Turin, Italy

anna.osello@polito.it, andrea.acquaviva@polito.it, anna.pellegrino@polito.it, elena.candelari@polito.it, giacomo.chiesa@polito.it, daniele.dalmasso@polito.it, matteo.delgiudice@polito.it, david.erba@polito.it, mannonochka@yahoo.com, md.iasef@polito.it, michel.noussan@polito.it, edoardo.patti@polito.it, marco.pippione@polito.it, alessandro.serra@polito.it, Shaghayegh.r@gmail.com, tomasi@ismb.it

Abstract
Building Information Modeling (BIM) provides a framework for collaboration, a multi-disciplinary environment that brings together all the parties of the Architectural, Engineering and Construction industries (AEC). The aim of this experience (an interdisciplinary PhD course based on the BIM methodology used in the Smart Energy Efficient Middleware for Public Spaces – SEEMPubS – FP7 project) was to investigate the team work sharing and the use of interoperability between software, to test the opportunities offered by BIM process applied at existing buildings at the campus of Politecnico di Torino. Two architectural parametric models were realized (one concerning a new building –Classroom I– and one concerning a historical building recently renovated –ISBM offices–) and imported into software for energetic and management analysis using different formats like IFC and gbXML. Several lessons have been learned from these processes in order to optimize the quantity of data that pass from one software to the other ones both for type of data and for format of exchange. This indicates that actually, there is a possibility to better the BIM process, but a support from software houses is required based on the real use of common standard.

Keywords: BIM, Interoperability, Energy assessment, Augmented reality.

1. Introduction
Significant benefits to be gained from the interoperability of BIM software have generated considerable recent research interest. BIM is not only the software, but it is the collaborative process, which integrates different fields of design, construction and management to obtain the optimal result in entire process of building life cycle. It is fundamental that *bim* (building information model) are shared and accessible in open and interoperable fashion in a way enabling data and meta-data available in *bim* to be accessed, pre-processed and mapped correctly with different applications. Many researchers have addressed the problem of interoperability, but there remains a need for an efficient method that caneasily transform data into different formats like IFC and gbXML for structural, energetic and management analysis. The purpose of this study is to examine and describe the teamwork sharing, interoperability between software and the opportunities offered by BIM process applied at existing buildings at the campus of Politecnico di Torino.

2. Methodology
During the course, as we had two Buildings to analyse and 12 participants from different fields and background (Architects, Engineer expert on ICT, Energy, Building and Management), we have divided all the practice activities into 5 main parts as follows:

- Building the model in a BIM software and sharing information using worksets and Central Model in Dropbox;
- Building performance and energy analysis using several software for a better interoperability;
- Feasibility of interoperable BIM and IoT system;
- Building lifecycle and management using BIM;
- Tablet application to show the different data by Virtual and Augmented Reality.

2.1 Building the model in a BIM software and sharing information using worksets and Central Model in Dropbox

For simulation and computer modeling of the buildings Autodesk Revit software was used, which is specifically programmed for BIM and provides a proper environment for interoperability by presenting the possibility of offering different workspaces, which allow each member of a group to work on specific part of modeling. Worksharing is a design method that allows multiple team members to work on the same project model at the same time. When worksharing is enabled, a Revit document can be subdivided into Worksets, where Workset is a collection of building elements (such as walls, doors, floors, stairs, etc.) in the building. Only one user may edit each Workset, all other team members may view this Workset, but are unable to change it, preventing possible conflicts in the project. Team members adding and changing elements in Worksets can save their work to a local file on the network or their own hard drive, and publish work to a central file whenever they choose. Using the Dropbox folder we attempt to solve the problem of sharing Central Model information; which worked in the beginning, but after several synchronizations from different team members at the same time, the Central model stopped responding and obviously synchronizing.
Another problem that we faced while building a model of a historical building was the complexity of the construction: former railway repair yards (OGR), freed by the railway, was behind the premises of Politecnico di Torino, this building was build between1885 and 1895 and reconstructed in 2000 for ISMB. Although, all the parametric objects forming a building exist in Revit Databases (families), there were many difficulties to model an existing building, because to accomplish the best result, all the details and components should be modeled the same as constructed in the building. A balance between the level of the details in the central file and local file was another problem we faced during the modeling. After synchronizing the model of main trusses with the central model, elements became invisible because detail scale of default view was normal while most of the structural elements are signified just in medium or fine detail-scale view.
We have elaborated the architectural model and tested the parametric approach to typologies of elements (wall's layers, thicknesses, materials) and connections between elements itself and planes. Moreover, we have tested the interoperability using the Revit model in different software. In particular, it is possible to export from Revit to 3dStudio Max using different formats. Firstly, we tried to use *.3ds files but, even if it was possible to open the file in 3dMax, we identified several problems in localization of geometries and in number of objects per layer. Secondly, we exported to 3dMax using *.dwg format and no localization problems occurred. Unfortunately, layers and geometries were decomposed into single elements and there were some conflicts between 3ds materials and Revit ones. We also tried to export Revit geometries into Ecotect and, after several attempts, we used a *.dwg file, imported in 3dStudio Max and exported as *.3ds in order to correctly position geometries in Ecotect, but several problems occurred. Firstly, all the geometries were condensed in only one calculation zone without any reference to layers, secondly, the file was very heavy and CPU consuming, thirdly, objects and surfaces were decomposed into triangles and in some cases duplicated. Finally, we tested the interoperability with Rhinoceros 4.0 and we have discovered that using *.3ds files the geometries lose their layers and every element is decomposed into triangles. Using *.dwg files it was possible to preserve layers, but the importation could be effective only if the file would be previously opened on CAD and then imported to Rhinoceros. We tried to reduce triangles and meshes by using Grasshopper Mesh Union tools and the results were good.

2.2 Building performance and energy analysis using several software for a better interoperability

The energy performance is among the key aspects of modern building design, and the limits imposed by current regulations require a careful calculation of the heat losses and energy system efficiency. The development of this sector has led to innovative solutions for thermal insulation and increase of energy efficiency of conditioning systems. The software available for energy performance analysis is in constant progress, with an improving accuracy of calculation and the integration of 3D building design in heat losses evaluation. However, there are still some limitations in interoperability with usual 3D modelling software, as the import of 3D-models in energy software lead sometimes to compatibility issues.
We have investigated the interoperability between the 3D model of an existing building developed with Autodesk Revit and two Energy performance tools: Autodesk Green Building Studio and Design Builder. The first is a web-tool developed for primary energy evaluation in preliminary design-stage, providing global building performance with minimum user input. The second, on the other hand, is a state-of-the-art software tool for energy and sustainability analysis in building design. The file format used for model import and export is gbXML (which stands for “Green Building XML”), which is an open schema designed to facilitate the transmission of building properties stored in 3D building information models to engineering analysis software. The export of the BIM model to Green Building Studio was completely successful, and no errors were detected during the operation. The software has calculated the energy performance of the model, but not all the parameters have been transferred to the energy analysis tool. The materials used for walls and windows

needed to be re-defined by the user. Moreover, there are some possible combinations for HVAC system choice, but the user cannot define custom parameters. The main inaccuracy related to energy system has been the approximation regarding the primary energy consumption, as district heating was not included between the options listed in the software. Thus, a natural gas boiler has been chosen.
The interoperability with DesignBuilder has lead instead to major import issues, which made impossible an energy analysis. The whole building was recognized as a building block, but all the information about the components and the windows has been lost. Only the external shading surfaces were imported correctly. This issue could be related to the definition of custom building blocks, but there is a need of further investigations.
Furthermore, for the energy simulation of a Revit model Autodesk recommends to export the model to 3dStudio Max and from that to Ecotect. Since this way had already been verified by Autodesk, we decided to test new possibilities with other programs. EnergyPlus was chosen as an open source software on energy simulation produced by the U.S. Department of Energy. The only format that can be imported to Energy Plus is idf: this is a format exportable from DesignBuilder Software Ltd, a software not open source, which in fact is a graphical interface for building the model. However, there is a plugin called Open Studio that allows to run the simulation through SketchUp. So, the goal of our work in this case has became the interoperability between Revit and SketchUp. The reason why we preferred SketchUp and not Design Builder was the desire to focus on open source software. In fact, we believe that in a world where there are dozens of different software with similar functionality, file exchange between designers can be facilitated by the use of open source software as a medium. SketchUp can import three-dimensional models with the following file extensions: 3ds, dwg and dxf. When you export from Revit, it is important to be on a three-dimensional view. If you export from the plan view, only two-dimensional plan is exported. Alternatively, you need to add a façade view to the plan view. In SketchUp the model is imported with the same layers as in Revit.
The interoperability between 3D-modelling software and energy analysis tools appears to be a key issue for the diffusion of BIM technologies. The possible benefits are interesting, in terms of accuracy and modelling time. However, further steps need to be done in improving the compatibility between different software.

2.3 Feasibility of interoperable BIM and IoT system

The Internet of Things (IoT) is an emerging computing paradigm where any physical object, enriched with electronic identities, processing and communication capabilities, becomes part of a dynamic, distributed, global network of heterogeneous devices that interact autonomously with the real/physical world and participate actively in business, information and social processes. In IoT scenarios, applications become “pervasive” and must be designed to interact with digital and non-digital objects with different roles and belonging to a large number of different object classes. For such reason, applications must undergo a paradigm shift: from custom-made applications working on a “closed” set of inputs towards context-aware applications working on “open” sets of inputs. The main challenge to achieve this paradigm shift is interoperability: object must in fact be able to interact with each other seamlessly and easily retrieve information about the environment where they are deployed.
Building information models (bim) potentially represent a precious source of data for pervasive IoT objects operating in buildings. For such reason it is fundamental that bim are shared and accessible in open and interoperable way enabling data available in the models to be accessed, pre-processed and mapped correctly with IoT applications.
In order to enable IoT/BIM interoperability, the following challenges must be solved: interoperability with any available “legacy” BIM models must be possible; software interoperability between components adopted for IoT applications must be possible (e.g. remote access via web-services or availability of library bindings with the programming language in use); interoperability with any external service useful to pre-process BIM data to serve IoT applications must be possible.
To evaluate preliminary feasibility of interoperable BIM and IoT system, a simple use case has been implemented i.e. the extraction from BIM of the topology of the walls to evaluate theoretical connectivity between different devices installed in the building. In order to achieve the results we have followed several steps: we analysed the state-of-the-art open products and selected the most suitable set tool to adapt towards the available BIM model - Solibri model viewer, BIMServer, IFCOpenShell, Blender. Conversion of the main Revit model to different formats (e.g. IFC), to assess the correctness and the conversion and identify possible issues related to the BIM format chosen for adaptation was our next step that showed that IFC format gives opportunity to validate and visualize the model through Solibri Viewer. Furthermore, the model was correctly accessed though BIM server and evaluation of its main functionalities through simple queries via web and via the SOAP interface showed that the available APIs allow simple querying on

components of the model. Extraction of the Wavefront geometry via IfcOpenShell, import in Blender and verification of the IFC identifiers in the blender model, addition of connectivity “Targets” and simple evaluation of connectivity through a Python-based framework resulted in correct exportation in 3D non-BIM format; objects identifiers were kept in the 3D model, so to enable future retrieval of BIM information even if the meta-data is temporarily discarded in this phase.
Although no best-in-class solution is available yet, open BIM tools are rapidly developing, providing useful instruments to support interaction with BIM models. Such tools provide interesting advantages concerning debug possibilities and extensions through inclusion of other open components. The performed developments, although extremely simple, demonstrate through a basic use case the possibility to query simple BIM models externally, providing positive inputs about the feasibility of a BIM/IoT interoperability layer. During the work also a number of possible future challenges have been identified. Not processing operation on complex BIM models are computationally heavy, so possibly in the future, solutions will be needed to simplify and partition the models and manage more efficiently memory-heavy structures. BIM interoperability did not cause major problems, but it is expected to be more problematic working with legacy models: with more complex entities relationship queried by IoT objects might depend on the design “style” of the BIM, and thus not easily integrable with “open” applications.

2.4 **Building lifecycle and management using BIM**

One of the areas of greatest importance in the world of construction is the field of management of buildings and Real Estate. This sector employs a very diverse set of tools to achieve the goals. The field of Facility Management is very complex due to the many factors that distinguish it and therefore the use of appropriate information tools may allow greater control of all the variables. BIM tools can provide valuable assistance in this field; tests and analyzes performed during the PhD program have been oriented to understand how to transfer information between different applications and especially how to handle all this information inside Revit applications.

Fig. 1: Overview of scattering information.

As the information contained within Revit and about the model can be exported to other software or other databases, the question was if it was possible to add information into the model by actors not involved for oneself on the same model such as suppliers, manufacturers, insurers etc. Such information includes, for example, the production characteristics of a product or guarantees of a particular element. COBie standard, short for *Construction Operations Building Information Exchange*, a framework for organizing data developed and accumulated during the course of a building project for delivery to facilities owner and operators involved in lifecycle management. COBie is an American standard, which enables different stakeholders in the construction process; through excel worksheets extracted directly from Revit, to enter into single shared document information in their possession. The result of this operation is ability to use a single simple tool, to collect uniquely the data regarding the model. The standard is organized in 16 worksheets, containing some standardized heading information and used in the building industry,furthermore project team can decide to add any kind of information regarding design, construction, management etc. Not all COBie data are, or can be, developed within the Revit model in fact only 8 worksheets of 16 contain information that can be develop inside Revit (for instance information regarding spaces, types, zones, components, systems etc.). In this case, we used a specific tool made for Autodesk called COBie Revit toolkit (v. Revit Architecture 2012) which assists project teams to provide automated data export from Revit to COBie spreadsheet.

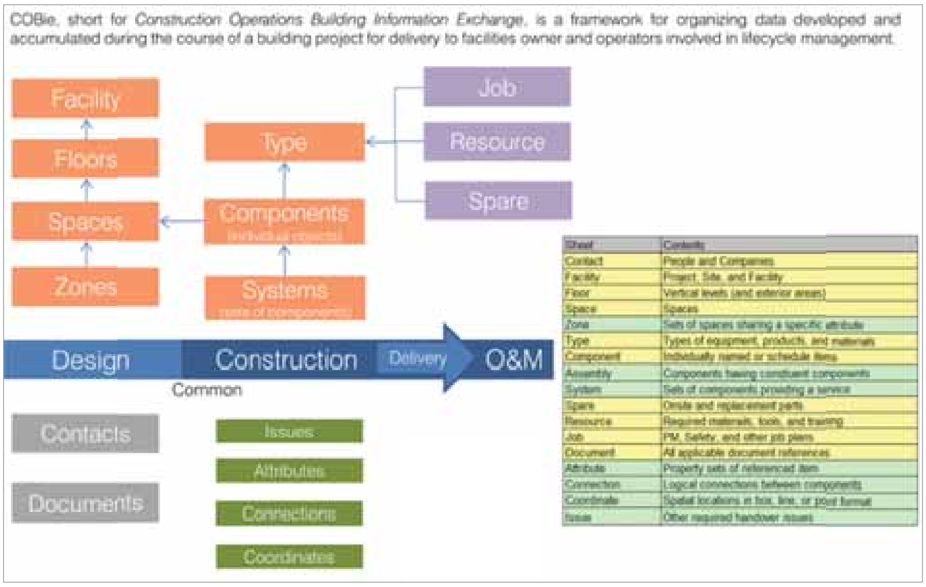

Fig. 2: Overview about COBie standard organization

The tests conducted, however, have revealed some problems related to the use of the standard, the most important of all is that the excel worksheet, containing the information, cannot be imported into Revit and consequently the final result is to have two separate operational tools. Nevertheless, this kind of approach, with precise and organized information represents an excellent way to reach the final goal to have a unique set of information without replication. In order to solve this problem (re-import in Revit) we have tested another solution: transfer information from Revit to individual operators through the adoption of DBlink that is a toolkit that allows creation of a bi-directional informational flow and can replace COBie worksheet which does not consider bidirectionality yet. This operational tool works within Revit and allows extracting, in this case in an Excel spreadsheet, the information contained in the Revit model. In this case the DBlink has been used because it is very dynamic, allowing the selection of the fields of Revit that it is necessary to extract and accordingly is very useful in case of shared parameters.
Using Revit DBlink two clear advantages are available: the first one is that extracting data in excel format allows non-expert Revit users to understand the information contained in the model and then make changes or validate it. The second one is that the excel file can be easily imported back into Revit, allowing an update of the information.
Operating in this way there is the certainty that the information remains always unique, without creating a multiplication of the same data that are difficult to manage and secondly allows a greater control on all transactions relating both to the design and the management.

The management of the building can also be enabled via 4D BIM. Its role is to add the time to a 3D CAD model, as the fourth dimension, and this allows the various participants of a construction project (from designers, contractors to owners) to visualize the entire duration of a series of events and display the progression of construction activities over time providing an intuitive interface to project team and other stakeholders to easily visualize the assembling of a building over time. 4D modeling enables construction simulation during preconstruction to evaluate various options and identify critical aspects. Also, 4D storyboards and animations make BIM a powerful communication tool giving architects, builders, and their clients a shared understanding of project status, milestones, responsibilities, and construction plans.
Tangible benefits offered by 4D BIM are: Savings in cost and time; Risk mitigation; Conflict detection; Improved productivity; Enhanced quality.
Meanwhile, intangible benefits are: Improved communication among various division; and Visual communication to non-technical stakeholders and get their buy-in.
To investigate and verify the full interoperability of software for parametric modeling (BIM) with software for the control of projects in order to build a single 4D/5D model which can be integrated with ERP (Enterprise Resource Planning) systems and integrated platforms for management of construction and logistics like Archibus we used following software: AutoCAD Revit Architecture 2012 for BIM modeling; Autodesk Navisworks Management 2012 as 4D modeler in order to maintain as much as possible homogeneous application platform; MS Project 2010 for resource planning and control; MS Access 2010 and SQL Server 2008 as databases for data storage.
As a result of the process represented in Fig. 4 our objective was to create a single 4Dmodel for both the control and monitoring of the project.

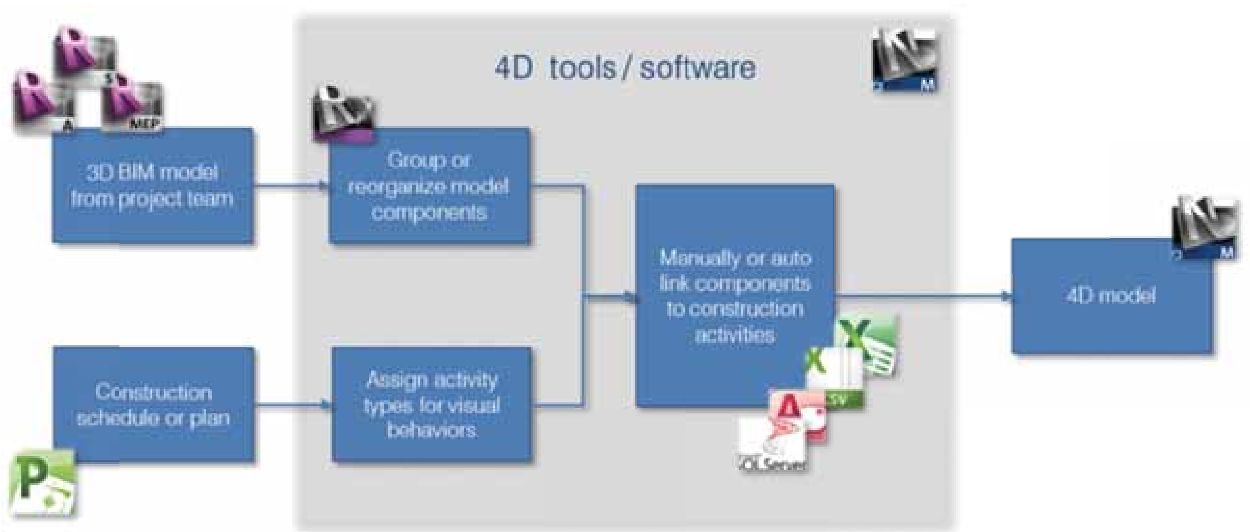

Fig. 4: The process of creating a 4D BIM.

During the import procedure of data from MS Project to Navisworks were added in the project only two attributes of all the activities, the dates of beginning and end of the project, meanwhile were not imported all other attributes such as the resources involved, precedence of the activities, constraints, project milestones and issues raised by the Critical Path Method. Also, once imported, the project is not in fact a true 4D model but only a BIM with a timing phase and the progress of the construction activities. For this reason the integration between the two environments cannot be considered a true and complete integration between the two environments because of absence of the key attributes for the control of the project. Furthermore, the exchange of information between the two environments is manual and not bi-directional: each change on the activities of the work plan (GANTT) must be turned in Navisworks model and connected to the phases of work and at the same time any change in the BIM model to be exported and connected to the working plane.

2.5 Tablet application to show the different data by Virtual and Augmented Reality
In order to increase the building awareness and to enhance any possible maintenance works, an Android application has been developed at Politecnico di Torino as task of the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) project and here tested, to provide building information exploiting both

augmented and virtual reality. The end users of this application are the Building and the Energy Managers. The purpose of this solution is to overcome the limits related to the 2D visualization, presenting a 3D environment populated with building informations. To obtain the results firstly, we modeled the building using Autodesk Revit application through which architectural, structural, mechanical, electrical and HVAC models are merged to allow visualization, simulation and analysis of the building's energy performance. Thereafter the architectural model has been integrated with sensors' models in order to allow observation of the temperature, humidity and lighting conditions of premises in real time. We modeled the parametric families of each sensor trying to make them likely, in this phase, particular attention was paid to the geometric and technical characteristics. In addition to the real sensors' modeling each room, some fictitious objects were inserted in order to allow the virtual navigation in the rooms. The next step was to export the building model created in Revit in .OBJ format and in this case, .FBX files were used because the geometry of these elements was not particularly complex.
As regards the materials, they are preserved in the passage from Revit to 3DStudio Max, however, the problems related to the subsequent conversion between .OBJ and .MLT files exist. In fact, most of them are lost and random materials are associated to the elements according to the layer to which they belong in 3d Studio Max. To overcome this drawback the materials should be reassigned to the objects through the material editor. Before proceeding with the exportation from 3DStudio Max, the geometry must be converted in mesh objects through the modifier "Edit Mesh". If this operation is not performed, the files .OBJ and .MLT do not contain any element. At this stage, it is important to verify that the exportation files do not contain geometric errors, in fact, it is possible to choose the method of approximation of the elements: triangulation, quadangulation, polygonal.
In order to ensure a fast maps loading in Android environment it was decided to perform a final files conversion from .OBJ to .JMF, exploiting the *Bonzai Engine* tool. Finally, through our application called *BIM Manager*, each .JMF file was loaded in the *BIM Server* in order to allow the virtual netsurfing of each room by tablet.
.MLT formats to be used for navigation by tablet.OBJ file contains the geometrical information of the model, while .MLT file contains the related materials. However, data exchange is not direct; in fact, the models must be imported in 3D Studio Max and exported after some modifications according to the formats required. Firstly, the model was exported from Revit using the .FBX format, subsequently, it was decided to use .DWG format due to some problems related to the geometry complexity. Using the CAD format it is possible to choose the type of solids that will be exported. In this case, ACIS geometry was used in order to drastically reduce the number of polygons that make up the various elements. During this procedure, the model has been broken down according to the types of elements. Furthermore, this choice is supported by the loading typology of the model allowed in the Android application, which specifically provides the subdivision of the model to improve navigation from a performance and methodological point of view.
The importation of the model in 3DStudio Max can be done in two ways: by creating a link to the source files through the Manage Links tool or as real importation of the source files. The link between files was chosen because with the direct importation the items were made independent from the file to which they belong. However, the second procedure, in fact, the nesting of the elements was lost voiding the process of rationalization followed during exportation. Importing .DWG formats allows to indicate the origin's source of the file while, using .FBX files, it is possible to choose the methodology for elements recognizing (depending on the material associated therewith, on the membership category or the family type, depending on not being combined entity or as a single object) and their subsequent grouping. During this process, some important information is altered: the units of measurement, the scale of representation, materials and the nomenclature of the elements. The units of measurement must be correctly set during the exportation from Revit, moreover, the option "rescale" must be checked and the units of measurement must be chosen again during .DWG files importation in 3DStudio Max.
The nomenclature of materials is automatically implemented with information related to the category of the element and the family type to which they belong. This represents a problem for the sensors and fictitious objects, which need to maintain their original encoding to be recognized. The problem can be solved in two ways:

- By renaming the objects concerned, but this involves a double work by the operator and a quite long procedure if those elements are numerous.
- Exporting these objects by .FBX format.

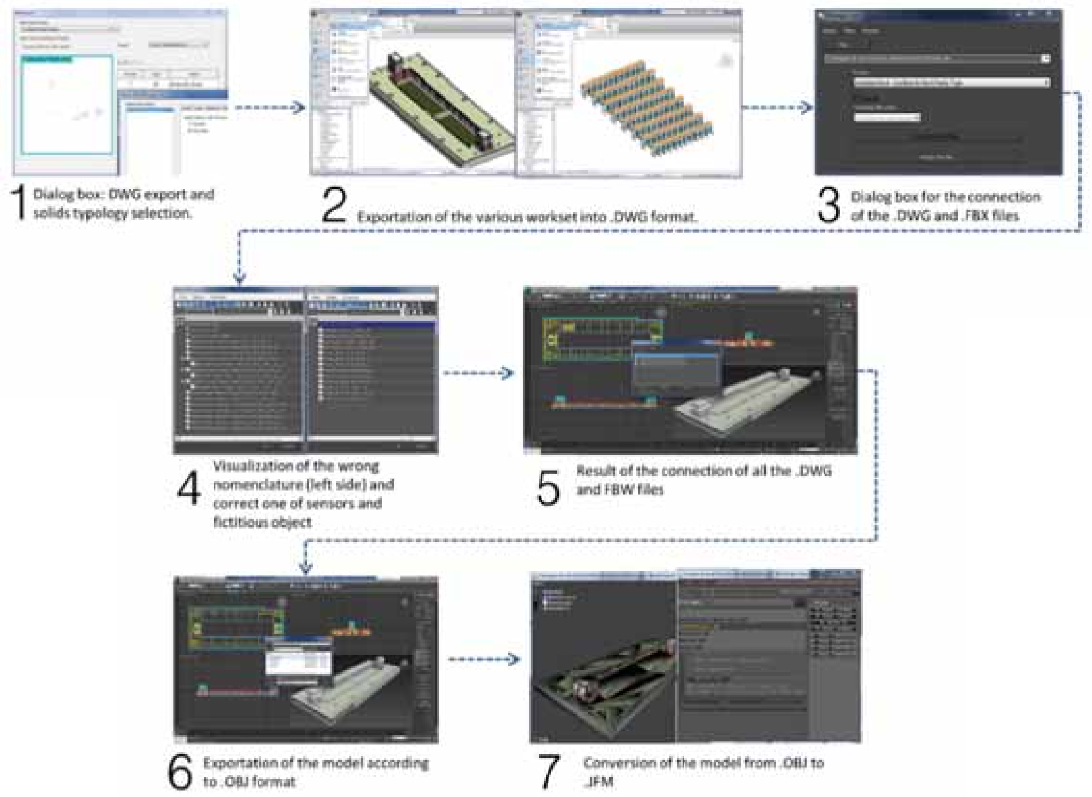

Fig.5: Operational step from Revit model to Android application.

In the following two images, there is an example of the Android App Graphic User Interface (GUI), where a 3D parametric model, described above, is shown using a tablet. The user can select information about: i) Architecture, ii) Furniture and iii) different systems such as Electrical, Heating and Ventilation. Moreover, these systems have been modeled using different colors (e.g. yellow for Electrical, green for Ventilation, etc.), as shown in figure below.

Fig.6: Visualization of the architectual model using a Tablet and of each system using different colours.

Finally, exploiting the augmented reality the Android App can provide information about rooms simply scanning its corresponding QR Code deployed into the building, as shown in figure below.

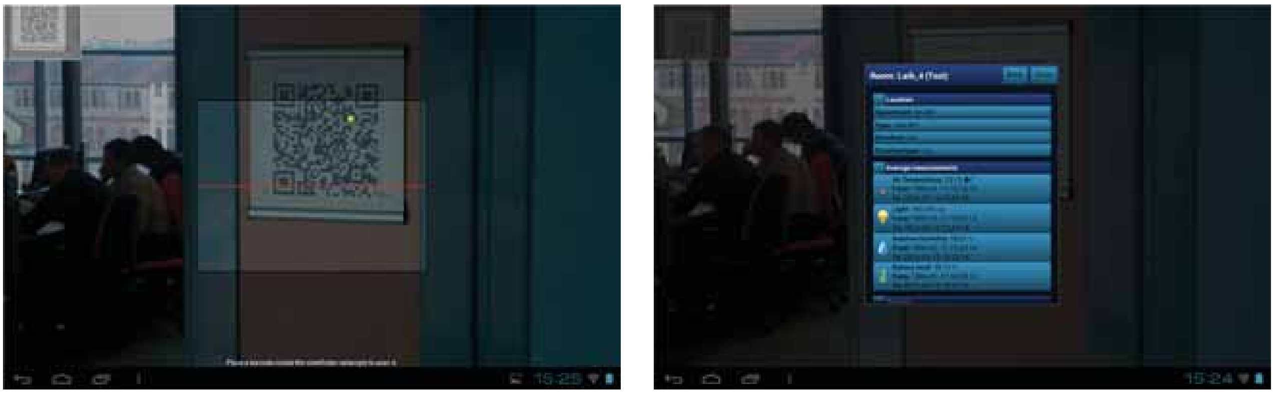

Fig.7: Example of room's information shown via Augmented Reality.

The general procedure can be summarized through the steps in the following picture summary.

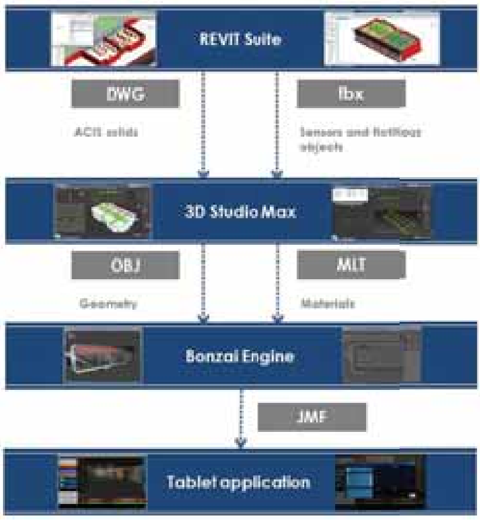

Fig. 8: Layout of the procedures followed.

3. Results

Although no best-in-class solution is available yet, open BIM tools are rapidly developing, providing useful instruments to support interaction with BIM models. Such tools provide interesting advantages concerning debug possibilities and extensions through inclusion of other open components.
The table of interoperability below is the result of the study we carried out during this course from different fields of study and different background. Of course, the table must be considered in progress as there are a lot of possibilities to use BIM software and for different compatibility processes.
Moreover, in this study, we evaluated the interoperability between BIM and tools for monitoring and control of projects with the expectation to create a single 4D model that would allow two-way exchange of information between the parametric model and the models created to monitor the progress of the project and the use of resources.
Tests have shown that, unfortunately, the full interoperability has not been achieved for a number of reasons:

- The model that is generated in Navisworks does not allow a bidirectional exchange of data and is not suitable to represent a 4D model itself, but only allows to visualize graphically the progress of a construction project;
- Data are not exchanged automatically between the software instead they must be exported and imported several times, with the risk of generating errors and inconsistencies;
- There is no integration SOA (Service Oriented Architecture) with ERP platforms like SAP, JD Edwards, Infor10, Microsoft Dynamics;

However, it must be said that there has been researched interoperability between software from different manufacturers and different technology 32 bit and 64bit; using Vicosoft software as 4D model generator and databases and software of the same by the same manufacturer (Oracle DB, BEA Weblogic, Spring, or SQL Server, MS Dynamics, MS Project Server) could be achieved a greater interoperability.

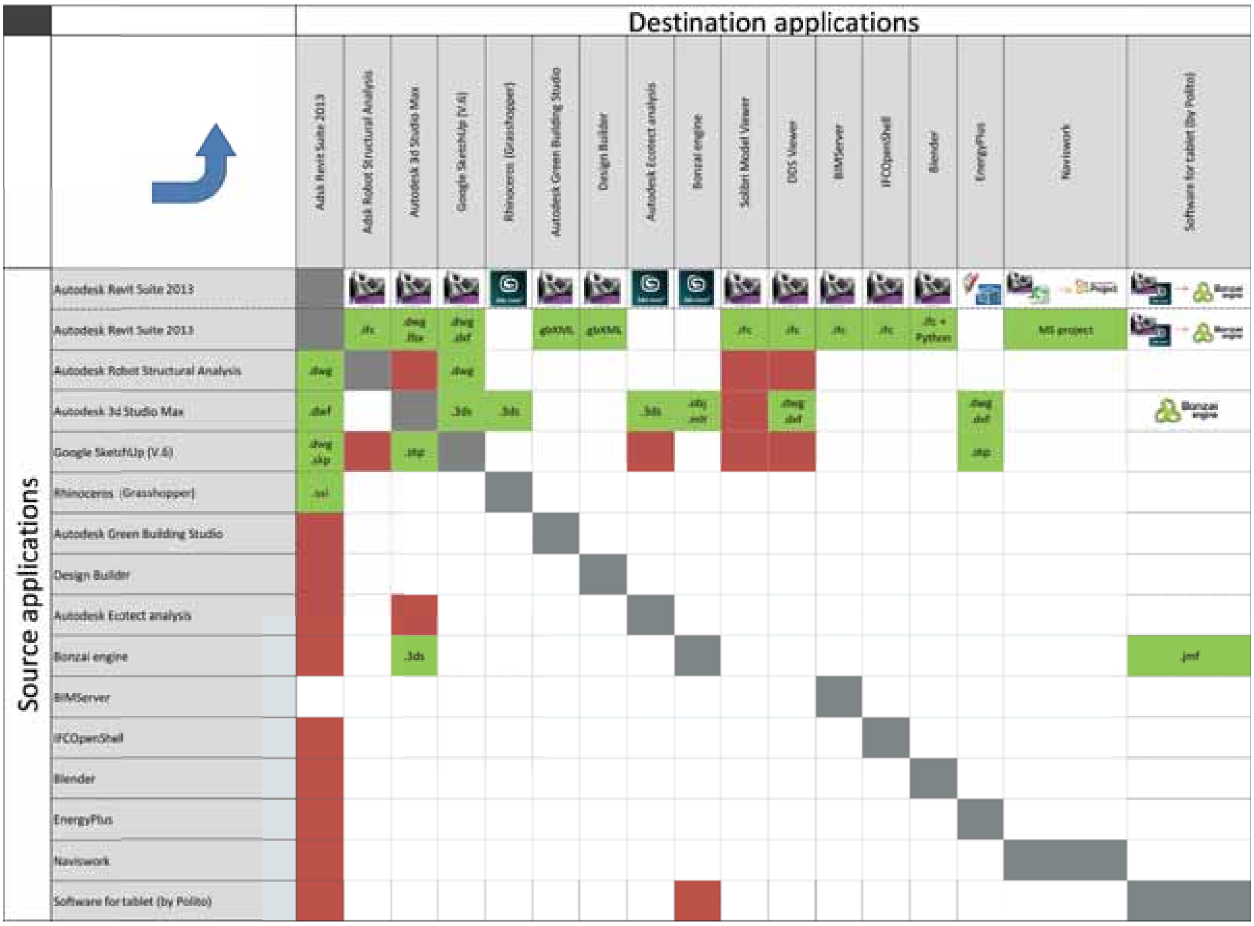

Fig. 9: Table of interoperability: Green Boxes- show the (best) possible solution to convert, Red Boxes- not possible to export from one applicatiom to another, White Boxes- cases under test.

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[5] REVIT http://www.autodesk.co.uk/adsk/servlet/pc/index?siteID=452932&id=14645193
[6] 3DStudio Max http://www.autodesk.co.uk/adsk/servlet/pc/index?siteID=452932&id=14596087
[7] TRNSYS 17 http://sel.me.wisc.edu/trnsys/
[8] REVIT DBLINK http://wikihelp.autodesk.com/Revit/enu/2013/Help/00005-More_Inf0/0001-Subscrip1/0096-Autodesk96
[9] COBie http://usa.autodesk.com/adsk/servlet/oc/offer/form?siteID=123112&id=18070390
[10] SHARED PARAMETERS http://wikihelp.autodesk.com/Revit/enu/2013/Help/00001-Revit_He0/2760-Tools_an2760/2979-Paramete2979/2980-Shared_P2980

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BIM and interoperability: A database to collect data errors and solutions

M. Del Giudice, C. Boido, D. Dalmasso & A. Osello
Politecnico di Torino, Torino, Italy

ABSTRACT: Interoperability between software programs don't is rarely error-free: the main problem is data loss during the export/import processes. The aim of our study is to create a Database to register the errors which are obtained during the interoperability processes. In so doing, we are creating an instrument to help stakeholders interested in construction projects. This database can be used not only as a simple archive, but also as an instrument to solve problems with the export/import processes. Many attempts have been carried out with various software applications and with different standard exchange formats. This effort is in an uninterrupted development, since new errors continuously appear in interoperability processes. This work is essential for Building Information Modeling: the subjects who are engaged in a construction project may collaborate with each other to obtain a better final project and the Database can provide a special contribution for achieving this aim.

1 INTRODUCTIONS

Much research in recent years has focused on Building Information Modeling and interoperability between software.

Building Information Modeling is an integrated process based on information sharing by the project owner, architects, engineers, contractors, authorities, suppliers, etc. So the heart of Building Information Modeling is an authoritative Building Information Model which is a shared digital representation founded on open standards for interoperability.

The model may be a database made up of a set of interrelated files and not just one entity. The method for communicating information in design projects has changed from paper-based drawings to three-dimensional Building Information Modeling, which enables efficient data management and quick decision-making. Interoperability creates the possibility for a far more efficient, and thereby cost-effective, business model that permits the reliable exchange or sharing of data among project participants. Consequently, different stakeholders can test the model, modifying, adding and extracting the information which is needed for the development of the project.

Although this topic offers a lot of opportunities, there are some difficulties when applying this idea in reality. The interoperability between applications is not always error-free: the main problem is data loss during the export/import processes. People who use interoperability between software have a lot of problems during the export/import processes: the model imported into a specific application does not correspond perfectly to the same model created with the original software. One possible way to solve this problem is the correct use of standard exchange formats and the correct modeling.

Few researchers have tackled this problem and while some research institutions have tested the different standard exchange formats, providing a lot of information about the strengths and weaknesses of each of them, no one has created an archive of the errors generated from the interoperability process, aimed at the users involved in a design project.

The purpose of this study is to create a public database – available on the internet – in order to register and to analyze the errors which are obtained during the interoperability process: the purpose of this work is to create an instrument useful for the AEC industry and for software houses. The errors generated from the interoperability process are causing difficulties for the growth of the BIM: engineers and architects cannot use the model without having solved the problems resulting from this process. For this reason the production of a database which contains errors from interoperability tests, provides a great instrument to help subjects interested in solving this problem, go on with their project.

First of all, we tested our architectural model exporting it into different specific application programs, using different types of standard exchange formats. Once errors had been obtained in each process a lot of time was spent to create the framework of the database to make it more useful for the users. At present, the database is continuously implemented with data errors from the interoperability process between architectural and structural or energetic models, in the future it would be possible to add data about time, costs and so on. Our intent is to provide a tool which has two uses: the first function is to archive the errors that occur when exporting and importing the model in specific applications. The second function is to consider the database as a search tool: professionals can use the archive to find a solution to an error, comparing this mistake with those described in the database.

2 METHODOLOGY

In order to investigate the interoperability process, a relational database has been developed which contains the errors from the export/import process. To achieve this result, some tests have been performed using a lot of application programs, from 3d modeling to specific calculation. The database is continuously implemented, so, whenever an error occurs it is analyzed together with the interoperable process and then it is added to the database.

The number and the type of applications are not limited to research purposes, as is also the case with standard exchange formats that were chosen. Seven programs and six standard exchange formats have been tested.

The database was developed with Microsoft Access, so it is designed for the user with little familiarity with the environment of the program. We have tried to make it as accessible as possible in its two meanings: storage and querying. So, before starting to make attempts, a decision on, how, to organize the data was made: a lot of time was spent developing the framework of the database.

As an example we used mind maps, where the organization of ideas and information that are linked by a logical thought process is very important. So we defined a radial and hierarchical framework, creating a principal table related to other specific tables in order to simplify the compilation step of the archive.

Figure 1 shows the conceptual framework of the database we have developed: we can see the two meanings of the archive, particularly the fact that the steps are linked to the data errors. In this way we created a principal archive with the errors which can be implemented or questioned.

Regarding the data input phase, we have studied the interoperability process, exporting and importing the files which must be tested many times, to find the key factors that could have affected the process, contributing to the generation of the error.

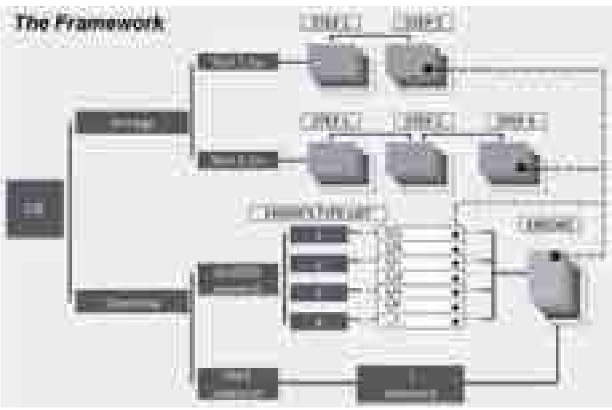

Figure 1. Conceptual framework of the database.

A significant number of tests has been done with different software applications (like Revit Architecture, Revit Structure, Axis VM, Ecotect, Daysim, Radiance, IES Virtual Environment, and TRNSYS17) and with different BIM standard exchange formats like IFC, gbXML.

The results and related errors produced have been inserted into the database. Inside it specific fields have been established to be completed by the user making the attempt. So, the first function is to archive the errors that occur when exporting and importing the model in specific applications.

As we can see in Figure 2, there are some fields which must be completed with the drop-down menu, to make the choice of the professionals easier, others with the Yes/No options. After Step 1 of the Test Archive you can proceed with Step 2. In this phase you can insert some information about the import process from the source application to the target software and the data error that occurred, following a specific path.

In Figure 3 Step 2 is showed: there are similar fields present in Step 1, but there are also some spaces dedicated to the error type. The second function is considering the database as a search tool: professionals can use the archive to find a solution to an error, comparing their mistake with those described in the database. So the ability of the database is its capacity to examine data in more ways than you might imagine, employing query to use the archive in a correct way,

Figure 2. This figure shows Step 1 of the filling part of the database.

Figure 3. This figure shows Step 2 of the filling part of the database: import data in the target software.

Figure 4. This figure shows the error's type list that the user found when running a search in the database.

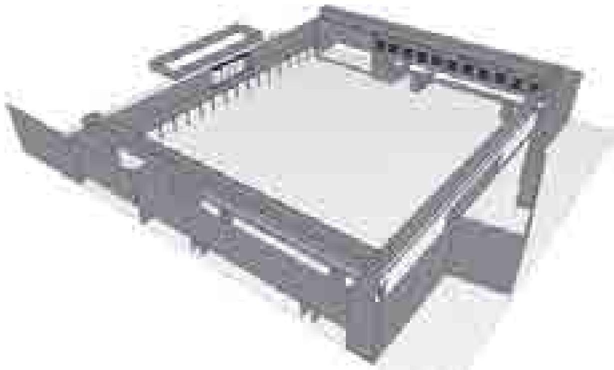

Figure 5. This figure shows the absence of the slabs and the curtain wall which occurred during a test, using gbXML standard.

exploiting its full potential. To achieve this goal, the database query and, consequently, the data search can happen in two ways: in the first way the user follows guided steps which lead to finding the errors searched for; in the second way the user can run a free search which is faster than the first way. In this case the subject can obtain the data errors they need by inserting a keyword which is linked to the error paper. To do this we have created a form containing a list of the data error families, for the guided search, and a free field to insert the keyword that is necessary for the free search. In this way the users can choose the keyword they prefer to search for the error which has occurred in their interoperability process.

3 RESULTS

The development of Building Information Modeling is changing building design and management. As a result of this phenomenon, many researchers are analyzing the interoperability process to find a solution to the various problems related to the export\import phases. The general aim of the database is to improve the interoperability process.

We have developed a professional tool which can ensure this goal, allowing users not only to insert new data errors that occur in their work with the application programs, but also to seek a solution within the database.

The idea of publishing this instrument on the network comes from the fact that it is necessary to increase the database with more information to enable users to find a solution to interoperability issues. Following this idea, stakeholders who encounter difficulties and errors in their interoperability process can use this instrument to solve their problems, sharing data with other people. In this way, professionals collaborate to overcome errors, improving the interoperability between software.

Obviously, this task is under construction because an uninterrupted development has been set up, as new errors continuously appear during interoperable processes. So, exploiting the network we think that the database can be enlarged, acquiring information from a higher number of people who use the interoperability process.

The growth of the database, along with the performance of the test with different standard exchange formats and different programs, has made it possible to solve problems with a 3D model, from Revit Architecture to Ecotect. Regarding this test, we tried the gbXML standard: slabs and glass façades were absent because we had not used the Room element which is considered the fundamental element for design performance analysis.

As we can see from Figure 5, it was impossible for us to test the model, without having regenerated the slabs and the windows: however, following this method, we would have lost a lot of time, developing the model on Revit again.

Only by repeating this test several times, analyzing the export and import process, did we discover the type of mistake we had committed during the process. All of the test was inserted into the database so anyone else who has this problem can find it in the archive, finding out the reason for the error, correcting it themselves.

It is evident that the database already exists but it is in a beta phase, so it must be implemented with other data errors and improved to produce a better instrument for design projects.

4 CONCLUSIONS

The presence of data errors from the interoperability process and a lack of standardized solutions, has allowed us to reflect on the importance of the existence of an archive that collects this information, which can be implemented or used to facilitate the user in the construction industry.

The database which has been developed, could certainly be modified and implemented to create an easy, but, at the same time an effective tool in order to help professionals in their work.

This research is essential to extend the idea of BIM, and interoperability is a key issue for introducing BIM process changes in a company. Adopting this kind of thinking, professionals can produce more accurate designs with fewer errors, less waste, a closer alignment to the owner's vision and engineers can increase coordination with architects and other engineering disciplines, improving the reliability of their design. Finally, in the hope that the subjects who are engaged in a construction project may collaborate with each other to obtain a better final project, this database can provide a special contribution to achieve this aim.

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Version1 – Part 1: Overwiew, Principles and Methodologies, Trasforming the Building Supply Chain Through Open and Interoperable Information Exchange.

From historical buildings to smart buildings via middleware and interoperability

Andrea Acquaviva, Laura Blaso, Daniele Dalmasso, Matteo Del Giudice, Giovanni Fracastoro, Valerio Lo Verso, Enrico Macii, Anna Osello, Alfonso Pace, Edoardo Patti, Anna Pellegrino, Paolo Piumatti
Politecnico di Torino, Italy

Abstract

The vast majority of historical buildings are very energy inefficient; as energy costs continue to rise, they need smarter energy management strategies, since traditional ways of improving energy efficiency through structural retrofits are very expensive and not always possible in historical buildings. The paper shows the development of a new smart strategy to improve the energy efficiency of historical buildings without significant construction work. The strategy is based on Information Technologies and Wireless Sensor Networks, Building Information Modelling and interoperable energy simulation tools and also requires and stimulates an improvement of human awareness and competence.
The paper reports the results of the first phase of the Smart Energy Efficient Middleware for Public Spaces project that addresses reduction in energy usage and the CO2 footprint of existing public buildings and spaces, by an intelligent ICT-based service which monitors and manages the energy consumption.
Preliminary results have led to the development of a middleware tool which enables the interoperability of software and Wireless Sensor Networks to monitor energy consumption, controlling environmental parameters such as luminance and temperature to take advantage of natural resources (i.e. daylight and solar energy) in order to ensure the best possible comfort conditions with the most efficient use of energy. The research project is a demonstrator for a theoretical model that can be applied to wide typologies of historical buildings in Europe, especially public buildings.

Keywords: Energy Efficiency, Building Information Modelling, Middleware, Interoperability, Thermal and Lighting Simulation.

1 Introduction

The improvement of energy efficiency in historical buildings is normally more difficult and expensive than in new buildings. Interventions such as retrofitting of building envelopes or systems to reduce energy consumption are not always possible or economically viable especially in historical buildings where conservation is a matter of priority.

This paper describes the development of a new smart strategy to improve the energy efficiency of historical buildings without significant construction works. The strategy is based on Information Technologies (IT) and Wireless Sensor Networks (WNS), and on Building Information Modelling (BIM) and interoperable energy simulation tools. In particular the paper shows the results of the first year of the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) project.

SEEMPubS is a collaborative research project of the 7th Framework Program (FP7) of EU specifically addressing reduction of energy usage and CO2 footprint in existing public buildings and spaces by implementing an intelligent ICT-based building monitoring and managing system. The proposed system will make use of the service-oriented middleware for embedded systems already developed by two partners – Fraunhofer-Gesellschaft zur Foerderung der Angewandten and CNet Svenska AB - in the previous FP6 Hydra project and use its potential to create services and applications across heterogeneous devices to develop an energy-aware platform.

The SEEMPubS platform will provide tools to add energy efficiency features to monitor dynamic sensor data in real time and to control the operation of both passive and active environmental systems so as to ensure the best possible comfort conditions with the most efficient use of energy. The functionality of this system will be demonstrated on existing buildings in the Politecnico di Torino Campus.

The first phase focuses on the process of energy performance simulation and the optimization of interoperability by BIM, energy simulation tools, middleware and sensor networks tested together. Some preliminary results deriving from analytical models on lighting, heating and cooling applied to the Valentino Castle in Turin (which dates back to the XVII century) are presented.

2 Methodology

This chapter describes the methodology used in the first phase of the project, this can be divided in three research topics:

- energy usage monitoring
- building simulation
- energy management through an Intelligent Control System.

2.1 Case Study

The Valentino Castle is the historical seat of Politecnico di Torino and is today the main campus for the Architecture Faculties. It was built in the 16th century, and then was completely restored from 1621 to 1660 by the famous architects Carlo and Amedeo di Castellamonte. The central building has the architectural features of 17th century French castles and Italian baroque buildings (Figure 1), with rooms and halls decorated with rich stuccoes and commemorative allegorical fresco paintings (Figure 2a). The complex was enlarged in the 19th century (the so called Chevalley building) and in the 20th century. The attic of the Chevalley building has been recently reorganized to house new offices.

2.1.1 Selection of the spaces to be monitored

In order to obtain a representative sample which can be widely applicable to public buildings, the first step of the project was, after an analysis of the different important parameters involved, to select the rooms to be monitored in the Politecnico campus. The selection criteria were based on three mains factors: indoor climate, indoor lighting and rooms' features (features are related to the architecture and to the heating and lighting systems of the rooms). Each test room has a reference room – a room with similar characteristics and orientation - to be tested in order to compare results between the traditional strategies and the innovative control strategies which are proposed in the project.

In Valentino Castle there are two test rooms, plus two corresponding reference rooms, and they are representative samples of two types of historical public buildings. The first room, called "the Green room", is in the central building and is the student office of the Faculty of Architecture; it is a high-ceilinged space with frescoed walls and vault, where modifications are not allowed due to the high value of the decorations (Figure 2a). The second room is in the "Chevalley" building and is an example of a retrofitted modern room within an historical building (Figure 2b) and is now part of the DIST Department.

Figure 1. The case study: photography of the main building of Valentino Castle.

Figure 2a (left) and 2b (right). The two test rooms: the student office (Green Room) on the left, and the DIST room on the right

2.2 Energy auditing and monitoring campaign

To provide information on energy performance of the different Politecnico Campuses, an energy audit was carried out. The energy audit is based on energy consumption data which was collected for past years and in particular on data collected for 2009. The data included both electric energy, district heating and natural gas energy consumptions. Furthermore, this data was referred to the meteorological local conditions monitored during the same period (monthly trends of horizontal global irradiance, air temperature, air humidity and air speed), as these determine the use of the HVAC systems (heating and cooling systems).
Besides this, in the selected rooms a series of field measurements of indoor climate and lighting conditions were taken (monitoring campaign), so as to validate the thermal and lighting numerical models which were created to simulate the real rooms.

As far as daylight is concerned, a series of one-week campaigns was repeated in summer and fall 2011, measuring simultaneously both indoor illuminance in two points in each room and outdoor illuminance on an unobstructed external horizontal plane for overcast, intermediate and clear sky conditions. The values of average and punctual illuminance (E) and of daylight factor (DF) were used to define respectively the average availability of daylight and its distribution within the room.

To define the microclimatic conditions, indoor air temperature and relative humidity were monitored during a week in winter. Again, depending on the room size and shape, two measurement points were selected. Beyond air temperature and relative humidity, surface temperatures were measured using an infrared camera (Figure 3).

The indoor microclimatic conditions are complemented by the meteorological data (air temperature, relative humidity and horizontal global irradiance) recorded on the roof during the same week (from 7 th to 14 th February, 2011).

Both thermal and lighting monitored data were used to validate the 3D simulation models (TRNSYS for thermal analysis and Radiance and Daysim for lighting analysis) and consequently to estimate the building energy demand.

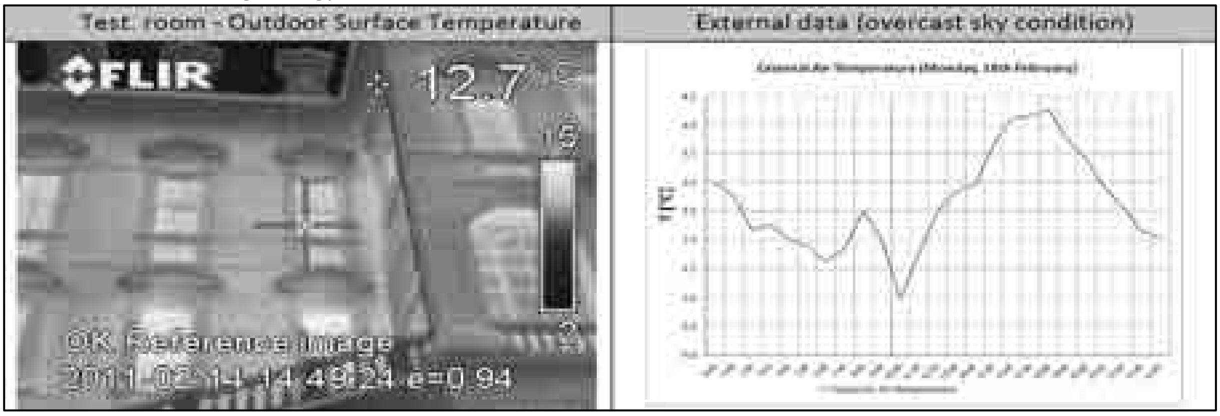

Figure 3. Outdoor surface temperature of the student office room (room1) and the concurrent external air temperature

2.3 *Simulation of the buildings through BIM and Interoperability*

The objectives of this phase are to simulate the thermal, lighting and energy quantitiy evolution of the rooms with different operation scenarios and to validate the simulation using the monitored results. Moreover, the research aims at investigating the possibility of using a Building Information Model to collect all the data and to carry out all the simulations by increasing the interoperability level between the software and the models.

2.3.1 Building Information Modelling

A building information model is an information or data representation containing geometry spatial relationships, geographic information, quantities and component properties [Teicholz P., et al. 2008]. The use of BIM in historical buildings has much to offer to create facilitiy data, an asset register, maintenance and service data, as well as service procurement data, although it can be expensive to set up. In this phase the investigation involved BIM for architectural, HVAC and lighting system modelling, and as methodology to test the interoperability for energy efficiency simulations.

The creation of the building information model started with the creation of 3D models of the selected rooms, as well as of their external environments through the parametric software Revit.

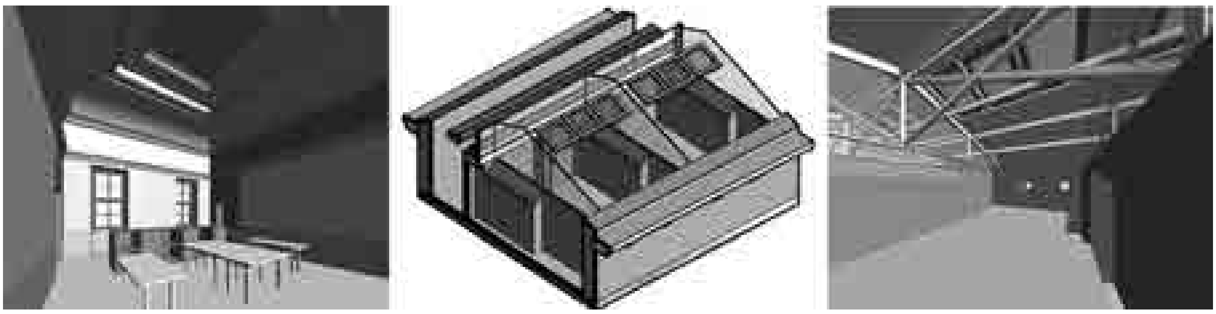

Figure 4. Views of the BIM model of the Valentino Castle test rooms.

2.3.2 Lighting and thermal simulation

To start the lighting simulation the parametric 3D models were imported into the computer simulation tools Radiance and Daysim through the software Ecotect. For the SEEMPubS project both Radiance and Daysim are used thanks to the interoperability between softwares: the former to validate the models, the latter to estimate the lighting energy demand and the savings obtained with the proposed control strategies. This allows running annul simulation for a given site, accounting for the specific dynamic climate conditions.

An initial validation of the model was done by comparing the output of the Radiance simulations (illuminance distribution) with the illuminance values measured in the corresponding rooms. Thereafter some simulations through Daysim were started in order to calculate the electric energy consumption for the type of lighting control system proposed for each case study.

The thermal simulations were carried out to test the interoperability between the BIM model and the software TRNSYS, an internationally recognized software dedicated to the dynamic simulation of thermal systems, for single or multi-zone buildings. In particular, the latest version of TRNSYS (v17) has a new 3D plug-in that, on several cases in the project, allowed the interoperability among all participants to be developed.

To perform the simulation it was necessary to define the thermal zones, the heating schedule, the meteorological data and adopt a suitable model for the fan coils and AHU (Air Handle Units) of the Valentino Castle.

2.4 Intelligent Control System Software Infrastructure

The strategy for smart building management and control is based on an ICT infrastructure, made of monitoring and actuation devices controlled by an appropriate stack of software layers. In this phase of the project development, control devices are mainly used. The control phase will be carried out in the second part of the project. However, from a software development viewpoint, the main infrastructure has already been produced and tested. The core of the software support consists of a web-service based and hardware independent software infrastructure, based on the LinkSmart middleware [Jahn M., et al. 2009], [Lardies F.M., et al. 2009], to provide interoperability between heterogeneous devices and networks, both existing and to be developed. Moreover, the proposed infrastructure allows easy extension to other networks, thus representing a contribution to the opening of a market for ICT-based customized solutions that integrate numerous products from different suppliers.

The system manages energy efficiency through the Wireless Sensor Networks, which are preferred in order to ease integration of new sensors into the system and to avoid the overload of cabling in old buildings. An innovative software infrastructure was developed to handle the heterogeneous wireless sensor nodes of different WSNs through web-services, based on the LinkSmart Middleware.

The software infrastructure provides the following main functions:

- It enables interfacing to the application layer by means of web services, through which sensor data can be desplayed or used to optimise energy management policies;
- It collects sensor data in a local database, so they can be accessed in an asynchronous way and preserved from network failures;
- It allows the remote reconfiguration of sensor node parameters such as the sampling rate of physical quantities to be monitored;
- It enables interoperability among heterogeneous networks, characterized by different microcontrollers and sensors.

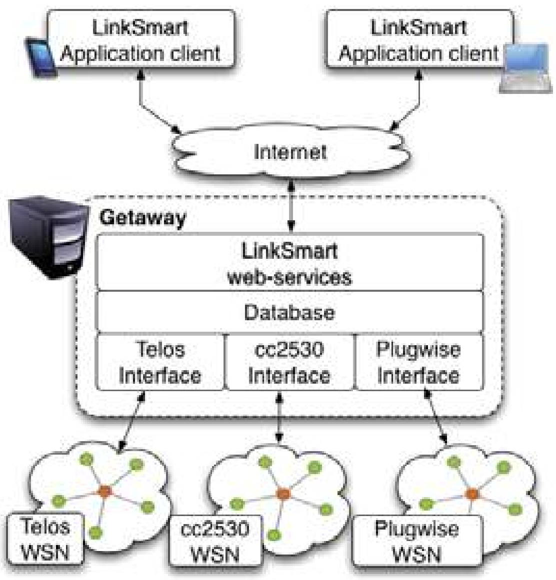

Figure 5: Software infrastructure scheme to handle heterogeneous Wireless Sensor Networks.

As shown in Figure 5, our software runs in a PC-Gateway (GW) and communicates directly with the heterogeneous networks. The dedicated *Interface* represents the lowest layer of our proposed stack, and receives all the information coming from the WSNs, regardless of the adopted communication protocols, hardware or the network topology. Hence, each WSN needs a specific software *Interface*, which interprets the data and stores them in an integrated database (DB), in order to make the whole infrastructure flexible and reliable with respect to back-bone network problems, since data are locally stored.

The web-service layer, implemented using LinkSmart, interfaces the WSNs to the web, making remote management and control easier. Moreover, it exports all the environmental data stored in the DB and collected by the wireless sensor nodes to the application client layer, the last in our stack.. At this layer, the information is available to the end-user and ready to be post-processed or to be shown via computers or smartphones.

Particular emphasis was given to the possibility to reconfigure each node, changing, for instance, some management parameters. In this scenario, the end-user sends the new configuration via web-services to the GW and stores it in the DB. The new settings will then be automatically sent to the receiver mote. The configurable parameters change depending on the hardware and the Operating System running on the end-node. However, using this software infrastructure, the user can choose only the right settings, ignoring the real physical hardware related to the virtual device.

In a nutshell, the proposed web-based infrastructure is a software that makes the underlying WSNs transparent to the end-user, abstracting all the information about hardware, protocol stack and embedded operating system. Furthermore, by the use of web-services, it facilitates the interoperability with third-party software.

3 Results

The results obtained in the first phase of simulation and modelling pave the way for the realization of the Intelligent Control System.

As in the previous section, the results are presented for the main research topic:

- Simulation of the building;

- Control strategies
- Definition and implementation of the Intelligent Control System.

3.1.1 Simulation of the building

The monitoring survey gave all the parameters necessary to perform the simulation. Moreover it was possible to carry out the simulation phase using the BIM model.

With regard to the lighting simulation, good results in the interoperability among Revit, Ecotect, Radiance and Daysim were obtained after some unsuccessful trial. The first trial adopted the traditional approach based on the exportation in IFC (Industry Foundation Classes) format, but it did not succeed because some elements were not exported or were displaced. The second trial was based on the exportation from Revit by a gbXML file, but some geometrical discrepancies in the surfaces generated by the solid elements made the model unsuitable for the lighting simulation. Finally the third procedure tested was successful: using 3DStudio as an intermediate software (to convert the .fbx file exported from Revit in a .3ds file to be opened with Ecotect) gave good results in terms of consistency of the exported model.

The validation phase with Radiance showed a difference between measured and simulated illuminances ranging from -12% to +30%, depending on the considered sky conditions (clear or overcast sky) and on the position of the verification point within the room. This discrepancy might be attributed to the interaction of the different aspects which are involved in the simulation process: 1) the correspondence of the sky model generated by Radiance starting from the measured outdoor illuminances (direct and diffuse horizontal illuminances) with the real sky condition; 2) the optical characterization of opaque and transparent room surfaces; 3) the accuracy of the instruments which were used; 4) the accuracy of the geometrical model, with particular attention to the modelling of the glass surfaces.

With regards to the thermal simulation, the research team realized that the data flow from the Revit parametric model to the analysis software (TRNSYS) is not completely interoperable. In fact the new 3D TRNSYS plug-in requires the creation of thermal zones, which are entities that do not exist in the Revit model. For this reason the exportation of the building information model to TRNSYS generates a model that can be used as geometric reference to facilitate the creation of the thermal zones. Another main issue is that the different rooms in the BIM model are separated by walls, i.e., physical entities characterized by a thickness, while TRNSYS thermal zones are divided by surfaces that have no thickness. This generates some geometrical and dimensional discrepancies, especially if the wall has a large thickness as generally happens in historical buildings. To solve this issue the research team developed a special method (Savoyat et al., 2011) to simulate the very thick walls and ceiling of the Valentino Castle. With this methodology it was possible to perform the thermal simulation even of the student offices in the central building of Valentino Castle, whose walls have thicknesses varying from 60 to 93 cm.

3.1.2 Energy control strategies

Starting from the monitored data and taking into account the architectural and system features in each selected room of the Valentino Castle, new specific control strategies were proposed. In particular, in the student offices (room 1), considering the low daylight availability observed both in winter and in summer (daylight factor below the required 1% and absolute illuminance values in summer often below the required 500 lux) it is not useful to propose a lighting control based on daylight exploitation. The control strategies that should be applied in this room are *time switching* and *occupancy detection* for task lighting. Due to the low absence probability in these offices the saving potential with automatic lighting control seems however to be quite limited.

In DIST offices (room 2) the architectural features, and in particular the presence of large skylights, result in a high daylight availability, as testified by the average Daylight Factor value (> 3%) and the high illuminances measured on the working plane, especially in summer. In this case the *daylight harvesting control* strategy could be applied successfully, together with occupancy detection and manual control for electric light. A control system for shading devices, based on outdoor illuminance or solar radiation, was also proposed. In this regard, the first results from Daysim annual daylight simulations showed a potential energy saving (comparing the new proposed control strategies to the existing one, i.e. manual control), equal to 48%, when both photo-dimming and occupancy sensors are considered, and to 30 %, when only an occupancy sensor is considered..

The air temperature trend during the monitored winter period reveals the need for a more accurate heating monitoring and control strategy: the air temperatures measured near the workplaces during the week are always above comfort and set point values, even during night-time. The control principle, that will in this case be a real necessity, is to switch off the heating when an absence is detected or when the electric (+ lighting) power is sufficient to cover the heating need.

3.1.3 Definition and implementation of the Intelligent Control System

In the first prototype, we explored the technological integration of different devices and simple control strategies for lighting and heating systems in the targeted rooms which are located in Valentino Castle. This integration provides an interoperable system consisting of a heterogeneous legacy and new devices that we need as a foundation to develop a more Intelligent Control System that will be developed in the successive tests. The system architecture proposed provides a good baseline to work with the LinkSmart middleware.

To date, we have been able to simulate the interaction with the pre-existing Building Management System (BMS), in particular using a manual control system with an Open Process Controll (OPC) server that could replicate the behaviour of the current system.

4 Conclusions

The project will continue with the creation of a wireless sensor network in the buildings of the case study to verify how much energy can be saved through the new strategy based on monitoring and controlling the energy consumption.

The validation of the most significant SEEMPubS results will allow an energy efficient model for existing buildings and public spaces with a significant economic impact all over Europe to be produced. In fact this model could also be applied to many different historical buildings (e.g. palaces, castles and museums) where old energy systems are already in place, avoiding in this way expensive construction work and possible damage.

SEEMPubS will provide control of appliances to optimise energy efficiency usage without compromising comfort or convenience and offering decision makers the strategies and tools needed to plan energy saving measures. SEEMPubS will make use of the service-oriented middleware for embedded systems and use its huge potential to create services and applications across heterogeneous devices in order to develop an energy-aware platform.

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Energy consumption management using CAFM application

Andrea ACQUAVIVA[2], Laura BLASO[3], Daniele DALMASSO[1], Matteo DEL GIUDICE[1], Giovanni Vincenzo FRACASTORO[3], Valerio R.M. LO VERSO[3], Enrico MACII[2], Anna OSELLO[1], Edoardo PATTI[2], Anna PELLEGRINO[3], Paolo PIUMATTI[1].
(1) DISEG - Department of Structural, Geotechnical and Building Engineering Politecnico di Torino, Italy
E-mail: daniele.dalmasso@polito.it, matteo.delgiudice@studenti.polito.it, anna.osello@polito.it, paolo.piumatti@polito.it
(2) DAUIN - Department of Control and Computer Engineering, Politecnico di Torino, Italy
E-mail: andrea.acquaviva@polito.it, enrico.macii@polito.it, edoardo.patti@polito.it,
(3) DENERG – Department of Energy, Politecnico di Torino, Italy
E-mail: laura.blaso@polito.it, giovanni.fracastoro@polito.it, valerio.loverso@polito.it, anna.pellegrino@polito.it

Abstract
Normally end users are passive users who do not participate in managing their energy consumption. International literature is demonstrating that involvement and awareness in facility management can help energy saving. For this reason, it is necessary that the subject becomes active and able to fit inside the energy management information.
From this point of view, the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS), a Seventh Framework Programme project, aims to reduce energy consumption in historic and modern public buildings through low economic impact construction works and an efficient ICT network for monitoring, detecting and managing consumption.
At the end of this project, consumption data, which were collected within a number of the test rooms, will be available to end users through a Facility Management application (Archibus) that will allow users to see energy consumption data visible in real time, and to perform a different kind of medium and long term analysis and consequently to plan construction works, when necessary.
At the same time, collected data, are used to study the methodology through interoperability among parametric software, both architectural (Revit Architecture), energetic (Daysim, Radiance and TRNSYS) and Facility Management (Archibus FM).
Therefore, SEEMPubS will be able to transform “users” into “informed-user” involving them in the global energy process.

Key-words: Archibus, SEEMPubS, End users, Facility Management, Interoperability.

1. Introduction
When we talk about end users we refer to subjects at the end of the process. Generally, this process ends when users performs their actions and tasks and receive a benefit. As just described these subjects are known as Passive Users as do not interact directly with the process, but are limited to suffer the consequences. On the contrary, Active Users are defined as subjects, that in response of a proper information, interact with the system productively synergistically; when operating in this way the subject plays a major rather than a secondary role.
Distinction between Active and Passive Users becomes of basic importance when we talk about energy efficiency and saving.

Since 2000, with the introduction of the European Climate Change Programme (ECCP), and subsequent amendments and additions, the European Union (EU) has pushed and encouraged the introduction of national policies for energy saving and reduction of greenhouse gases.
Alongside with the actions that National Governments have enacted with the aim of pursuing the objectives of the Program 20/20/20 (Directive 2009/28/EC), one of the indirect goals is just to increase information, about energy saving, and transform users in active users able to act in practical ways to reduce consumption.
The advent of Building Automation or rather the concept of Smart Buildings, in which different types of systems are managed in an integrated way, has allowed the involved users to increase their awareness and control about energy saving and energy management. However, this type of building management system was limited to commercial buildings.
The extension of this concept to the majority of people came with the introduction of Home Automation, which is the science that deals with the study of technologies to improve and optimize the use of home places.
Dissemination of these two applications is, in both cases, strongly connected with a strong diffusion of the concept of energy saving and user interaction.
The awareness of a single person, who understands that his role, however small, can lead to significant savings in energy terms, is the basis of current policies that are implemented with increasing force, at all organizational levels. It is in fact understood that the monitoring of the role played by rooms occupants is essential to control the total consumption of a building.
The Politecnico di Torino is an institution more sensitive to the energy saving and for several years has been engaged in initiatives and projects related to this topic.
All these projects always consider the active presence of end users and their interaction with the process; for example, it is possible to mention the initiative called “M’Illumino di meno” which took place on February 17th, 2012: all Politecnico’s employees were asked to do energy-saving actions paying particular attention to power consumption and to switch off all energy consuming equipments (e.g. printers, computers, etc..) when they are not used, as well as to close windows and lower thermostats.
The monitoring of consumption, combined with user information campaign and to the implementation of the suggested actions, resulted in a saving of over 6.000 kWh.

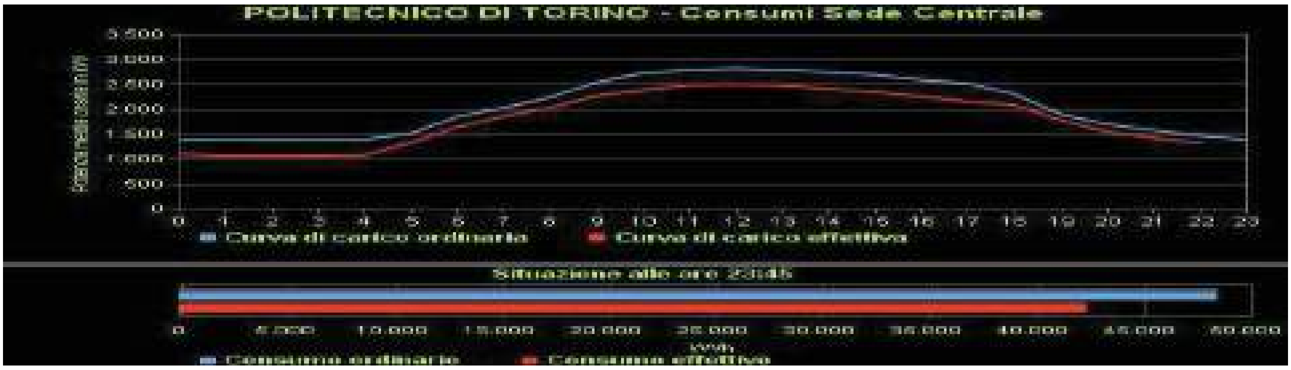

Fig. 1: Representation of the ordinary and effectives consumption on February 17th, 2012, for the Headquarters of Politecnico di Torino [taken from web site: http://smartgreenbuilding.polito.it/]

This is just one initiative where users are involved directly, there are also research projects developed with national and international contributions, involving the study and analysis of scientific methodologies for monitoring and reducing consumption, such as the European project SEEMPubS.

2. SEEMPubS

The European project SEEMPubS (Smart Energy Efficient Middleware for Public Spaces) is a project of the 7th Framework Programme; it specifically addresses reduction in energy usage and CO_2 footprint in existing Public buildings and Spaces without significant construction works, by an intelligent ICT-based service monitoring and managing the energy consumption. The project bestows special attention to historical building in order to avoid damage by extensive retrofitting.
The project focus start considering that in most public buildings the system management is performed in independent and not integrated way, as a result it is difficult to obtain an optimal management of different type of consumption.

Specifically, the project includes use and implementation of a system based on “LinkSmart” (also called Hydra), a middleware service, developed in other European project (Jahn et all., 2009), (Lardies et all., 2009).
The "LinkSmart" is designed to support the development of embedded systems networks, simplifying the interconnection between devices, which are often heterogeneous, and principally communicate with different protocols for data exchange. Therefore, SEEMPubS platform allow to monitor and control, in an integrated way, different type of system (such as lighting and HVAC) and its consumption.
All collected data will be constantly compared with the external climatic condition in order to crate the best interior comfort.
The middleware implementation provides development of an ICT network able to detect consumption data resulting from different type of wireless sensors connected to the system and subsystem and consequently allow to analyse them.
Additionally, all data about energy consumption and energy saving will be made available in a web-site being implemented in order to increase awareness of energy saving and efficiency in public buildings by the users.
The project goals can be summarized as follow:

- Developing an integrated electronic system to monitor different building models, technical building services, electronic devices and operations in order to optimize and integrate all maintenance functions.
- Implementing an interoperable web-based software solution for real-time energy performance monitoring and control of lighting, heating, ventilation and air conditioning services through wireless sensor networks in existing buildings and open public spaces.
- Raising people’s awareness for energy efficiency in public spaces.
- Providing multi-dimensional visualization of parameters of building operations and data sharing from technical systems.
- Validating the developed monitoring system through an iterative methodology.
- Translating the most significant research results achieved within the project into a model for existing buildings and public spaces in Europe.
- Disseminating and exploiting the project results according to a strategy based on several awareness-creation means and to the specific business and market targets of the individual partners.

3. Case Studies

The first activity, necessary for data acquisition, was the selection of the rooms. Particularly, 6 pairs of rooms were selected, each one is formed by a test room and a reference room (where Building Management System (BMS) will be implemented for lighting, heating/cooling and electric appliances control and monitoring). The 6 pairs of rooms have a lot of different features between them while the differences within the pair are almost nil.
In this way, we can work with rooms for which it will be possible to make not significant construction works and evaluate energy savings (test rooms), at the same time we are being able to compare these values with the state of the similar environment (reference rooms). The selected rooms are located in the Valentino’s Castle, in the Main Campus of Corso Duca degli Abruzzi and in the Cittadella Politecnica. The choice of these three different types of buildings is connected, as mentioned, to the desire of having buildings with different constructive characteristics and different periods of construction.

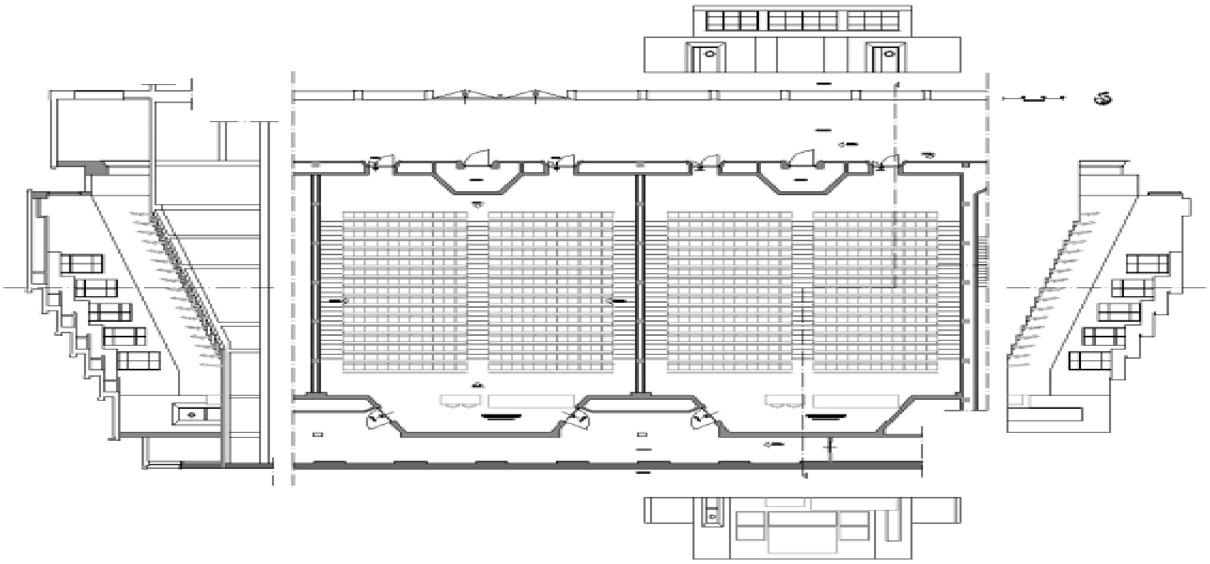

Fig. 2: Classrooms used as case study – it is possible view the test room (on the right) and the reference room (on the left).

4. Interoperability to assess performances for different control strategies

A detailed relief of architectural features of each case-study (geometry, furniture and equipment, surface reflection/transmission properties, lighting/HVAC systems etc.) was carried out so as to create accurate 3D models of the selected rooms. The models were used to run energy simulations (TRNSYS for thermal analyses and Radiance and Daysim for lighting analyses), which were validated through monitored data and then used to estimate the building energy demand for different control strategies. As far as lighting simulations is concerned, Radiance was used to validate the models, comparing the simulated illuminance distribution to the illuminance values measured in the corresponding rooms, while Daysim was used to estimate the lighting energy demand and the savings obtained with the specific control strategies proposed for each case-study. Daysim in fact allows running annual simulation for a site, accounting for the specific dynamic climate conditions.

Before starting the simulations, the use of BIM for architectural, HVAC and lighting systems modeling, as methodology to test the interoperability for energy efficiency simulations, was investigated. The BIM approach started with the creation of 3D models of each case-study, including their external environments, through Autodesk applications. In particular Revit Architecture was used for architectural modeling and Revit MEP for the modeling of heating and lighting systems.

In order to run the lighting simulations, it was not possible to import the parametric model from Revit into Radiance/Daysim directly.

The software Ecotect was hence used as interface to lunch Radiance/Daysim. As a result, the import from Revit into Ecotect was addressed: the first trial adopted the traditional approach based on the exportation in IFC (Industry Foundation Classes) format, but it did not succeed because some elements were not exported or were displaced. The second trial was based on the exportation from Revit by a gbXML file, but some geometrical discrepancies in the surfaces generated from the solid elements made the model unsuitable for the lighting simulation. The third procedure eventually succeeded: using 3DStudioMax as an intermediate software (to convert the .fbx file exported from Revit in a .3ds file to imported into Ecotect) good results in terms of geometrical consistency of the exported model were obtained.

At the end of the interoperability process, lighting simulations were run to validate the models and to use them to evaluate the potential energy savings concerned with the proposed control strategies.

The validation phase with Radiance showed a difference between measured and simulated illuminances ranging from -12% to +30%, depending on the considered sky conditions (clear or overcast sky) and on the position of the verification point within the room. This discrepancy might be attributed to the interaction of the different aspects which are involved in the simulation process: 1) the correspondence of the sky model generated by Radiance starting from the measured outdoor illuminances (direct and diffuse horizontal illuminances) with the real sky condition; 2) the optical characterization of room opaque and transparent surfaces; 3) the accuracy of the instruments which were used; 4) the accuracy of the geometrical model, with particular attention to the modeling of the glass surfaces.

According to the characteristics of the selected rooms, a first series of monitoring and control strategies was proposed. In particular as for lighting new control strategies were proposed (IESNA 2000) (Acquaviva et al. 2011): for spaces with high daylight availability and medium/high users absence probability, a combination of daylight harvesting and occupancy control was proposed; for spaces with low daylight availability, a lighting control based on occupancy sensors was proposed, while a peculiar solution was defined for large classrooms with no daylight: students absence probability during the day is very low, but the classroom area could be only partly occupied when a small number of students attend the lectures. In this case, it was planned to use several occupancy sensors to dim to a minimum the lights corresponding to the unoccupied classroom areas. Anyway, in all cases users were provided with the possibility to override the automatic control via manual command. Based on these assumptions, some recurrent combinations of lighting control strategies were initially proposed for the selected rooms:

- time switching, occupancy detection for personal light and manual control: this mix of control strategies was proposed for the Student Offices where daylight availability is very low and the general lighting is provided by means of High Pressure Metal Halide lamps, which can not be switched on and off instantaneously and can not be dimmed
- daylight harvesting, occupancy detection and manual control: this combination of control strategies was proposed for DIST offices, Administrative offices and DAUIN private offices. In these cases the automatic dimming of lights based on a daylight harvesting control strategy could be applied successfully thanks to the high daylight availability and it could be useful to control lights on the basis of room’s occupancy too, as a medium absence probability could be truthfully assumed for these offices
- occupancy detection and manual control: these control strategies were proposed for classrooms 1&3 and for the DAUIN open-plan offices as daylight is not allowed to enter the rooms (in classrooms) or is quite low due to the glazing characteristics and the external obstructions produced by the structure of the double façade in the DAUIN offices
- shading device control based on outdoor illuminance or solar radiation: this control strategy was proposed for DIST offices, where motorized blinds are installed on the roof lights, to control overheating and glare due to solar radiation.

For each room, the initially defined control strategies were simulated in Daysim and the corresponding energy demand for lighting and the potential savings were estimated, comparing the energy demand for the new strategy to the demand for the currently installed control system.

The obtained results outlined that, in most cases, the initially proposed control strategies would not provide the expected energy savings (from 5% to 30%). This might be due to the fact that the automatic on and off implies the switching on of lights whenever someone enters the room, independently of the indoor lighting conditions that might be determined based on daylight. Once switched on, lights are kept on, in standby mode, even if daylight is sufficient to fulfill the lighting requirement. Based on this, it seemed fairly probable that energy savings could be increased by using the occupancy sensors only to switch the light off when users leave the rooms, while leaving the occupant the task to switch them on if the lighting level is perceived too low. Increasing user information and awareness is one of the key goals of the SEEMPubS project. This should reduce the number of hours the lights are on, or in standby mode. Based on this, new improved strategies (‘updated strategies) were defined and analyzed through new sets of simulations: it was then found that the most effective control solution for some of the analyzed case studies was a mix of manual and automatic control instead of a fully automatic control as initially proposed. The best results were obtained assuming that users have an active behavior in controlling blinds and lights, thus increasing the potential energy savings (range 13% ÷ 39% for an equal mixed passive/active behavior and between 14% ÷ 71% for the active behavior, where passive and active users are based on two different stochastic models implemented in Daysim) (Reinhart 2004).

5. Intelligent Control System

The strategy for smart building management and control leverages upon an ICT infrastructure made of heterogeneous monitoring and actuation devices, such as Wireless Sensor Network (WSN). An innovative web service oriented software infrastructure has been developed to manage heterogeneous and commercial wireless sensor nodes belonging to different WSN. The LinkSmart middleware (Jahn M. et al. 2009), (Lardies F.M. et al. 2009) has been adopted to provide interoperability between heterogeneous devices and networks, both existing and to be deployed. Moreover, the proposed infrastructure allows easy extension to third-party software, such as Archibus, and to other networks, thus representing a contribution to the opening of a market for ICT-based customized solutions integrating numerous products from different vendors. The system manages energy efficiency through the WSN, which is preferred in order to simplify the integration of new sensors into the system and to avoid the overload of cabling in old buildings. The software infrastructure provides the following main functionalities:

- It enables the interfacing to the application layer by means of web services, through which sensor data can be read and used for visualization or to feed energy management policies;
- It collects sensor data in a local database, in such a way they can be accessed in an asynchronous way and preserved from network failures;
- It allows the remote reconfiguration of sensor node parameters such the sampling rate of physical quantities to be monitored;
- It enables interoperability among heterogeneous networks, characterized by different microcontrollers and sensors.

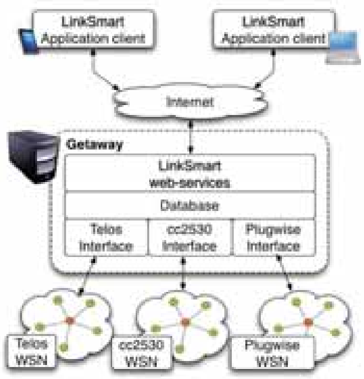

Fig. 3 Software infrastructure scheme to handle heterogeneous Wireless Sensor Networks.

As shown in Figure 3, our software runs in a PC-Gateway (GW) and communicates directly with the heterogeneous networks. The dedicated *Interface* represents the lowest layer of our proposed stack, and receives all the information coming from the WSNs, regardless of the adopted communication protocols, hardware or the network topology. Hence, each WSN needs a specific software *Interface,* which interprets the data and stores them in an integrated database (DB), in order to make the whole infrastructure flexible and reliable with respect to back-bone network problems, since data are locally stored.

The web-service layer, implemented using LinkSmart, interfaces the WSNs to the web, making easy a remote management and control. Moreover it exports to the application client layer, the last in our stack, all the environmental data stored in the DB and collected by the wireless sensor nodes. At this layer, the information is available to the end-user and ready to be shown via computers or smartphones or to be integrated with the data coming from Archibus.

Particular emphasis was given to the possibility to reconfigure each node, changing, for instance, some parameters about power management. In this scenario, the end-user sends the new configuration via web-services to the GW and stores it in the DB. Then, the new settings will be automatically sent to the receiver mote, when it will wake up from the sleeping period, through the specific WSN software *Interface.* The configurable parameters change depending on the hardware and the Operating System running on the end-node. However, using this software infrastructure, the user can choose only the right settings ignoring the real physical hardware related to the virtual device.

In a nutshell, the proposed web-based infrastructure is a software that makes transparent to the end-user the underlying WSNs, abstracting all the information about hardware, protocol stack and embedded operating system. Furthermore, by the use of web-services, it makes easy the interoperability with third-party software.

6. Data management using CAFM application

The best way for manage a large number of data is to use one or more databases, implemented and customized so as to receive, contain and store data that is decided to manage. Very often the database's structures are the basis of more complex applications whose task is to provide an IT support for the management.

Among the numerous families of applications available today, there is one called CAFM abbreviation of Computer Aided Facility Management. This family of applications has been developed to provide appropriate tools for managing facilities. Therefore the Computer Aided Facility Management are a computer products that are able to give access to a range of information related to capital assets of a company through an integrated alphanumeric and graphic database. Many of the aspects, to be managed inside a business

organization, have strong ties with the space in which they are held, such as the management of the rooms, management of employees or management of equipment and energy data connected to it; accordingly management software, as well as operate through tables and graphs must be able to interact with aided or parametric design software. Politecnico di Torino has adopted one year ago a CAFM application called Archibus FM, and is currently using for space management, maintenance on demand management and fire asset management.
This software, like many other similar products, consists of modules, each of which is responsible to contain and manage data on a particular aspect of business such as management and inventory of assets, employees or space management. Each module exists as an autonomous entity and contains within it all the features and all the tables, related to the database, that allow at facility managers to do their job.
One such instrument remain the professional responsibility of having to make choices about the content, but it is only a tool to infer information and perform analysis about a particular aspect of a organization business, after having examined data concerning it.
This product is currently on the point to be open at all users of the Politecnico, in this way the management of spaces, employees, or equipment, is not achieved in a centralized way but instead are the individual Departments, the individual Division, and in some cases the individual users to edit data and manage them.
The idea of collecting data about energy consumption of the rooms and make them available to users is one of the final stages of the project SEEMPubS and thus, a natural tool through which to make available these data, will be Archibus.
Archibus application, adopted by the Politecnico, has developed with client-server structure, a client side where it is possible to manage graphics tools and a server side that containing the alphanumeric information, then through a web interface, users can see graphical information and alphanumeric information linked together.

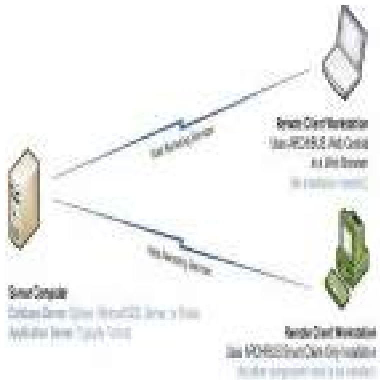

Fig. 4: Client-Server structure of Archibus FM application

Archibus, as described above, bases its operation on the link between graphic information and alphanumeric information; in particular the management of the spaces represent the support on which will be developed subsequent management actions, for example the placement of an object or a employee or rentals management is strongly connected with spaces identified and cataloged.
As just described, the graphical basis for the development and customization of Archibus is made using CAD maps, however, were performed tests in order to use BIM models realized using Revit Architecture.
Omitting the way whereby it is possible to connect graphical data with alphanumerical information using Cad file (.dwg) we can explain how to connect that information using Revit Architecture (.rvt).
First of all, it is absolutely essential that the parametric model has executed in a correct and complete way, at least as regards the architectural part, while it will be possible, at any time, add new information.
Another essential feature, in order to connect the graphical data (contained in Revit) with the numerical data (contained in Archibus), is the fact that each room created in Revit, and therefore enclosed by walls and floors, is also been cataloged using an appropriate Revit's entities called "Room".
This entity allows to catalog every single space assigning it a identifier name and entering information, related to the room, on the local schedule in Revit.

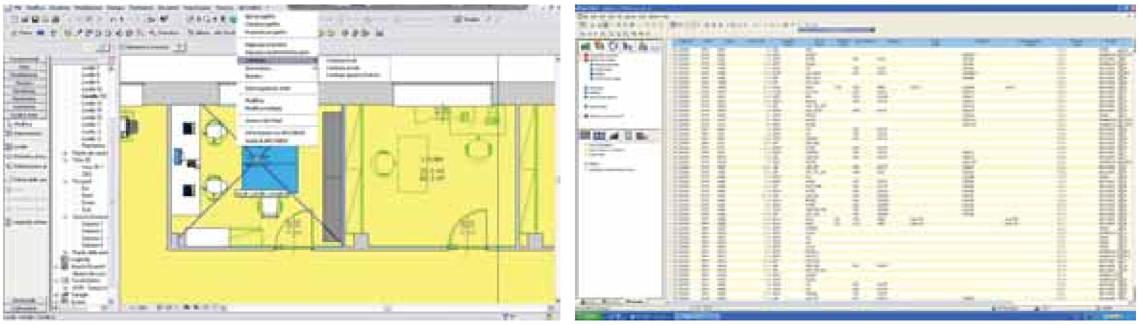

Fig. 5: Revit's interface with "Room" entity and Archibus menu, used to connect graphical data with numeric data.

When the previous operation is done it is possible to proceed connecting Revit data with Archibus data. About this operation it is possible follow two paths, the first is to load in a massive way all identifiers of local (this is the official codes adopted by Politecnico di Torino to identify rooms, for example a single room may be identified by the following code TO_CEN03_XP01_B005 where it is possible to recognize site, building, floor and room), if we work in this way, when we decide to connect the room graphic data with the numeric data contained in the Archibus database, will be possible to speed up the connection operations.
The second way allow to work step by step; each time we link a room we have to populate Archibus table with the correct information about the room such as structure, type of room, capacity, etc.: However any additional information about room can be loaded into the database in following steps.
Regarding energy data management collected for the different rooms it is possible to carry out the management and the subsequent visualization, by a procedure similar to that described above.
Regarding data in Revit Architecture model, connected with the indications of SEEMPubS project, the following features are been implemented:

- vertical walls (insulation, orientation, inertia, performance (value of U), disorders),
- low floors (insulation, orientation, inertia, performance (value of U), disorders),
- roofs (insulation, orientation, inertia, performance (value of U), disorders),
- windows (frame, glass, orientation and mask, performance (value of Uw), surfaces).

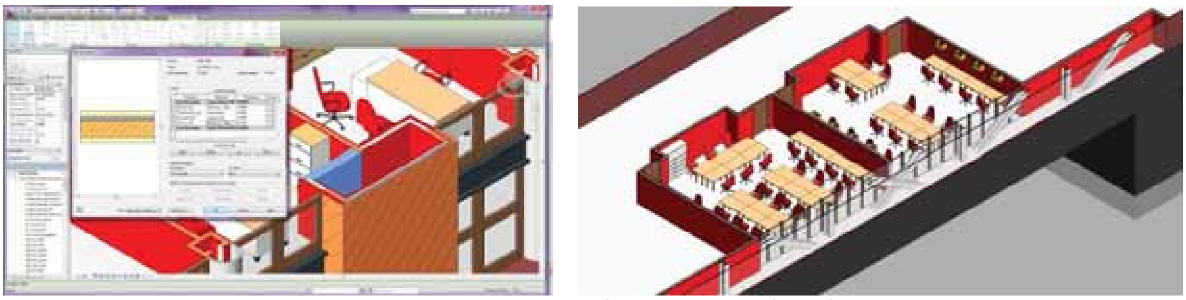

Fig. 6: Revit's model concerning the two kind of case studies of the Cittadella Politecnica

Regarding systems modelling, it is possible insert in Revit MEP model information about heating, cooling, ventilation and lighting system.

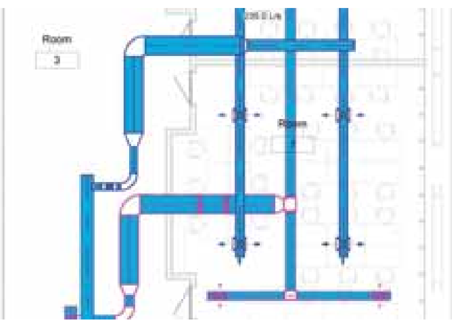

Fig. 7: Particular of the Revit's model, concerning HVAC system of the Cittadella Politecnica

This information can be displayed and managed inside Revit Architecture or Revit MEP, in the schedules that are created during the creation of the elements.
As regards data that we can insert in Archibus we can manage:
Characteristics of sites:
- geographical location,
- year of construction,
- constraints / assets of the site,
- orientation of the construction,
- definition of surfaces and heated volumes.

Characteristics of system:
- Lighting system (type of lighting: direct/indirect; Type of lamp: fluorescent etc.; Presence of emergency lighting lamp, type of control system)
- Shading system (type con shading system and type of shading control system)
- Heating, cooling, ventilation system (type of heating and cooling system, type of ventilation system, air temperature value, CO_2 concentration, type of control system).

Regarding monitored parameters it will be possible insert the following:
- Environmental and occupancy parameters (indoor air temperature and relative humidity, illuminances, presence/absence detection),
- Outdoor parameters (outdoor air temperature and global radiation),
- Energy parameters (fan velocity and supply air temperature of fancoils to calculate thermal energy consumption, electric power for lighting and appliances' loads.)

Regarding management of these features and dissemination of information to users will be developed a procedure characterized by the following operations. The data recorded by sensor, placed in various rooms, are organized into a database specifically created and that will keep the data as they are collected; then, through the interchange and alignment procedures, these data will be caught and dumped into specific tables inside Archibus database.
Through the Archibus's interface customization, that will be special views where, for each local, users can take vision, in real time, of the data mentioned above such as the internal temperature of the room, CO_2 concentration, etc., furthermore it is possible get an overview of the historical data for rooms and consequently have a vision for the medium or long period.
Users will be able to see their consumption data and consequently may make changes to control systems such as lowering the temperature or increase the air exchanges.
Another advantage will be to make available an additional tool for the Politecnico to undertake energy saving actions.

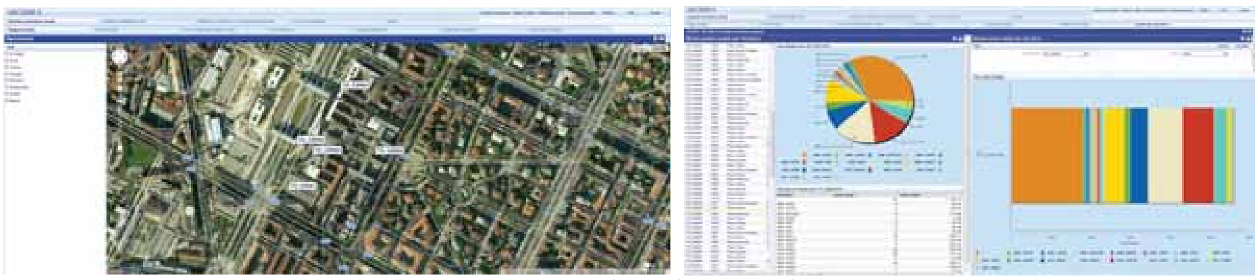

Fig. 8: Archibus's graphical user interface of Archibus for the Politecnico di Torino

7. Conclusion

Through research projects and initiatives involving energy efficiency will be possible to involve end users doing so that they become an active part in the process of energy saving. The SEEMPubS project has already seen active participation of the concerned users since its departure. One of the most interesting activity is about the study of the interoperability between software in particular before starting the simulations to assess energy savings, the use of BIM for architectural, HVAC and lighting systems modeling, as methodology to test the interoperability for energy efficiency simulations, was investigated.
BIM technology for buildings modeling has proved to be very useful as far as transmission of information and editing items are concerned. The model must still be implemented in a balanced way or rather must contain

exactly the information necessary to those who use it. This is useful to avoid having models that are too heavy and unmanageable. However there is also the possibility to implement the model with other type of information. In this case, though, some aspects remain to be investigated especially with regard to some interoperability errors that are still being analyzed and studied.
With regard to lighting simulations, the results outlined that the initially proposed control strategies would not provide the expected energy savings. For this reason, new improved strategies ('updated strategies) were defined and analyzed through new sets of simulations: it was then found that the most effective control solution for the presented case studies was a mix of manual and automatic control instead of a fully automatic control as initially proposed. The best results were obtained assuming that users have an active behavior in controlling blinds and lights, thus increasing the potential energy savings. Rising people awareness is one of the key goals of the SEEMPubS project.
Next steps will involve the implementation of procedures for entering energy collected data within Archibus through the personalization of the graphical interface; at the present Archibus is used by Politecnico di Torino's users regarding display of the spaces and the related features and for on demand maintenance, consequently the possibility to make available energy data collected can only make users more aware.

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A DIGITAL PROCESS FOR GIVING A FUTURE TO SPONTANEOUS STONE HERITAGE

Isabella Bianco, Matteo Del Giudice, Andrea Maria Lingua, Anna Osello, Paolo Piumatti, Pablo Angel Ruffino
Politecnico di Torino
Torino, Italy
isabella.bianco@polito.it, matteo.delgiudice@polito.it, andrea.lingua@polito.it, anna.osello@polito.it, paolo.piumatti@polito.it, pabloruffino87@gmail.com

***Abstract*—The awareness toward the value of spontaneous Cultural Heritage is experiencing a moment of increasingly interest. The purpose of this contribute is to show some of the results coming from the AlpStone-Interreg research, an international still in progress project whose main objective is the protection, valorisation and management of an endangered asset located between Italy and Switzerland. Both local people and professionals are indeed involved in the goal of regiving life to a stone architecture that is expression of the culture and traditions of this territory. The digital technologies nowadays available give the opportunity of improving the interoperability between different building operators, the project dynamicity and the share of data, all concepts that are translatable with the term of BIM. Even if this work methodology has been conceived for new projects, the challenge of the research is to find the best way to fit this philosophy to historical buildings too. The major difficulty lies in the strong irregularity of the stone asset elements, which seems to be an obstacle for parametric software as Autodesk Revit. A possible solution in order to continue thinking in terms of BIM has been found in the point clouds 3D survey, technique that allows not just an exact scansion of the real geometry but also the communication with parametric software; the point cloud can indeed be transformed in mesh, meaning a surface able to store information and be linked to data tables. This kind of output is achievable with laser scanner tools or image-based modelling, techniques that differ for costs, precisions and time. They have both been tested, and quantitative comparing results about the respective performances in modelling irregular stonework are already available.**

Keywords—BIM for Cultural Heritage, 3D point cloud survey, Laser scanner and image-based modeling, Digital process for building valorisation, Spontaneous endangered architecture

I. INTRODUCTION

In Europe the traditional "spontaneous" buildings represent an important and widespread Heritage both from the cultural and real-estate point of view. In recent years the necessity of recovering these existing buildings is increasing; as a consequence it is important to update the asset to the current standards (energy efficiency, structural improvement, facility managent, comfort, etc.) still preserving the traditional values (building techniques, materials, volumes, etc.). This kind of architecture is often called spontaneous according to long-established use [1]; in this paper the term is employed to identify the traditional stone buildings common in Alpine environment.

In this recovery direction is moving the AlpStone project, a still in progress international research whose interest is the protection, valorization and management of an endangered asset located in the area between Italy (North of Piedmont) and Switzerland (Canton Ticino). As shown in Fig. 1, this typical architecture is made up of stone buildings with a quite regular and simple geometrical scheme (they often are parallelepipeds with some possible annexed bodies) and *piode* roofs (very thick schist sheets). These constructions are deeply bound with the territory and are directly sign of a cultural tradition, a pastoral way of life and an interdependence with the environment. Even if the local people habits are nowadays changed, the will of preserve and give a new life to this asset is still strongly alive. Looking at this aim, the improvement of the technologies and ways of communication well support the goal; a digital approach can indeed be the key for the whole recovery process, both from the instrument and methodological point of view: tools as laser scanners, digital cameras and data elaboration software take part in the development of a work process that tries to think in terms of Building Information Modeling (BIM). In other words, the effort is to create a

Fig. 1. Alpine traditional stone architecture (located in Veglio, hamlet of Montecrestese, Italy)

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dynamical and interoperable 3D work environment, need which arises from the will of making more efficient the share and transfer of the different kind of data that contribute, in a complementary way, to the Cultural Heritage recovery process. Moreover, the parametric approach doesn't close its benefits with the recovery, but, at the contrary, will be a fundamental tool for the future building management too.

However, if the BIM methods have been largely tested on new building projects (for which this method has effectively been conceived) [2], its usage in the field of Cultural Heritage is at the moment fringe research. The obstacle of fitting this methodology on an historical asset lies in the difficulty of creating parametric objects of "as-built" elements.

Anyway, some researchers have already begun to investigate how to make use of digital processes in the Cultural Heritage field. A project conducted by Lerones, P.M. et al. [3] has studied a possible way for obtaining 3D digital models for interventions on Spanish churches; a point cloud survey coming from laser scanner or photogrammetry is simplified in a series of polylines that become the input for the creation of a 3D AutoCad model. This kind of approach is however a mainly manual procedure and no intelligence is added to the objects. Nearly the same tools (laser scanner and AutoCad) have been used by a Taiwanese group of research [4] developing a project whose main aim was the creation of a Cultural Heritage archive: the 3D point cloud has been converted into 2D building plans, that find an efficient employment in cartography by increasing, furthermore, the precision of historic building dimensions. On the other hand, a more dynamic archive has been created by Fai, S. et al. [5] who have investigated the construction of a database incorporating both quantitative assets (intelligent objects and performing data created with a Revit reconstruction) and qualitative assets (adding different nature information: historic photographs, oral histories, music). Even if the latter clearly has a BIM print, the major problem, as underlined by [6] remains the lack in automation: the process requires skilled workers and is particularly time-consuming, labour-intensive and subjective. In this direction has worked an Irish team [7], who proposes a novel prototype library of Renaissance parametric objects based on historic architectural data and mapped with point cloud and image survey information. Their results are really remarkable, but actually still little applicable on the spontaneous Heritage. The Renaissance elements, even in their complexity, follow indeed geometric rules governing the distribution and combination of parts, which become the key for the parametric object realization. At the contrary, the stone Alpine buildings are made up with strongly irregular elements and a standardization doesn't appear feasible. The challenge of our research is therefore to find the way to best fit the potentialities of BIM to the necessities of the traditional Cultural Heritage. Indeed, it still doesn't exist a consolidated method to add intelligence to a 3D model of an object that, for its nature, cannot be shut in a repeatable scheme.

The present paper shows a possible solution to employ a digital process to define and model the traditional stone architecture. Looking at the goal of recovering and valorizing this Heritage, the work has been organized in a first phase of 3D survey that takes advantage of point clouds coming from laser scanner or image-based modeling and a subsequent phase of modeling with the parametric software Autodesk Revit.

II. METHODOLOGY

Since this paper describes part of the digital process of survey and data modeling of traditional dimension stone buildings, the methodology chapter is composed by two themes: A. an overview of the methodological plan; B. the description of the methodology used in the case studies, which concerns the evaluation of the BIM model of a stone wall.

Traditional small stone buildings are often characterized by irregular walls (Fig. 2). In particular ancient Alpine buildings such as stables, barns, but even rural housing were built with dry stone walls; such stone masonry often shows a high degree of irregularity: the surface of the walls is not planar, there are cracks in the walls, etc. To restore and revitalize these buildings, such irregular stonework has to be surveyed and managed in the digital design process. In fact irregularity has to be considered because it can affect: the energy recovery; the structural behavior; the internal living space; the positioning of hydraulic lines.

The recovery design and management process is based on models. In the next future the design process will be based on Building Information Modeling. But nowadays the BIM software are not tailored to easily model irregular stone buildings. A BIM model of an irregular traditional Alpine building can easily be too simplistic or, on the other hand, too detailed and time-consuming, because the standard parametric families are unsuited to take into account this kind of irregularity: "How complex or simple a structure is depends critically upon the way in which we describe it"[8]. For this reason, the choice of the methodology used for modeling traditional Alpine buildings strictly depends on the expected targets.

Starting from the consideration that in this stone spontaneous architecture every element differs from the others and remembering that BIM processes find support in 3D data,

Fig. 2. Interior stone wall of an Alpine traditional building (located in Veglio, hamlet of Montecrestese, Italy)

the choice has been to firstly survey the Heritage with techniques employing point clouds. The latter is an output obtainable with both laser scanners and image-based modeling. Both the techniques have been tested during the research.

The Terrestrial Laser Scanner (TLS) survey has been carried out with the instrument CAM2 Focus3D by FARO: the choice of this instrument has been made considering lightness, portability, accuracy for short ranges and scan speed. Twenty scans have been acquired with angular resolution of about 0.040° which allows a density of about one point every 7 mm to 10m of range. The scan quality has been set up to 4x,with about 122000 points/s. Each scan contains about 30 million of points (an example is shown in Fig.3). Scans have been approximately georeferenced using acquired compass data (inside the instrument) and building corners which are visible inside a large scale map. The laser scanner automatically saves the point clouds data in .fls folders; back in office the survey can be easily imported in its specific software (FARO SCENE), which allows the 3D visualization and some post-processing operations.

On the other hand, the photo-modeling consist in taking a series of pictures with a common digital camera by following some important criteria that will allow the software to rightly create a 3D mesh of the object. In order to process the images software have firstly to identify parameters related to the internal geometry of the camera (e.g. focal length, distortions, sensor dimension); then it begins the individuation of homologous points in different photos and the relative orientation of the images: homologous projection rays allow to find the coordinate of the visible points (the pixels) that compose the object. Once that the software working principles are clear, it is easier to understand the ploys for having a good modeling: since the software has to recognize analogous pixels in different photos, the images have to be shoot (with a large overlapping) without flash, in good conditions of light, few contrasts, no shining or moving objects and have to be taken always with the same focal length and approximately orthogonal to the facade. The processing moment providing the 3D model creation can be accomplished by different available software. In particular we have tested the software Autodesk 123D Catch, ESAT Arc3D and AgisoftPhotoscan; while the first two (opensource) do not allow a large control on the output data, the latest one (commercial) permits a major management of the output variables (number of vertex, accuracy, colors, etc.). Finally, a post-processing phase with the free software MeshLab has been carried out: it has indeed been useful for the meshes repairing, their alignment, the surface reconstruction, the comparisons of analogous point clouds, etc.

Fig. 3. Laser scanner 3D survey of a traditional Alpine stone building

In reason of the photo-modeling kind of process, the number of survey points is therefore very variable, depending on the images quality and number, employed software, required accuracies, etc. Nevertheless it is considerably lower than the laser scanner survey one.

The choice of the laser scanner technique rather than the one based on photographs is furthermore basically in function of time (laser scanner is exponentially faster), costs (photographs are much cheaper), survey conditions (image-based technique requires a good light but is more easily applicable in case of non accessible buildings) and expected precision (see the Results chapter).

Once the survey has been made, the important following objective is to obtain a 3D model representing the irregularities of the walls for parametric applications.

Software such as Autodesk Revit allow to link or import point clouds, surfaces or meshes; nevertheless, these objects do not belong to the model and it is not possible to associate them specific features or parameters. It is for this reason that the 3D survey has just been used as a support to define the wall profiles. The methodology concerning the phase after the survey is divided in: A. insertionof the 3D survey in Revit;B. Walls modeling.

A. Insertion of the 3D survey in Revit

The point cloud obtained by laser scanner survey and the mesh generated by the photo-modeling have been the input data.

Some ploys are necessary in order to correctly insert the 3D survey into the parametric software.

In the point cloud case, the importing process is simple: the .fls file obtained from laser scanner is opened in the FARO SCENE software in order to transform it in a .pts file through the usage of the "Export scan point" function. Revit application is able to automatically convert the .pts file into a .pcg file, indispensable step for visualizing the point clouds in Revit.

On the other hand, with the image-based generated meshes, the steps are slightly more complicated. The mesh obtained through the usage of a photo-modeling software is then exported in a .dxf file format by MeshLab. Then, to insert it into Revit the .dxf file has to be necessarily imported in a local mass.

B. Walls modeling

The surface roughness of the walls is obtained by creating a local mass and by approximating the profiles obtained from the

3D survey with curved lines defined by 4-5 points. These splines are drawn in vertical sections perpendicular to the walls and are placed at a distance of 1.3 m one to another (Fig. 4). The 3D model is obtained through the command "create form" after selecting the correct "mass lines". In this way we created a local mass. Using the command "wall by face" and selecting the mass surfaces, the walls modeling is completed. To increase the correspondence between the mass and the 3D survey profiles it is necessary to decrease the profiles distance and increase the number of points that defines the spline. However, the software isn't able to generate the solid if complex lines mass are involved or if the number of mass lines is too high. Considering this limit, the challenge is to obtain the most possible accurate mass.

III. RESULTS

The Heritage that allowed the turn in practice of the methodology previously shown is located in Veglio, hamlet of Montecrestese (Italy). It is indeed a little village where the traditional architecture is harmoniously integrated with the natural environment, but whose abandonment in the '50s -due to an avalanche risk- let the lack of maintenance make its work of degradation.

The results coming from our still in progress research can be analyzed according to the two macro-phases composing the digital process, which means the 3D survey moment and the parametric modeling one.

A. 3D survey results

In reason of the strong irregularity of the stone elements and, furthermore, projected through the BIM methodology, it has been favored, as shown before, a point cloud survey. This kind of output has been obtained both with laser scanner (20 scansions, of which 15 interiors and 5 external sights) and image-based modeling (tested at the moment on a single stone building).

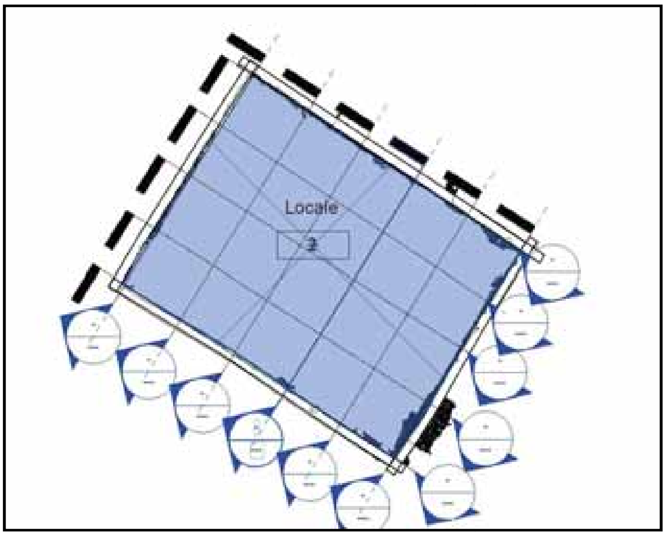

Fig. 4. Revit plan showing: A. the position of the sections employed for the walls profile drawing; B. The creation of a delimited room within the irregular walls

In order to firstly have an idea of the tools reliability, a comparison between laser scanner and photo-modeling has been carried out. Importing both the point clouds on the software MeshLab and considering the one coming from laser scanner as the reference, it resulted that the 3D survey made with photos has an average error of 2-3 cm in a total of about 50 m^2 of wall. As illustrated in Fig. 5 indeed, a red color has been conferred where the point clouds were coincident, while the wall is progressively colored till blue (max distance, set to 3 cm) when the distance increases. Taking into account the irregularity of the walls, the objectives of the research and the low costs of the photo-modeling technique, it has been considered this latter as an efficient alternative to the already consolidated laser scanner method, even if it is more time-consuming.

Other significant results obtained during the survey phase are directly connected to the goals of the research: since the building irregularity will influence several aspects of the recovery (e.g. from the structural, energetic, logistic and management points of view), it would be useful to quantify the non-planarity of the walls. With this aim, the software FARO SCENE allowed a comparison between the laser scanner point cloud and a vertical plane interpolating the wall points. From this operation, carried out on about 40 walls of Veglio buildings, it emerged that there is an average distance of 17 cm from the most protruding points to the most rearward ones of the same wall. Moreover, a visual colored output allows making some considerations about the wall pace. For example, the wall shown is Fig. 6 is clearly inclined toward the exterior (blue indicates parts staying behind the vertical plane of reference and progressively till red parts staying ahead; in this case from blue to red, the range is set to 15 cm).

B. 3D modeling results

The survey data elaboration has carried satisfactory results, showing, at the same time the related limits.

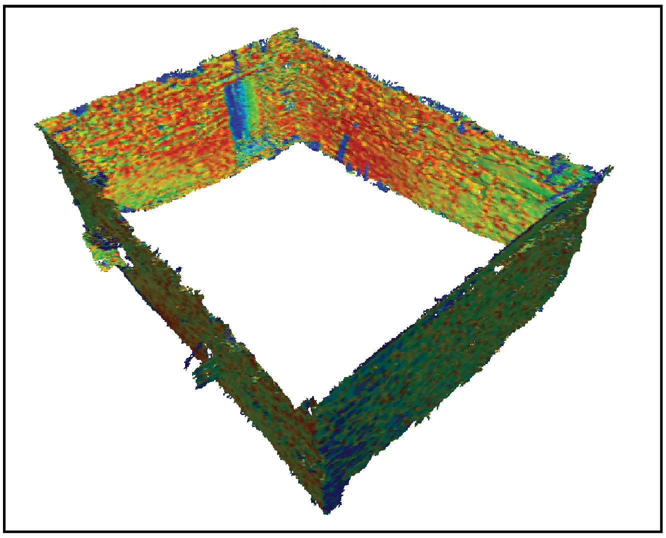

Fig. 5. Comparison between point clouds from laser scanner and photo-modeling (the later processed with Agisoft Photoscan software): progressively from red (minimum distance) to blue (maximum distance, set to 3 cm)

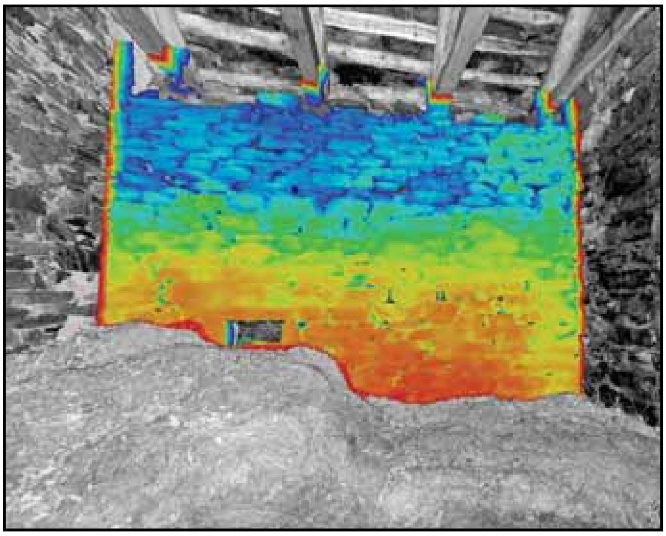

Fig. 6. Visualization of the wall irregularity compared to a vertical interpolating plan: progressively from red (most protuding points) to blue (most reaward points)

The most interesting result is the creation of a Revit model that follows the trend of the irregular profiles of the building through the approximation of the 3D survey (Fig. 7). The obtained walls are a system family, meaning that it is possible to exploit the parametric tools of the software. First of all, the object is not only a three-dimensional shape but a component capable of holding information. This is useful, for example, in order to exchange or share information between different software and operators or for the creation of a database.

As regards the walls modeling, the exploitation of laser scanner point clouds rather than meshes obtained from photo-modeling do not affect the result in reason of the approximation with just 4-5 points of the survey profiles.

Another output of this research is the possibility to import the Revit generated mass in MeshLab. The mesh geometry can indeed be exported using a .dxf format in order to convert it in a .3ds file using Autodesk 3ds Max software and, finally,

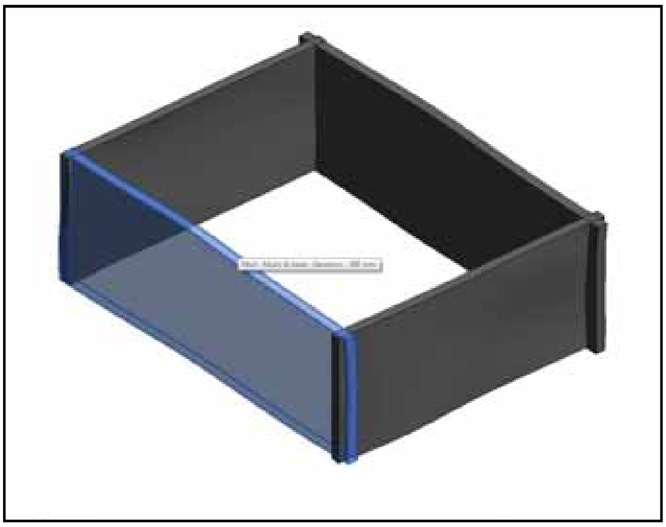

Fig. 7. Parametric model of the irregular stone walls (created with Autodesk Revit)

opened in MeshLab. It is so possible to align the mesh exported from Revit with the one obtained with the photographic or laser-scanner survey: in this way the operator can both have a qualitative and a quantitative idea of the approximation degree of his model in comparison with the 3D survey.

Another aspect, that at this time of the research is still potential, is the assessment of the volume enclosed by walls. Revit allows indeed the creation of a room delimited by walls (Fig. 4) but the volume calculation does not take into account the surface irregularities, providing therefore an incorrect value. The right evaluation could for example be useful in order to estimate the volume loss when a rigid panels thermal insulation is expected.

However, the major limit remains in terms of time: the modeling phase is still quite long-lasting and complex. This is inevitably due to an imperfect interoperability between the surveying software and modeling applications. Future plans on historical BIM should find a way to improve the communication between survey and modeling phases with functions allowing the creation of easier and more efficient 3D interoperable work environment (in this sense a support is required from the software houses too).

IV. Conclusions

An increasing interest toward Cultural Heritage has encouraged the development of new digital techniques supporting the protection, valorization and management of various kind of assets.

Several are the approaches employed by the various research teams: if the start point is often the same (a 3D point cloud survey coming from laser scanner or image-based modeling), the way of elaborating the data takes different directions. Groups as [3] and [4] employed Autocad in order to obtain respectively a 3D model or cartography plants. A more parametric approach is recognizable in the research of [5], which made a Revit model of a urban historical cluster. A Renaissance objects library based on European classical architecture has been finally created by [7].

Nevertheless it still doesn't exist a consolidated digital method able to fit the BIM approach to assets belonging to a traditional territorial architecture. For its nature, indeed, the latter is not regulated by dimensional or compositional rules and the same single elements composing the building are often strongly irregular, as shown for the stone Veglio walls. This paper arose therefore with the aim of purposing a possible process making use of the digital technologies in order to define and intervene on territorial Heritage in a way as much as possible interoperable.

Starting from a point cloud survey –furnishing tridimensional data- it has been possible to parametrically modeling the irregular historic asset with Autodesk Revit software. This means that it has been possible, after a sequence of steps, to add intelligence to the 3D survey and let therefore the process speak the BIM language. The significance of these results lies in the possibility of work with a 3D database able to store information of different nature and able to be interrogated on several aspects concerning the whole building process: from the survey phase, to the recovery one, till its future management.

Nevertheless, there is still space for enhancements: future researches should in fact follow-up work designed to improve the compatibility between software, the interoperability and the data sharing in order to guarantee always more efficient tools for interventions on the Cultural Heritage.

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