REPRESENTATION CHALLENGES
Augmented Reality and Artificial Intelligence in

Integrated Technologies for Smart Buildings and PREdictive Maintenance

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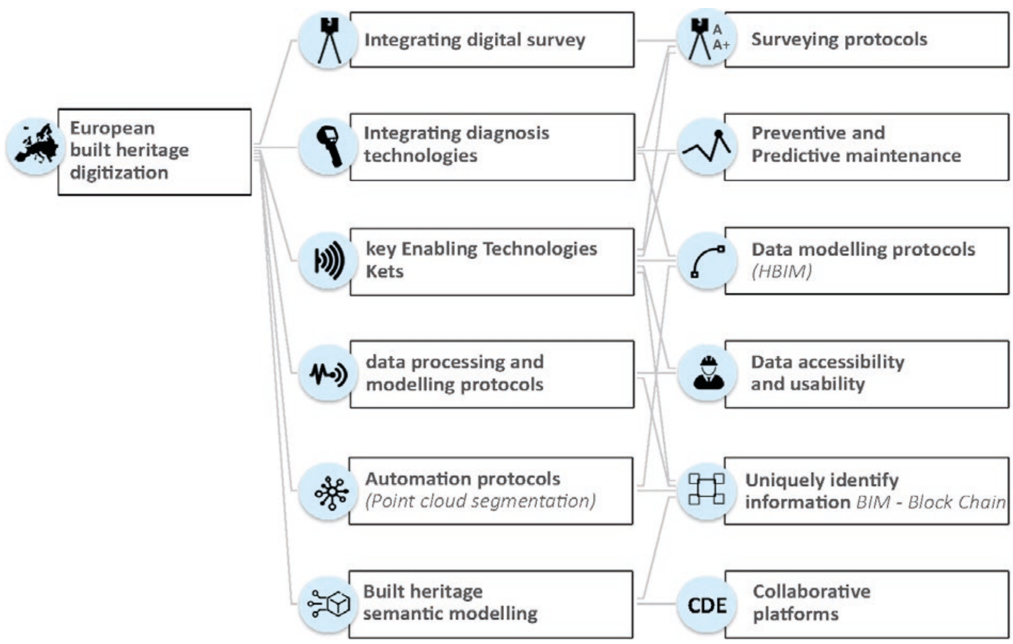
Abstract

The preservation and the regeneration of the existing built heritage is still characterized, even in the context of an increasing digitization of the value and supply chain, by inefficient time and costs management, along the whole life cycle, as well as by discontinuity and lack of information on the one hand, by redundancy and duplication of data on the other. Accessibility, usability and feasibility in order to univocally implement information, also by real–time monitoring, are areas of growing interest to all actors of the building and construction value–chain, with particular reference built heritage knowledge phase, as well as for the stakeholders of complementary industries as ICT, for the development of integrated digital solutions for data acquisition, modeling and visualization.

Keywords
information modeling, digital documentation, information visualisation, built heritage, KETs.



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Introduction and Overall Framework

The InSPiRE project, Integrated technologies for Smart buildings and PREdictive maintenance [1], is funded under the Smart Specialization Strategy of Emilia–Romagna Region, call for "Strategic Industrial Research Projects" 2018 [Hegyi 2021], and implements the architecture of a predictive diagnostics system for monitoring the state of preservation of materials, components and systems of the existing built heritage that, under normal operating conditions, is approaching the end of its useful life. At the end of the first year of the activity the project is facing several challenging actions aimed at wide spread data integration and sharing, starting from a methodological and technical advancement in built heritage digital documentation.
As part of digitization process applied to built heritage as well as to Cultural Heritage, digital documentation and visualisation of the whole building life cycle, from project phase to facility management phase, is emerging as effective strategy in order to support both decision making and sharing of information from different data sources: shape and morphology; diagnostics; safety in use; risk management; maintenance. Implementing collaborative real–time monitoring platforms based on enabling technologies, such as sensor networks, is one of the main goals of the InSPiRE project.
Morever, similarly to the intervention on the cultural heritage, the intervention on the built heritage is characterized by: multiplicity and variety of information sources, with reference to different periods of the building life cycle; lack of homogeneity, and often absence, of organization and hierarchy of information; plurality of design purposes; multiplicity of methods of investigation and technologies applied; plurality of professionals involved [Garzino 2011].

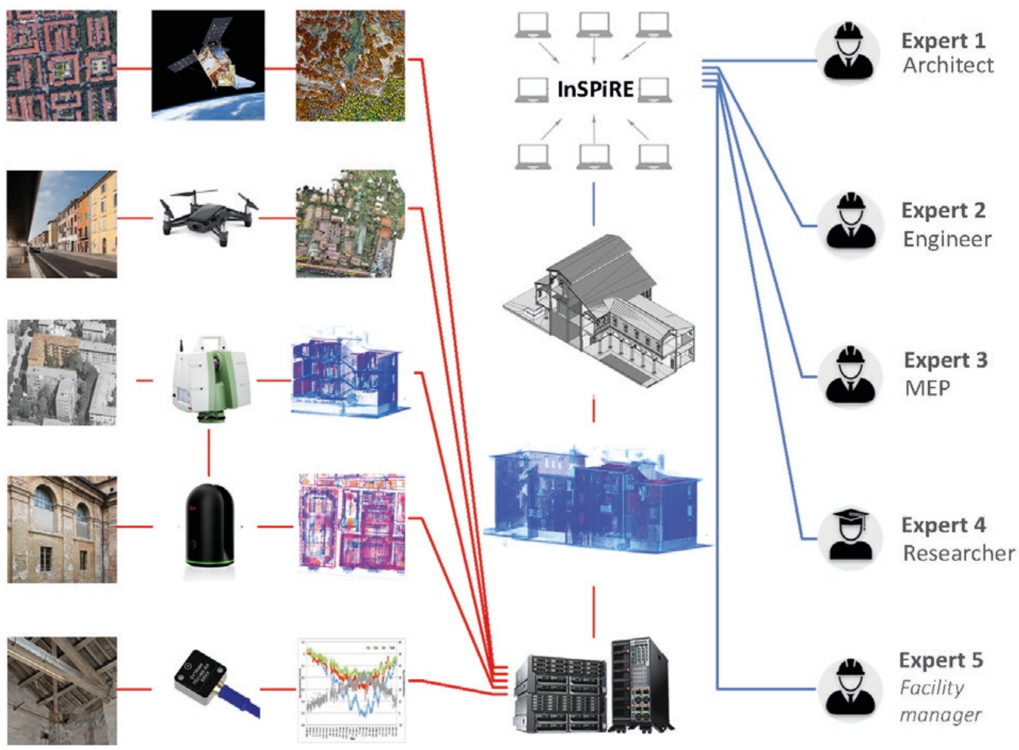

Fig. 1. Project requirements: multiplicity of data sources characterized the intervention on the built heritage.

Digital documentation and visualization of the built heritage

The overall project workflow is developed starting from requirements: what type of data characterized the project on the built heritage (fig. 1); what kind of information the variety of professionals involved are asked to provide in order to manage effective decision making processes; with reference to the new ICT technologies applied to the project, such as BIM tools and methods, what kind of both opportunities and boundaries have to be taken into account. Through networks of wireless sensors, based on smartbrick technology, case studies of

public housing are placed in continuous monitoring in order to: implement monitoring systems based on Integrated Enabling Technologies (KETs); develop predictive algorithms; implement a platform for displaying and managing information, even real time data, supporting awarness during the preservation and the regeneration phases of the existing built heritage.
The sensor network is currently being tested in the context of an ACER case study in Bologna, consisting of a 1950s block–type residential building.
The acquisition of information from the sensor network and the management of the dataset originated from the diagnostic campaign by multispectral images are currently being implemented within the framework of the above–mentioned case, in order to identify trajectories of behaviour of the building system, in particular in the fields of structural and seismic safety. Starting from previous research results financed within the "Por Fesr Impresa 2015" call, the result of the InSPiRE project is a digital platform, currently under development, of strategic decision support for predictive maintenance and management activities that, by implementing intervention procedures on an existing built heritage in borderline and/or emergency conditions, increases its useful life and capitalises its economic value. The involvement of local companies – such as international leaders in the market for the production of materials and systems for the intervention on the existing buildings as well as in the management and processing of big data and in the development of advanced sensors –, which is a strategic action in order to support effective project results, regional and trans–regional cluster industrialization specialisation and value–chain innovation and competitiveness [European Commission 2019], favors the implementation of the specifications of the architecture of the monitoring platform, contributing to the validation and demonstration in the relevant environment (TRL5–6), and to demonstrate the prototypes in the operational environment (TRL7).

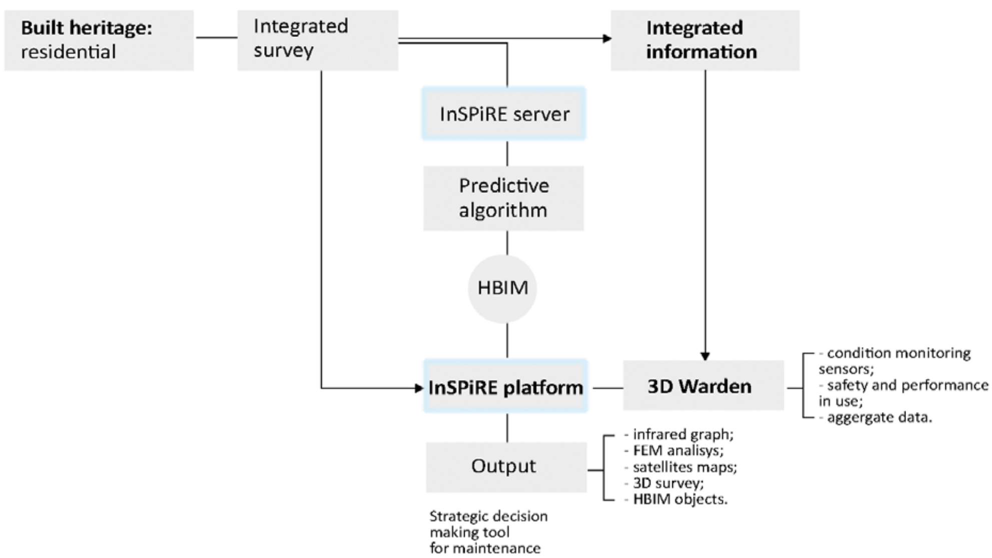

Fig. 2. InSPiRE platform architecture.

Data Integration and Information Modeling

The need for the implementation of strategic decision making tools has originated from the fact that there are both a variety of sources of information and methodologies regarding the built heritage documentation.
As a result, the availability of so many active sources providing valuable information to be used by a variety of experts and actors of the value–chain determines whether data redundancy or loss of information when hierarchy, segmentation, accessibility, usability of data as well as built heritage nomenclature are not properly considered.
The starting point in order to implement the InSPiRE digital platform is the data sources hierarchy with reference to the case studies investigated. Each partner deepens, in accor-

dance with the project objectives, specific skills and pilot tests, a number of different types of source data such as: historical data sets related to the interventions of ordinary and extraordinary maintenance; satellite data for the analysis of the territorial scale; data from continuous monitoring for the analysis of the structural behavior of the building; data from integrated diagnostic campaigns for the evaluation of the energy behavior of the building; data from direct diagnostics for the analysis of mechanical and physical–chemical characteristics of materials in place.
Subsequently, the data modeling phase and definiton of information hierarchy allow to define; trajectories of behavior, for those phenomena that allow an approach to the evaluation also of predictive type; criteria for the subsequent visualization, accessibility and usability of information, with reference to different categories of experts identified as end users of the project results [European Union 2018].

Toward Applications and Digital Protocols for Built Heritage Management

So far, InSPiRE project aims at defining a data integration protocol for built heritage management. From one point of view, the system responds to the request for timely anticipation of the degradation and damage phenomena, by leading the maintenance actions in an adaptive way, with respect to the phenomenology of the degradation cause. Subsequently, the project makes use of the technological skills of industrial ecosystem of the regional territory, whose development can potential benefit from the collaboration during the entire life cycle of the project. Definitely, the development of the different components of the monitoring architecture requires that platform integrates and cooperates with expertise in the field of: restoration of both cultural heritage and built heritage; construction science; digital technologies applied to the survey and diagnostics phases; computer science; chemical and mechanical characterization of the building materials; integrated technologies for building preservation, retrofit and maintenance. The intersectorality and interdisciplinary nature of the project involve strategic sectors and disciplines that respond to the drivers of innovation identified by European Smart Specialization Strategy for the construction industry. The development of technologies for predictive diagnostics applied to facility management is a cross–sectoral challenge to the regional Clust–ER ecosystem, such as Emilia–Romagna industrial and research network, and to the European strategic objectives, relying on enabling technologies (such as new smart materials or the pervasiveness of the Internet of Things technologies) framed, specifically for the Emilia–Romagna Region, in the Clust–ER "Build", "Create", and "GreenTech".
According to the InSPiRE workflow the data integration protocol definition process started studying what and how surveying data to be included in InSPiRE digital platform, as well as analysing how information to be modeled in order to achieve both interoperability and accessibility. Definitely, data visualization is closely related to methodology of archiving and retriving digital information in order to make definition of common topology effective. The platform thus implemented will undergo a testing process by different target end users: professionals; managers of complex real estate assets; maintainers; facility managers.

Conclusions

Developing integrated digital tools for the management and visualization of information related to the intervention on the built heritage responds to the dual need, expressed by European policies and beyond, to: supporting the adoption of data–driven tools to make decision–making processes more effective, less expensive and more sustainable; promote the industrialization of the supply chain.
Consequently, the objectives that the project pursues are closely related to the diffusion of H–BIM protocols for the existing heritage [Hung–Ming 2015]. In this sense, the results of InSPiRE are implemented by both objectives and results of other projects Por Fesr funded, such as the eBIM project: existing Building Information Modeling for the management of the intervention on existing heritage. The definition and implementation of semantic

ontologies in order to organize the knowledge around the complexity of the intervention on the existing heritage cannot be separated so much from the definition of a common lexicon as from the correlation to the purposes of the intervention, rather than to the categories and typologies of the built heritage [Pauwel 2013].

Notes

[1] The project "InSpiRE – Integrated technologies for Smart buildings an PREdictive maintenence" involves five partners, including national universities and research centers, such as: Laboratorio TekneHub, Tecnopolo of the University of Ferrara (Lead partner); CIRI EC, Interdepartmental Center for Industrial Research Building and Construction, University of Bologna; CRICT, Interdepartmental Center for Research and for Services in the Construction and Territory Sector of the University of Modena; CNR Istec, Institute of Science and Technology of Ceramic Materials; Flaminia Center for Innovation. Moreover, seven companies are part of the partnership, from the regional territory and beyond, with reference to: production of materials and components for the chain of intervention on the built environment; ICT products; enabling technologies; diagnostic services for the built heritage.

[2] The project "eBIM: existing Building Information Modeling for the management of the intervention on the built heritage", which has received funding from Por Fesr 2014-2020, involves five partners, including national universities and research centers, such as: CIDEA, Interdepartmental Center for Energy and Environment, University of Parma (Lead partner); Laboratorio TekneHub, Tecnopolo of the University of Ferrara (Lead partner); CIRI EC, Interdepartmental Center for Industrial Research Building and Construction, University of Bologna; Centro Ceramico; Certimac. Moreover, ten companies are part of the partnership, from the regional territory and beyond, with reference to: architectural and engineering firm; production of materials and components for the chain of intervention on the built environment; ICT solutions.

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Extended Reality (XR) and Cloud–Based BIM Platform Development

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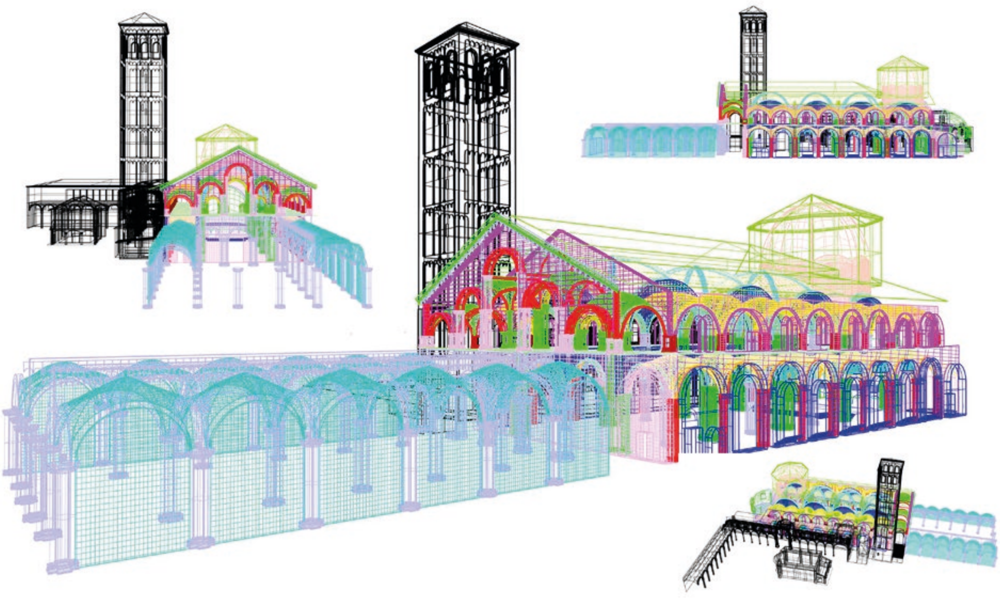
Abstract

Extended reality (XR), Artificial Intelligence (AI) and Building Information Modeling (BIM) for the digitization of cultural heritage are proving remarkably successful in different fields of application. The convergence of innovative methods, latest–generation technologies, and software applications for the representation, storage, transmission of tangible and intangible values of architecture, turn out to be increasingly decisive both in supporting the project's needs of the professionals involved in the valorisation and management of the built cultural heritage and in enhancing the transmission of computer–generated perceptual information for all types of users (expert and non–expert). For those reasons, this article presents research focused on the development of an open–source cloud–based BIM platform and XR projects capable of sharing a knowledge process based on new levels of interactivity and digital creativity.

Keywords
extended reality (XR), artificial intelligence (AI), cloud–based BIM platform, interactivity.



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Scan–to–BIM Process Meets Computer Science Development and APIs

Emerging technologies such as eXtended reality (XR), artificial intelligence (AI) and building information modeling (BIM) provide innovative opportunities to increase the transmission of tangible and intangible values of heritage buildings during the building life cycle and integrated design process [Alizadehsalehi 2020]. In the digital cultural heritage (DCH) domain, the transmissibility of those values is crucial during the processes aimed at the preservation and restoration of buildings. The interdisciplinary nature of these processes requires interactive environments capable of sharing a large amount of data in real–time among all the professionals involved in the process [Banfi 2020, pp. 16-33].
In recent years, innovative results have been found in various fields of application such as entertainment, gaming, healthcare, marketing and consumers, retail and education. At the same time, sectors such as architecture, engineering and construction (AEC) industry, arts and design, real estate, tourism, and automotive industry, have benefited from new state–of–the–art tools (software and hardware) capable of increasing the levels of interactivity, immersion and knowledge of digital models [Banfi, Oreni 2020, pp. 11-136; Brumana et al. 2020, pp. 391-400]. Accordingly, the challenge to create new and increasingly innovative solutions able to support experts in DCH domain has been taken up by various institutions, research centres and European projects [Alizadehsalehi 2020]. For all those reasons, the aim of this research was to create a digital repository capable of enhancing the use of informative models deriving from a scan–to–BIM process capable of effectively representing the reality detected through which is possible to share a huge amount of building information (fig. 1).
Scan–to–BIM process, AI and cloud system have been extensively investigated in various forms, methods and projects in the last decade [Giordano et al. 2018, pp. 50-73; Graham,

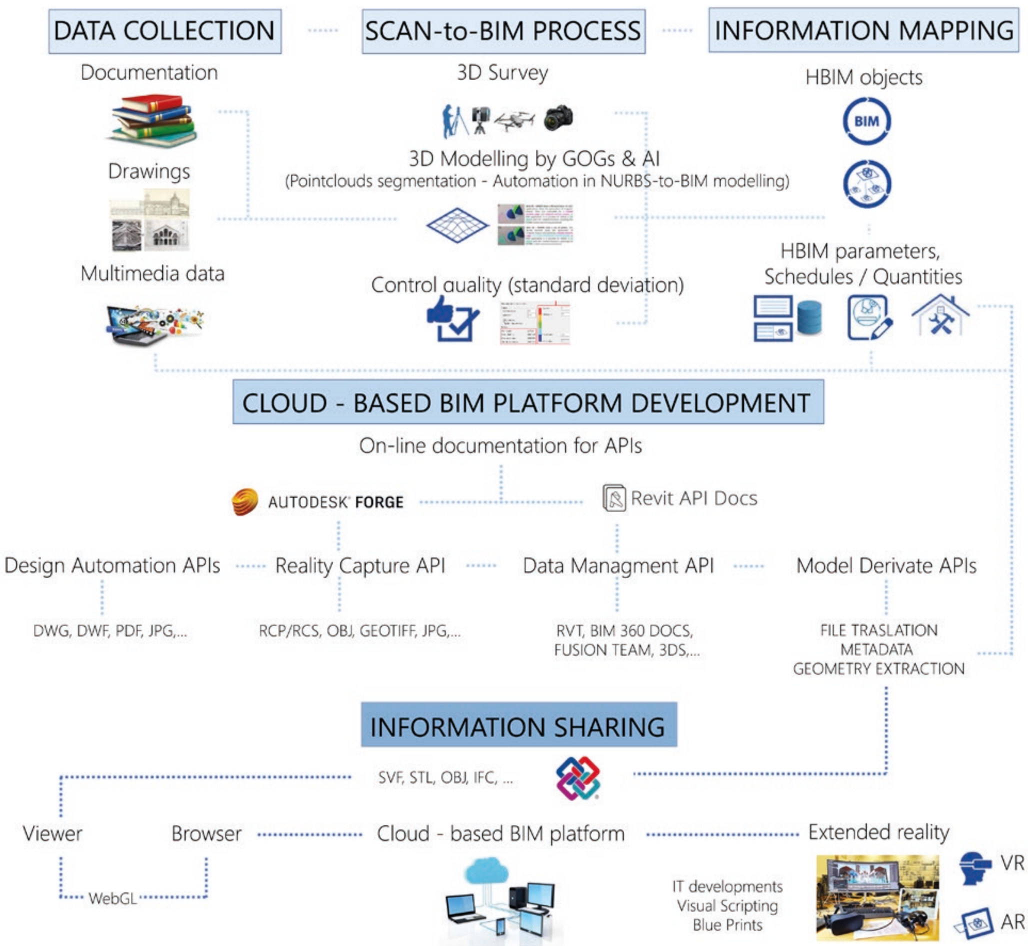

Fig. 1. Workflow of the proposed integrated approach: from scan–to–BIM to extended reality (XR) and cloud system.

Chow, Fai 2019, pp. 553-568; Ioannides, Magnenat–Thalmann, Papagiannakis 2017]. Several types of research have shown how the integration of those disciplines allows professionals to lay the best possible bases for all those types of BIM – based analysis that require high levels of detail (LOD) and information (LOI) such as structural analysis, building monitoring, infrastructures (InfraBIM), energy analysis, advanced prototyping, plant engineering, scheduled maintenance, construction site and restoration [Luigini et al. 2018, pp. 288-302; Oreni et al. 2017, pp. 153-158; Porro, Cocchiarella 2019, pp. 40-56]. Furthermore, several cloud solutions have been proposed by the main software developers such as Autodesk, Graphisoft and Bentley to host a large quantity of data (models and information) in a shared form. Besides, online applications such as Autodesk A360, BimX have demonstrated how through new exchange formats (proprietary and open–source) it is possible to share the wealth included in digital models via a web interface within everyone's reach. The next challenge, therefore, was to share geometry and the contents in a single solution and through different types of devices (PC, mobile phone, tablet and VR headset) e 3D exchange formats (proprietary and open–source), supporting different types of users in their own daily practices and operations in real–time (fig. 2).
The research and development activity conducted in the last two years by the author focused on reaching new forms of interaction, immersion and sharing through the creation of an open–source cloud BIM–based platform capable of sharing different types of data such as materials, building techniques, monitoring data, schedules/quantities and digital drawings. Thanks to definition of novel Grades of Generation (GOG) based on AI, pointcloud segmentation and automation in NURBS–to–BIM modelling has been possible to digitalized the reality with high LODs and accuracy [Banfi 2020, pp. 16-33]. The next paragraph describes the research–development process that led to the creation of this platform, focusing on the development and sharing of the main XR and HBIM projects developed in recent years. In particular, the Basilica of Collemaggio in L' Aquila, the Basilica of Sant'Ambrogio and the Azzone Visconti bridge in Lecco, represent the main case studies developed and included in this digital library, but at the same time, they represent a starting point for an open development logic and new levels of interoperability and sharing ready to welcome other experiences and architectural artifacts of high historical and cultural value.

Model Interoperability: Cloud–Based BIM Platform and Extended Reality (XR) Projects

Tests and analyzes conducted on the new paradigm of interaction between the real and virtual world and thanks to the implementation of new scan–to–BIM requirements (GOGs based on AI, pointcloud segmentation and automation in NURBS–to–BIM modelling), computer languages and application programming interfaces (APIs), it was possible to create an interactive data

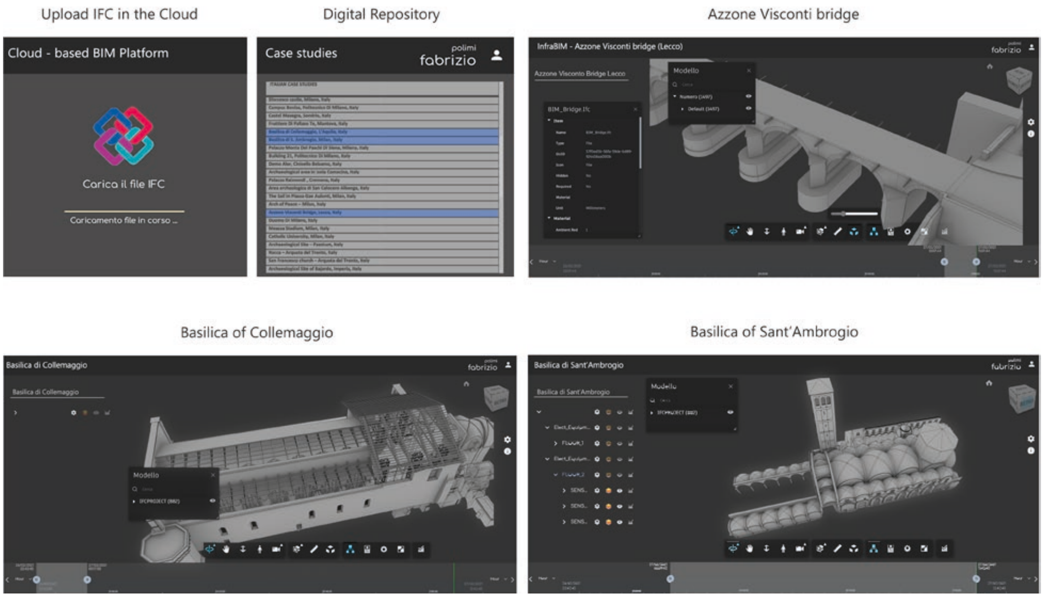

Fig. 2. The developed cloud – based BIM platform and the display of different type of projects.

repository composed of case studies of national and international interest, integrating various ways of real–time visualization of digital models. In particular, thanks to the Forge Platform and Revit APIs doc which offer Web–based, searchable, and extensible API documentation, it is possible to undertake IT development process oriented to the creation of custom digital hub for different research case studies. Design and building a viewer that converts and displays models on a browser favoured high level of information sharing, moving from professional and proprietary platforms/formats to an open–source logig. As shown in figure 2, BIM modeles (as–found, as–designed and as–built projects), once uploaded to cloud using the IFC (Industry Foundation Classes) format, can be explored, modified, commented and analysed. Furthermore the developed platform allow the upload and download of a many varieties of data type such as Viewable 2D and 3D design file formats (3DM, 3DS, ASM, CAM360, CATPART, CATPRODUCT, CGR, DAE, DLV3, DWF, DWFX, DWG, DWT, EXP, F3D, FBX, GBXML, IAM, IDW, IFC, IGE, IGES, IGS, IPT, JT, MODEL, NEU, NWC, NWD, OBJ, PRT, RVT, SAB, SAT, SESSION, SKP, SLDASM, SLDPRT, SMB, SMT, STE, STEP, STL, STLA, STLB, STP, WIRE, X_B, X_T, XAS, XPR), media and office file formats (AVI, GIF, JPG, PNG, TIFF, DOC, PDF, PPT, TXT, XLS,...). It should be emphasized that the export of the BIM project in the open IFC format and the subsequent upload of the file to cloud platform has avoided the loss of the information previously included in the BIM model, favouring a easily 3D / 2D read by expert and non–expert users. Thanks to a simplified interface, user can select each BIM objects and read all the parameters and information previously inserted and connected to the BIM project. This last phase has allowed one to move from a digital logic based on proprietary files to an open common data environment (CDE) and real–time sharing. Finally, thanks to the level of interoperability achieved the final development step was to include the ability to share VR and AR projects (developed using Unreal Engine ad its visual scripting Blue Prints) via multiple devices and HBIM models at the same time. Figure 3 shows the multiple configuration and devices which could be used for dynamic access to data and digital models enabling them to immersive projects that expand our real–world and combine it with virtual elements and contents.

Research Results and Future Prospectives

The cloud BIM–based platform developed allows the sharing of BIM projects, the remote immersion in eXtended reality (XR) projects and the implementation of an augmented reality (AR) library of architectural, artistic, historical elements cultural and unique of their kind. The main results of this research development process are:

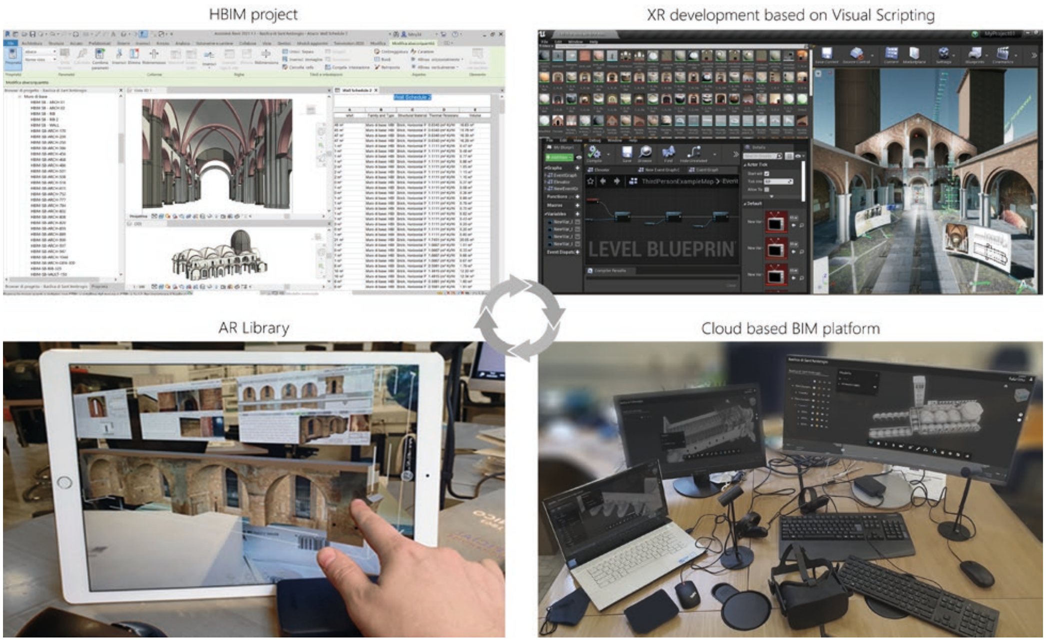

Fig. 3. From Scan–to–BIM and XR projects to AR library and cloud based BIM platform for multiple devices.

- creation of a cloud platform capable of hosting and sharing scan–to–BIM projects characterized by the use of a large quantity of data such as point clouds coming from laser scanning and digital photogrammetry (primary data sources) and historical reports, digital drawings, multimedia files (secondary data sources);
- greater coordination and collaboration, efficient workflows, user friendly 3D visualizations and better project results
- making VR projects more accessible by sharing executable files for the installation of dedicated apps for each project developed;
- implementation and sharing of AR objects,
- improvement of the levels of interoperability of digital models through the use of exchange formats (proprietary and open–source).
- diversified modes of use through smart glasses, VR headsets, PCs, mobile phones and tablets.

Future developments are oriented to increase the level of interactivity of the cloud platform thanks to the connection of data coming from monitoring. The final goal will be to integrate digital models and real–time data into one digital solution, helping to increase the awareness and intangible values of our built heritage.

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H–Bim to Virtual Reality: a New Tool for Historical Heritage

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Abstract

In recent years, the application of Building Information Modelling to cultural heritage has led to the development of solid operating methods that have enabled a more efficient management of information. The use of other real time methodologies, such as Virtual Reality (VR), has also begun to be tested in the architectural context. The objective of this work is to test whether BIM models can be exploited to create immersive experiences in digitally simulated environments, with the aim of setting up new visualization and evaluation modalities for the built space. Giovanni Michelucci's Church provides an opportunity to test the use of Historic–BIM (H–BIM) models for the development of VR.

Keywords
H–BIM, virtual reality, revit, unreal, Giovanni Michelucci.

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Background

The use of Virtual Reality in the architectural field has recently become more and more widespread, opening up new opportunities for interaction between people and the built environment. In the case of historic buildings, it is becoming a powerful tool for the preservation and the enhancement of the historical heritage. This might also give to the professionals involved in the conservation process the chance to exploit it for decision making.
For many historic buildings, most of the available documentation consists of the original paper documents dating back to the time of construction. Lacking a pre–existing digital model, one often needs to be created specifically for VR applications. However, the increasing use of H–BIM has made digital models of these buildings available in some cases. To what extent BIM models can be re–purposed for VR use is, however, unclear, and this will be the objective of this work. The subject of the current study is the *Beata Maria Vergine* Church designed by *Giovanni Michelucci*. The church was built in 1957 for the industrial village of *Larderello*, near *Pisa* in Tuscany, Italy. Most of the original documentation has been provided by *Fondazione Giovanni Michelucci*, Florence, Italy.

Fig. 1. Left: 3D model of the church in Revit. Right: the same model imported in Unreal.

BIM–VR Interfacing

The BIM model for the church was built using Autodesk Revit. Unreal Engine is the game engine chosen for the implementation of the VR. The communication between Revit and Unreal is managed through Datasmith, a collection of tools and plug–ins that enables models, scenes and layouts built with a variety of 3D design applications to be imported into Unreal. With the 'Export Datasmith' Plug–in, elements from Revit are exported as '.udatasmiht' files. Through the Datasmith importer, the content of these files is transformed into a set of "actors" (the objects of a scene). Datasmith enables the export of geometries, materials and textures and their assignment (both Autodesk default materials and customised ones), lights and cameras. Visibility settings need to be carefully selected in Revit prior to export, since Datasmith will only export objects set as visible in the Revit 3D view.
Every solid geometry inside a Revit project is imported into Unreal as a Static Mesh Actor. A Static Mesh is a piece of geometry made of polygonal faces connected to create the object. Therefore, the Static Mesh Actors are created as a collection of surface faces, not tied to a unique solid volume. Every Static Mesh Actor in Unreal is generated based on families defined inside Revit. If there is more than one solid inside a family, these parts will be imported as a single actor, and cannot be selected separately in the main environment.

During the import process, some identification codes and tags from Revit are imported along with each geometry: 1) the name of the family; 2) two identification numbers automatically assigned to the object by Revit; 3) the level the object was linked to in Revit, and, if present, the identification number of the hosting element.
The identification data match between environments, maintaining the correspondence between the objects in Revit and the actors in Unreal. This makes it possible to carry out targeted substitutions of elements from Revit in Unreal.
Datasmith also imports materials and textures from Revit as Unreal assets. The static mesh actors maintain the material and texture assignment from Revit families (fig. 1), but with some limitations. For example, every face of the geometries is mapped, meaning that 2D coordinates are assigned to the vertexes of every surface. This coordinate system is used to define how the texture of the materials is applied to the faces of the solid geometry. In Revit every surface of a 3D object has the same default coordinate system, so that textures are applied with the same orientation on every surface. However, Revit does not allow a flexible coordinate system to manage the orientation of textures assigned to the materials. This might result in unrealistic texture visualisation in VR. When this occurs, it is necessary to import the element into another 3D design application where it is possible to modify the texture mapping data. Then, the element can be imported again into Unreal, and the faces of the mesh will show the texture with the proper orientation.

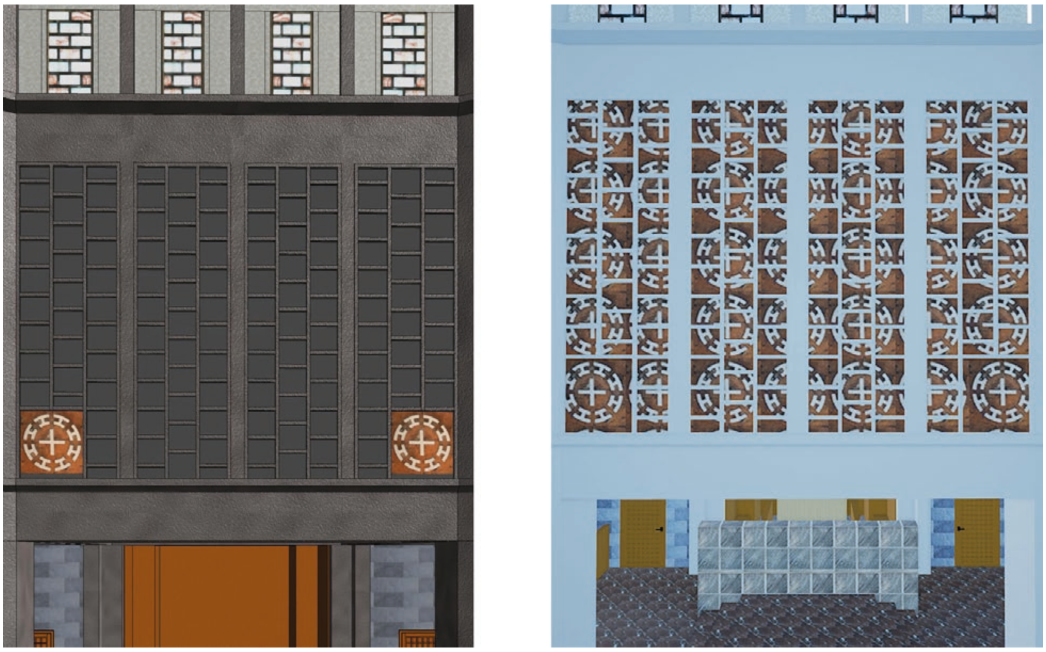

Fig. 2. Left: wall material assignment using Paint tool in Revit. Right: same wall material assignment after import process in Unreal.

Another issue about the import process regards the loss of information caused by the use of the Paint tool in Revit. In Revit, the material of the external faces of a volume can be modified separately from the main material assigned to the volume of that same object. This change, applied using the Paint tool, only affects the external appearance and is not transferred to the data about the main material of the volume. Individual sub–regions of a surface can also be modified with the Paint tool. However, the export procedure assigns only one material to the entire object. Also, the information about the shapes of existing sub–regions is not transferred during the export to Unreal. For example, in our case study, some sub–regions have been created to add pieces of decorations on some of the walls and floors. In the example reported here (fig. 2), the decorations were created as square patches on the surface of the wall. Once imported in Unreal, this surface information was completely lost: the patches disappeared, and the appearance of the entire wall matched the material assigned to the decorative patches in Revit.

Management of the VR Model

As previously mentioned, information about materials and textures is maintained during the transfer process. However, the final result in Unreal is rather rough and incomplete, probably due to the different encoding of material properties between the two applications. In Revit, materials are managed through a pane where the appearance properties are listed together with their assigned values. This list is fixed based on the class of the material and it is not possible to add or delete them. Properties can only be changed by modifying the values of their parameters.

In Unreal, materials are one of the most critical and complex aspects to handle, because of the wide variety of options for material characterisation managed through a network of visual scripting nodes (called Material Expressions). Every node contains a piece of code that is responsible for one aspect of the physical behaviour of the material. Different nodes are connected to achieve optimal visual results, especially when it comes to the interaction of surfaces with light.

However, in Revit, some material properties are either not modelled or managed in background without being explicitly reported in the data for the material. Instead, Unreal needs specific handling of these properties to achieve optimal visualisation. Nevertheless, during the import process, the Material Expressions are automatically populated with nodes, many of which are not necessary for the specific material or contain incorrect values. Therefore, these Revit–derived material structures might be very difficult to interpret and handle in the Material Editor. In our specific case, we often resorted to re–programming the network of nodes entirely, retaining only the properties relevant for the visual restitution in VR.

Addition and Display of Informative Resources

One of the most important features of BIM models is that all kind of information can be included directly inside the project. Unfortunately, this information is not exported in Unreal and cannot be automatically recalled in VR. In this case study, we tested the use of info–points as a method to include some pieces of information manually for real time visualisation of the resources. This was limited to a small portion of the information, but the same methodology can be extended to the rest of the data. The info–points are specific spots inside the scene where it is possible to bring up multimedia panels presenting the information. These panels consist of screens, realized with a blank plane rectangular actor, showing manually inserted media content, both in the form of videos and images.

These panels are normally hidden and can be made visible through QR codes linked to them. These QR codes mark the location of the info–points and can be activated by the user with the controllers by proximity.

When the QR code is activated, the panel pops up displaying its content. The info–points were placed in meaningful locations inside the scene, next to points of interest, for which they provide information when queried. For example, a panel describing a stained–glass window was located just below this object. The user could visualise this additional material while standing in front of the window in the VR environment.

However, when it comes to generic information, such as blueprints, this methodology showed some limitations, because the panels could only be recalled at the specific locations where the info–point had been placed. Therefore, optimal solutions will need to be developed for this kind of data.

Conclusions

Using BIM models as a base for building VR is possible and it is effective in the transfer of 3D geometries. However, the communication between the two applications used in this study is still not optimised for seamless transfer of data. Of notice, these are two standard applications used in their respective fields. It is therefore expected that the challenges described in this work will be faced by other users and designers interested in BIM–VR

Bottlenecks	Suggested developments
Neither platform allows modification of surface mapping to adjust texture orientation when applied to the objects	Developing a plug–in to add this specific feature to Unreal
Material properties assigned with the Paint tool in Revit are not transferred to Unreal	Implementing automatic separation of surfaces with different materials to preserve the correct assignment in Unreal
The encoding of material properties is different in the two environments	Optimizing the translation of Revit material properties to the visual scripting environment used in Unreal
It is not possible for BIM metadata to be automatically transferred to Unreal models	Implementing transfer protocols within the Datasmith plug–in to allow efficient integration

Tab. 1. Problems met in the transition from Revit to Unreal and possible developements to address them.

interfacing. Hence, it is necessary to streamline the communication between the people and teams responsible for these two aspects of project design. It is also important to note that BIM models are often insufficient to convey all the necessary information for optimal material modelling and rendering for VR applications. Therefore, external references are of paramount importance for the correct modelling of the materials in VR. Finally, the passage of metadata between the two modelling environments is quite limited and the rich BIM information often has to be manually transferred in the VR model. This could further increase the workload in case of revisions and updates. The table below summirizes the bottlenecks in the process, suggesting possible developments to address these issues.

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Experimental Value of Representative Models in Wooden Constructions

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Abstract

Drawing has always been a necessary model for directing architectural realization. The design of the shape has become a nodal condition for multiple analysis integration, which is increasingly necessary to meet the performance requirements to which the design must react holistically as a result of digital representation, which has resulted in the enrichment and sophistication of the simulation's predictive capacity. The aim of the study is to test the theories that have been proposed and to ensure that the results are accurate. It is important to test the accuracy of the adopted solutions using the models themselves, through the use of an empirical approach that must be abstracted into a constructed representation capable of synthesizing the qualities to be detected. The current research, which has resulted in the development of some case studies in the field of wooden constructions, is set in a framework that emphasizes the relationship between simulation and realization.

Keywords
multi–objective optimization, digital simulation, wooden structures, generative algorithms, parametric design.

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Introduction

The importance of representation as a model–building site is focused on the digitization process and the convergence of the different aspects of the form into digital computational tools. Models gather and analyze data and information through interconnected and interdisciplinary routes in order to turn them into knowledge. Due to its transdisciplinary nature, representation becomes the language of knowledge incorporation, introducing its own field of experimental and heuristic intervention, with paths that must be validated.
The research, which was formed as part of a collaboration between the Department of Civil and Environmental Engineering and *Abitare+*, a local creative wood construction start–up, provided an opportunity to put in place a direction that aimed to achieve these objectives of innovation and knowledge transfer. Simultaneously, joint competencies have been developed to kick–start product and service innovation processes. The analysis of generative models aimed at multi–optimizing the form, energy efficiency, structure, and cost of wooden houses leads to the integration with BIM models. To encourage this practice, an Ames room has been developed with a high media impact to highlight the proposed creative approach. The study then moved on to multi–optimization of wooden structural walls from this first direction. Simultaneously, a study of a new 'breathing house' model was conducted, applying responsive solutions to indoor hygrometric changes. To check the validity of such solutions, a test room was built as an abstract representation of a wooden house reduced to the size of a paradigmatic room.
Generative modeling, BIM, and software solutions unique to the various disciplines involved are useful tools to integrate architectural, representative, positive, resources, and communication aspects. Once ready for the industrialization process, the models, which in this case are materialized in a physical form (the model of the model), must be tested.

The Research Path

The analysis of generative models [Bianconi, Filippucci, Buffi 2017; Filippucci 2012] is followed by a proposal for an integrated mass customization–based design and production process [Duarte 2005; Paoletti 2017], which is aimed primarily at wood construction technicians and specialists but also useful as a dissemination tool for students and researchers. The study looks into the possibility of using generative models and evolutionary principles to inform the design and customization process. The first case study [Bianconi, Filippucci 2019] aims to provide individualized housing designs to central Italy.
These square–plan houses, designed as modular solutions that can be transported and assembled easily following a simple manufacturing process, can be combined to build custom multi–family homes and villages that conform to both the environment and their inhabitants. The generative process specifies a variety of design options, all of which depend on genetic algorithms to adapt and optimize the architectural model. The design concept is focused on the analysis of local codes and X–Lam and Platform–Frame building systems with the goal of reducing waste and optimizing the construction process. With the study's goal in mind, energy consumption, thermal, and visual comfort, as well as price, were evaluated with the construction company and through iterative processes. The results of this first study, which began with the selection of solutions available to the company, have prompted a closer examination of each element that makes up the envelope.
The realization of the Ames room is exemplary in this regard [Ames, Ittelson 1952]. It is an application of perceptual theories [Arnheim 1965; Gibson 2018] that reviews digital algorithms to concretize an architectural expedient based on image culture [Pinotti, Somaini Elcograf 2016] and that has led to a model that synthesizes the research's multiple questions [Bianconi, Filippucci 2020].
The focus of the investigation then shifted to improving the energy efficiency of wooden structures that had previously been customized to meet the location's specific requirements. The aim in this case is to use generative design tools to optimize the preliminary cost and efficiency of wood walls for X–Lam and Platform–Frame structures, with the goal

of evaluating the actual performance of the built solutions [Seccaroni, Pelliccia 2019]. As a result, the described workflow begins with the implementation of parametric algorithms in Grasshopper that return thermal transmittance, decrement factor, time shift, costs, and verify the absence of interstitial condensation while varying the wall materials and thicknesses from time to time [Aste et al. 2015; Rossi, Rocco 2014]. The selected parameters can be processed in a multi–optimization direction based on the application of evolutionary principles through the Grasshopper plug–in Octopus [Diakaki, Grigoroudis, Kolokotsa 2008], in which more than 5000 possible material and thicknesses combinations have been automatically analyzed.

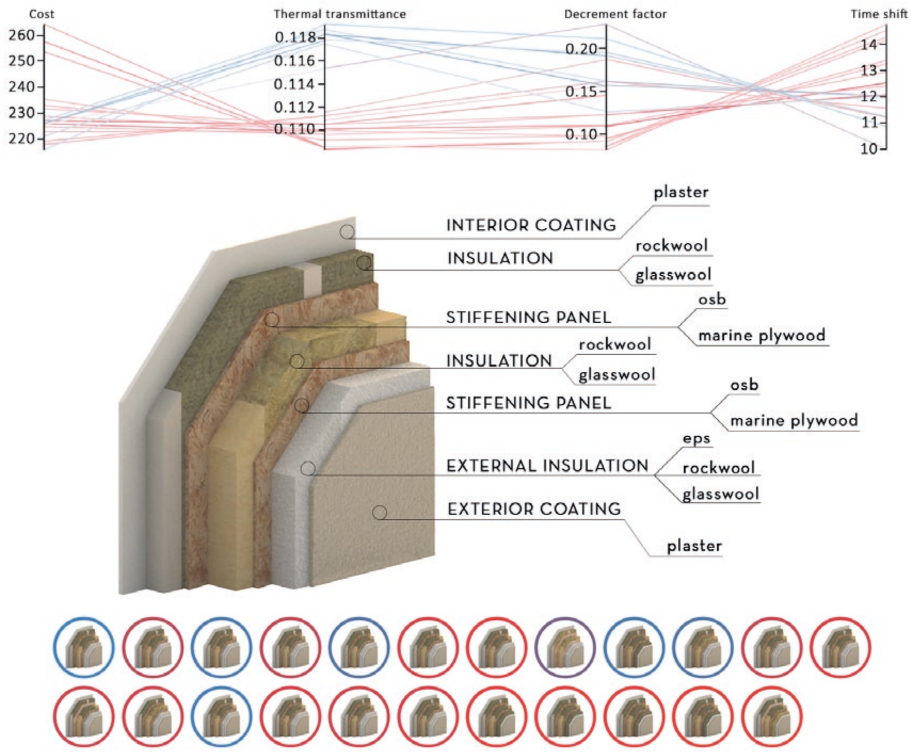

Fig. 1. The selection of various possible optimized walls according to thermal parameters, materials or cost.

The best solutions can thus be selected, identifying the Pareto front [Wang, Zmeureanu, Rivard 2005; Wright et al. 2002], in which the combinations simultaneously present optimal values of the various parameters that evaluate the wall's summer and winter behavior, as well as the overall cost (fig. 1). Because of Octopus' genetic multi–optimization, the approach just mentioned is based on the development of an algorithm capable of simulating human decisions in finding the most suitable solutions from both an energy and economic standpoint. As a consequence, the algorithm acts as an Artificial Intelligence (AI) [Ridolfi, Saberi 2019] because it simulates human decision–making and also allows for the testing of a wide number of potential combinations. The research then moved from virtual to physical with the construction of a test space. The test room is an abstract representation of a wooden house scaled down to a paradigmatic space's dimension. It stands out thanks to a removable wall that can be replaced with any kind of X–Lam or Platform–Frame construction. This architectural aspect was realized with one of the walls optimized by the algorithm and was monitored once fitted with sensors and data acquisition systems to compare the data obtained from simulations with the real ones and thus understand the actual usefulness of the optimization tools used. The in situ transmittance was calculated using thermocouples, flux meters, and additional temperature and humidity probes, and compared to the algorithm simulation using UNI ISO 9869 [ISO 9869–1:2014 Thermal Insulation – Building

Fig. 2. Thermocouples, fluxmeters, temperature and humidity probes and anemometers inside the test room.

Elements – In–Situ Measurement of Thermal Resistance and Thermal Transmittance – Part 1: Heat Flow Meter Method 2014]. The obtained results confirm the simulated model's consistency with the structure's actual behavior, taking into account a percentage of error due to various factors that may affect field measurements (fig. 2).

Conclusions

The relationship between digital and wooden constructions opens up impressive fields of use, as shown by the integrated action promoted by an international call [Bianconi, Filippucci 2019b]. It has also led to the development of a research network involving more than 150 researchers from all continents [Bianconi, Filippucci 2019a]. The great cultural value of this initiative can be ascribed to the new key role of representation for contemporary research. The research outlined the value of preliminary digital simulation for form–finding, both in terms of the project's actual final configuration and in terms of the less tangible aspects of the building's efficiency. As a result, representation takes on a new position as the 'place' of the model. The dynamic passage between real and virtual in a spatial model helps in representing intangibly, with high reliability, what is concretely abstract. This demonstrates the representative models' experimental importance. By using artificial intelligence's analytical capabilities and reinterpreting the flow of data collected during the monitoring, the study aims to define and validate the best performing solutions for the particular architectural project.

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Automatic Recognition Through Deep Learning of Standard Forms in Executive Projects

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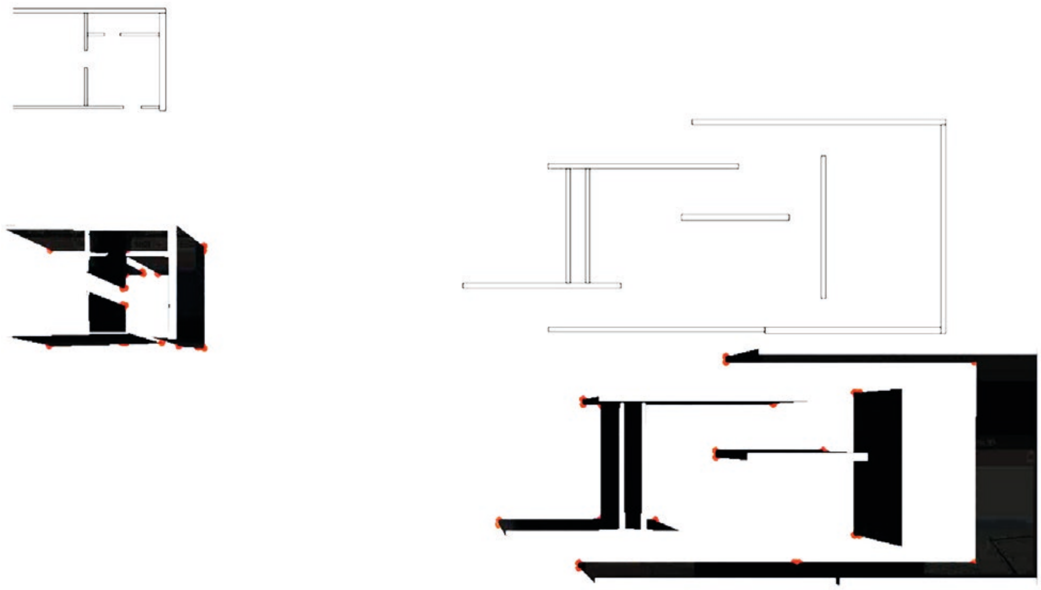
Abstract

In this paper is presented a possible methodology for automation through the use of deep learning of BIM modeling starting from different types of formats, such as digital processing of paper documents and CAD formats. The work is configured as a proof of concept of a possible contribution that a technique currently scarcely used in the architectural field such as deep learning can bring to the design, in particular in the realization of the information model, which today represents one of the most consuming–time activities.

Keywords
deep learning, computer vision, BIM, automation



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notBIM to BIM

The production of information, in the construction sector and in a very widespread domain, is undergoing a transformation process in recent years that involves the transition from the use of CAD to the implementation of BIM as regards the generation and extraction of graphic and non–graphic data. This process, although strongly favored by national legislation, is still in a phase in which CAD software often plays a role of primary importance, especially in the initial stages of design, while BIM is sometimes relegated to the final stages of the design process, during the final and executive project, only to be abandoned in the construction phase. It is also true for many realities that a large part of the built heritage preserves documentation in paper or CAD format.
In the production of projects and graphics, the current state of a BIM model shows drawings drawn up in different formats, with different methods and purposes for the design disciplines: there are cases in which there is a need to create a model for the management of an existing building artifact, to draw up a building restoration project, for the variation of methodology that can take place between levels of subsequent technical study in the design, such as the transition from a final project developed in CAD to an executive project developed in BIM.
The creation of a BIM model finds in the modeling of geometric data one of the activities of greatest time consumption, with consequent dilatations in the planning times, which are reflected in an increase in costs for organizations [Deutsch 2011]. The existence of graphic data created with paper or CAD formats, although used as an initial data for BIM modeling, only partially exploits the amount of time spent in the production of such data, with consequent waste of the work carried out previously, as the data starting graph must be manually recreated within the BIM model, like for example the production of digital text files starting from handwritten documents. In addition to being extremely laborious, a data recreation process of this type also depends on the experience and expertise of the operator involved [Koutamanis, Mitossi 1992].
In this work we try to obtain through Deep Learning methodology those geometric data, present in paper or CAD drawings, useful for the creation of BIM objects, and to use such data for the automatic creation of such objects through algorithms. With reference to the existing bibliography, it is a question of updating experiments already carried out with advanced algorithms, evaluating the speed of execution, accuracy and integrability. It is possible to find basic algorithms starting from the early 90's [Kaneko 1992]. Such algorithms mainly work on symbol recognition [Mokhtarian, Abbasi 2004]. These first specialized works, which served as cadastral plans to demonstrate the correctness of the awards, were followed by applications dedicated to architectural representation for the transition from 2D drawings to three–dimensional models [Lewis, Séquin 1998]. The analysis models have become more specialized, in a direction of increasing effectiveness towards different disciplines and electronic media [Dosch et al. 2000; Lu et al. 2005; Yin, Wonka and Razdan 2009]. The application to the generation of BIM models as output has instead been explored only recently in which the recognition is applied to all building elements, such as doors and windows [Lim, Janssen and Stouffs 2018]. In fact, this work aims to show how it is possible to integrate, in a single BIM modeling environment, through visual programming, Computer Vision and Deep Learning libraries.

Methodology

The project exploits existing libraries for Deep Learning and Computer Vision in order to recognize objects from suitably digitized paper formats and to recreate these objects in a BIM environment using VPL. For this purpose, the visual programming environment Autodesk Dynamo in its version DynamoCoreRuntime 2.7.0 was used, given the impossibility of integrating Python libraries for Deep Learning in the current versions integrated into the BIM modeling software Autodesk Revit (Autodesk Dynamo Revit 2.5.0 for Autodesk Revit 2021), and OpenCV (Open Source Computer Vision Library), a software library for Computer Vision and Machine Learning.

The graphic drawings taken into consideration are the plan views, as they represent in most cases the most important documents in the architectural field [Koutamanis, Mitossi 1993].
The process can be divided into 4 stages:

- preparation of the image;
- image processing;
- subdivision of detected objects:
- creation of objects from extracted geometric information.

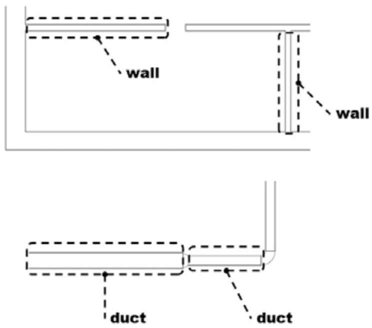

Fig. 1. Element recognition scheme. Elaboration by the authors.

The image preparation phase involves the digitization of images from paper format or the transformation of vector files into matrix form. The search for the most suitable method for the CAD–matrix transformation is currently underway, however the export of tables in JPEG form seems to be the quickest and easiest method for preparing the CAD data.
In the case of digitized paper documents, the creation of tracing elements of the beginning and end of the analysis area and identification of the coordinates, as well as identifying the scale of the objects contained in the document, is deemed necessary.
In the processing phase, the image imported into the Visual Programming Language (VPL) is provided as input to a Python script that uses openCV in order to identify simple geometric shapes formed by 4 vertices in the image. The library uses appropriate filters to identify, through matrix operations, the presence in the image of vertical lines, horizontal lines or edges in order to determine the presence of vertices in a certain region of the image.
The currently implemented algorithm applies a single transformation to grayscale images that provides for the application of a threshold to each pixel, for which the pixel values above the threshold are brought to 0 while the higher values are taken to the maximum value supplied as input, in this case 255. A second function identifies possible outlines of elements in the image, which are subsequently discretized by obtaining the vertices of the figure.
The list of vertices is filtered by selecting only the figures whose number of vertices is equal to 4. The vertices are then decomposed into their own X–Y components and supplied as output.

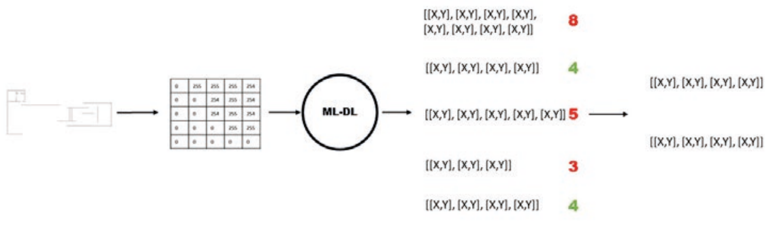

Fig. 2. Algorithm operation diagram. Elaboration by the authors.

The list of coordinates obtained is then used to create the related points in the VPL environment, which will create four–sided polygons that are analyzed in their geometric information in order to perform a further skimming on the objects in the initial image.

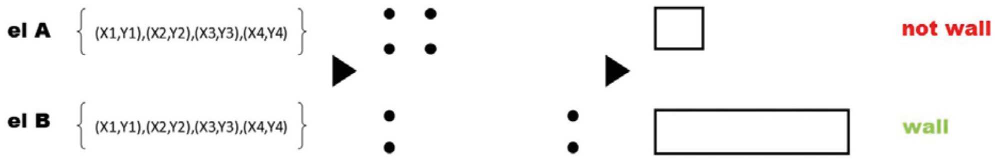

Fig. 3. Results classification. Elaboration by the authors.

The objects are created starting from the geometric or textual information obtained from the drawing. In the case of textual information, an algorithm can be set up which, using openCV, recognizes text elements, obtains their position and content and associates them with the forms detected using the algorithm described above.

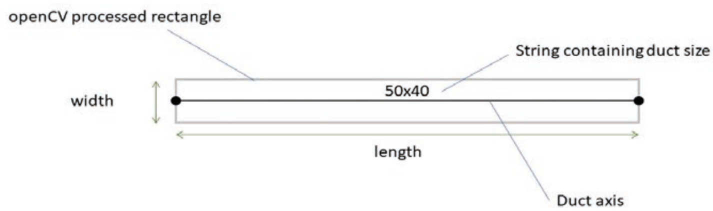

Fig. 4. Information extraction. Elaboration by the authors.

The currently developed algorithm is an extremely simplified resolution of the identification problem and represents a proof of concept of the possibility of integrating this type of operations in a single environment.
For a real application, the algorithm requires further developments such as:

- a part of better pre–processing of the image, in order to ensure better results for non–standardized images from the point of view of color, contrast;
- the training of a neural network that can autonomously classify elements within the image based on pre–training on typical representations of architectural elements in plan (walls, pillars, floors, doors, windows ...).

From this perspective, the algorithm would not be limited to the recognition of rectangular shapes only, but would be aimed at the recognition of elements of any shape and their classification on the basis of the classes provided during the training phase. The algorithm would then obtain, depending on the class, different information for the creation of objects in the BIM environment. For example, for the creation of wall elements, the axis of the wall (major axis of the rectangle) and the thickness (minor axis) would be derived from the identified rectangle, for the creation of door elements, the centroid of the identified polygon (position of the door in the closest identified wall element. In this sense, we would approach an almost complete recognition of the graphic information contained in the original work, which can be divided into three types [Koutamanis, Mitossi 1993]:

- Recognition of the geometric element: extraction of geometric information by element from the graphic;
- Recognition of the Building Element: extraction of classes by element from the graphic;
- Recognition of the spatial articulation, training a neural network to recognize the spaces formed by the association of different elements (concerning the architectural discipline), or zones (concerning the MEP discipline).

Results

The results obtained in the processing of an image representing part of an HVAC system are shown below. Note how an extremely simple form such as that of the rectangle takes on a multitude of meanings in architectural language based on the context in which this graphic symbol is placed. The variation in meaning occurs both in relation to the discipline and in the relationship between the element and the context. A rectangle can therefore represent a wall, a floor or a piece of furniture in the architectural discipline, a pillar or a beam in the structural discipline, a rectangular or circular duct or a connection in aeraulic systems. The need to train a neural network for the discernment of such cases is therefore recognized.

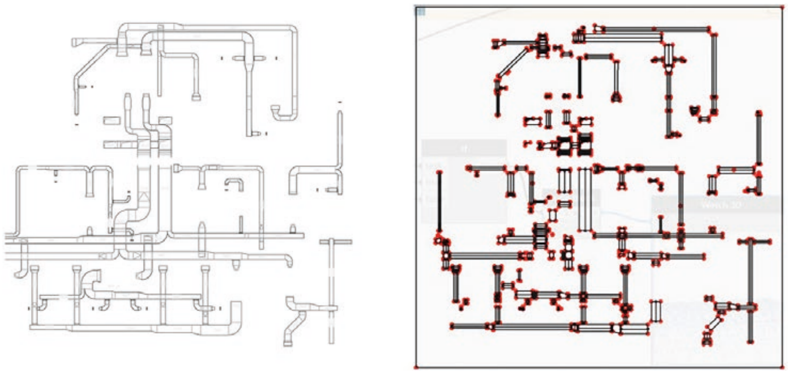

Fig. 5. Information extraction. Elaboration by the authors.

It is possible to note that a sketched and very simplified version of the algorithm already achieves good results in recognizing simple elements and tracing their axis. In this case, a subsequent algorithm will be responsible for the grouping of shapes on the basis of the connection by means of objects of different shapes, representing in this case the fittings of the ducts. At this point you have all the geometric information necessary for the creation of the elements in the BIM environment. The work carried out has undoubtedly demonstrated the greater speed of execution of a deep learning/object recognition algorithm compared to methods of analysis according to geometric formulas, previously experimented by the authors. To this must be added the high accuracy rate in object recognition for simple geometric shapes or scarcely variable shapes achieved by the current available algorithms. However, it is necessary to create more complex neural networks that can recognize and classify a multitude of objects belonging to the common architectural language for a complete or semi–complete automated modeling of BIM objects starting from the considered formats. In order to have a fully operational IT product, it is also necessary to develop a method for verifying the dimensional correctness of the outpute and the subsequent correctness of positioning of the elements in space.

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Interactive Information Models and Augmented Reality in the Digital Age

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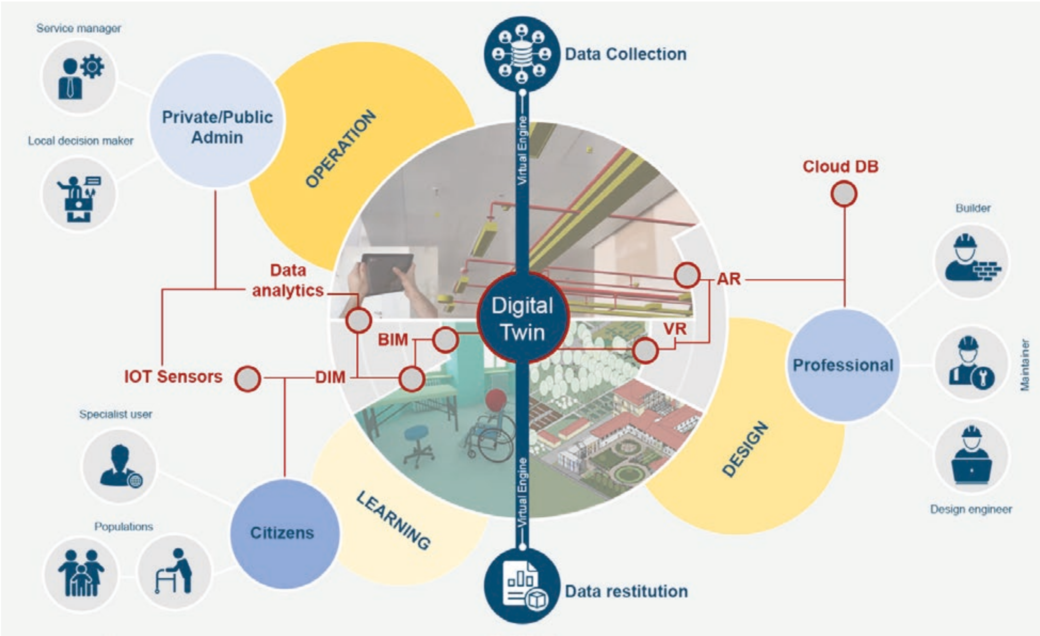
Abstract

The construction industry in the digital era has seen significant changes in design, construction, and spatial process learning through new technological systems. These processes influence management and how data is collected, cataloged, and monitored using sensors and connected users. The real challenge that the digital era imposes on the society of the future is to define new secure and resilient digital models coupled with interoperable methods that minimize the impacts of our built heritage throughout its lifecycle. For these reasons, new models are being investigated to educate, gain detailed knowledge of places, design inclusive spaces that meet users' needs and finally manage and maintain the built heritage. New technologies of Augmented and Virtual Reality support principals and users to define stable and interoperable relational processes. Although the challenge is ambitious, it is essential to find efficient solutions in governance policies for the city's future.

Keywords
augmented and virtual reality, digital twin, construction digital twin, participatory digital model.



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Introduction

In recent years, the spread of innovative tools that increase communication between users has highlighted the adoption of new tools and methods for managing built heritage data.
Within this technological evolution, the building artifact becomes a digital model in which the rapidity of data exchange highlights new awareness and limits expressed within a society in continuous change [Salgues 2018]. Digitization of the construction industry involves the management of various data domains brought into the system to meet the needs of the involved actors. In this sense, Information and Communication Technologies (ICTs) transform citizens' lifestyles in buildings and cities, developing new dynamic characteristics, going beyond the static nature of social relations.
Cities and their systems need solutions that optimize the information that governs the smart society by cataloging the progress highlighted during the digitization process [van Dinh 2020]. This transformation's efficiency is based on a network composed of nodes, real databases, and virtual environments. The new technological borders of information exchange between users and virtual systems are artificial intelligence (AI), Internet of Things (IoT), Machine Learning (ML), Deep Learning (DL), cognitive computing, and big data analytics that define the boundaries beyond which reality is pushed by virtuality [Sharma 2018]. Smart and digital services, Augmented (AR), and Virtual Reality (VR) tools are emerging to facilitate the integration between the physical environment and cyberspace, enabling the adoption of these innovative methods to process, manage, and compute real–world processes [Baheti 2011].
The contribution examines the optimization of the information process through digital models and related virtual interfaces aimed at education, in–depth knowledge of the places, the design of appropriate spaces, and finally, the management and maintenance of the artifact.
The development of these information–rich models and the proper use of enabling technologies to transform parametric digital models into true Digital Twins (DTs) in which data transmission is characterized by information bi–directionality with cyber–physical systems.
Besides, DT's definition can be integrated with the concept of Construction Digital Twin (CDT), as the ability of a system to adapt to complex social flows that regulate the management of the building life cycle [Boje 2020].

Methodology

The ability to develop a digital model capable of relating to the physical environment has to be compared with the need to use graphical interfaces connected to various databases, providing information content to different users. For this reason, the development of a DT, a virtual replica of reality [Grieves 2015], plays a key role in this digital transition phase. The starting point for this action is to identify specific objectives of the information model and their different uses that differ according to the user. Therefore, depending on the user–virtual environment interaction, the adoption of specific technologies based on desktop and mobile applications facilitates the various selected databases' connection.
From a methodological point of view (fig. 1), it is possible to describe the relationship between the involved representation scale involved, the employed strategies, and the adopted tools for developing specific graphical interfaces. Consequently, from selecting the specific field from building to urban scale, various representation strategies can be considered starting from hand–made drawing to informative modeling based on Building Information Modelling (BIM) with different levels of maturity. Moreover, the useful tools can be more or less immersive depending on the type of interaction required. Therefore, the importance of users viewing this information according to their needs is emphasized according to the project's specific purposes. For this contribution, three experiences have been examined (fig. 2) that apply in a multi–disciplinary way what has been described above, starting from the generation of BIM models using the Autodesk Revit platform.
The first selected case study focuses on the Santissima Trinità hospital in Fossano (Cuneo). The hospital complex is located within a historical building of the eighteenth century.

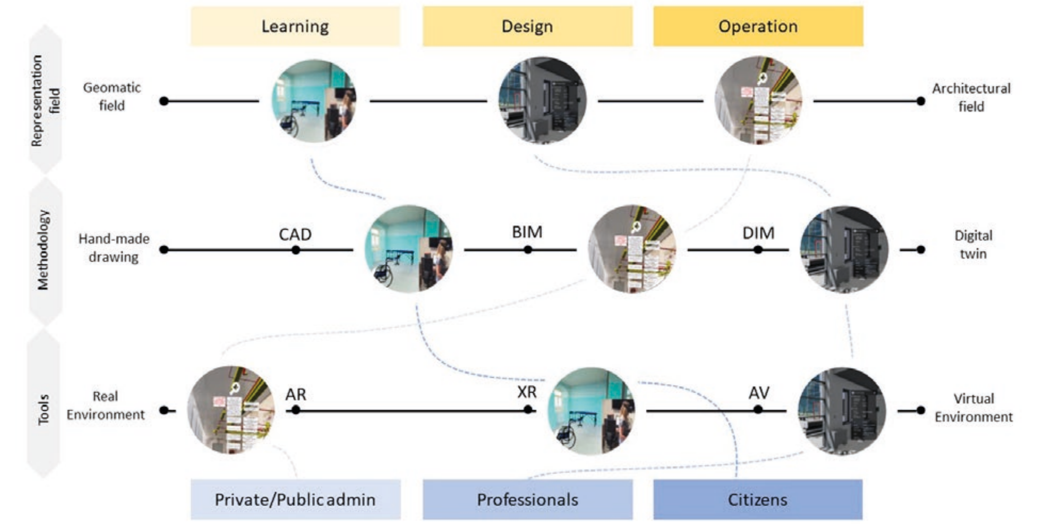

Fig. 1. AR Framework for AEC Industry (authors' elaboration).

Fig. 2. Case Studies selected (authors' elaboration). The images are extracted from the master students thesis listed in the acknowledgements.

The building is a monumental complex characterized by complex architectural elements (i.e., vaults) that have changed over the years. These characteristic elements are digitized to simulate innovative spatial scenarios through the BIM methodology, making comfortable the environments intended for patients' motor rehabilitation through VR technologies. In this case, Unity 3D was selected as the VR platform, while the HTC Vive Head Mounted Display (HMD) was selected as the immersive technology. In particular, two specific areas (e.g., gym, hospital room) have been identified as the basis for the virtual environments. The immersive application has been characterized by aspects related to both the gamification approach and the therapeutic elements.
The second use case selected is the Trompone complex (Moncrivello, VC), which offers several healthcare services to support high complexity patients and relatives. It consists of several buildings, including a nursing home, an assisted healthcare residence (RSA), a convent (part of which is now used as a training center), and the sixteenth–century sanctuary. In this case, the attention is given to designing a small daily center for Alzheimer's patients within the existing complex. Starting from a BIM model, different VR software platforms were investigated to improve the new spaces' design, controlling the possible interferences between the architectural, structural, and systems disciplines. The interaction with the digital model has taken place through two VR tools, Enscape and Autodesk Live. While the first

allows you to navigate within the space even before the projects are done, implementing changes in real–time through HMD devices, the second enables to query the model's components by displaying its alphanumeric properties.
The third case study is the service center of the single headquarters of the Piedmont Region (Turin). It is a five–story above–ground building with a lobby and a nursery on the ground floor. The information management for the operational step of the equipments, has been studied through the development of an AR application for mobile devices, based on the Unity 3D platform integrated with Apple ARKit. In this way, the specialized technician can visualize information useful for the localization and maintenance of plant visible and hidden components by storing and updating data exploiting the links with external databases. The tested methodology acquires various aspects according to the field in which it is applied: as an example, in the construction phase, the operator can verify the reliability of the model by comparing it with the shop drawings.

Results

The different use cases selected for this paper highlighted how the digital evolution imposes different virtual models but also across the growing needs of the interactive user.
In this sense, the connection of the three use cases defines the right procedure for optimal human–building interaction, overcoming interconnected systems' limitations. The results obtained from these experiences allow describing the first image of DT aimed at both the collection and the enrichment of data required for a participatory DT. This definition implements the digital twin features based on physical objects, virtual models, and connections by including user interaction as the fourth main component for its implementation.
A digital model was obtained as a real Construction and participatory DT from the analysis of the real environments (fig. 3). The next step will be implementing AI and ML techniques by using standard and open–source data exchange formats to increase its level of maturity. Unfortunately, to date, many obstacles do not allow for the best integration of different systems and different data sources with real user needs. The applications developed are considered a prototype useful to raise some thoughts about developing a DT.
In the first case, the user interacts with the virtual environment by composing a virtual puzzle and using motion sensors and immersive HMD devices. The advantage the selected technology consists on medical progress monitoring during rehabilitation, learning and memorizing shapes, colors, and positions. Currently, data automation is the real critical issue, which is fixed through web protocols. The second use case highlights the potential of participatory design with BIM through VR platforms to support decision–making.
The most critical issue found concerns the loss of data due to proprietary viewers who have some limitations in returning answers in real–time. The following aspects are evident through the immersive experience: i) understanding of space and relationship with pre–existence; ii) reconstruction of paths and memorization of objects and settings; iii) developing a sensory environment oriented to Alzheimer's patients. The AR application developed with the third case study also highlighted the potentialities of overlaying digital content in the real environment. Currently the model georeferencing with the reality is one of the major criticalities that, in this case, has been solved by inserting a fixed positioning point. About data updating, further developments are required according to the challenge of data–sharing.

Conclusions

The AEC industry is facing a transition phase in which new technologies highlight the current gaps that traditional systems can no longer fill. Using ICTs and Augmented and Virtual Reality systems as tools for participatory design, learning and operations lead to a new vision of working and thinking about the built environment. In this way, the construction industry is educated better to meet human beings' needs and an intelligent city. Through the experience offered by the proposed use cases, the paper evaluates strenghts and weaknesses of the relation between virtual and physical environments world, considering different degrees of immersion. Although the interaction between the digital and physical worlds is not yet optimal, artificial

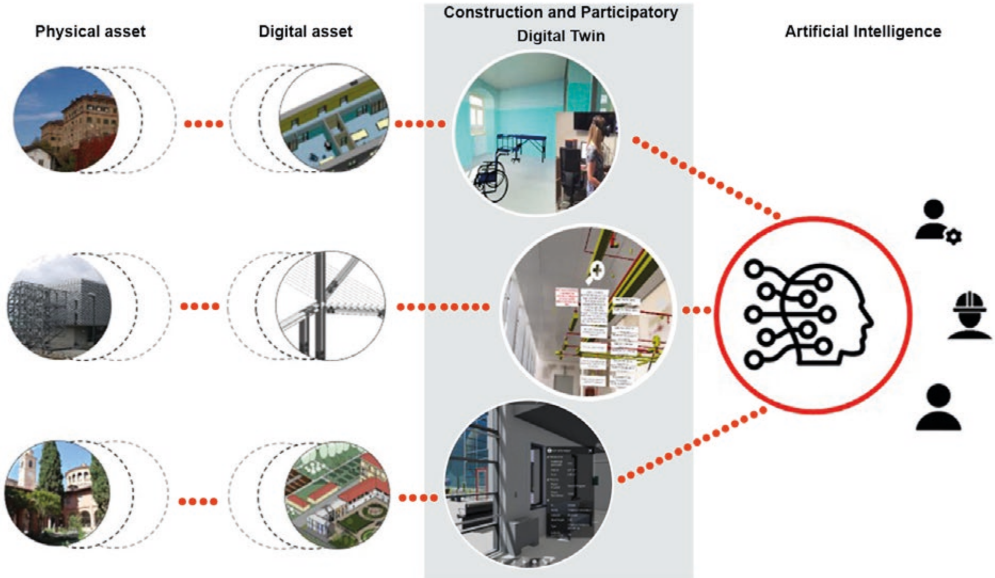

Fig. 3. Construction and Participatory Digital Twin for AEC Industry (authors' elaboration).

intelligence through algorithms and augmented reality may soon facilitate their interaction through collaboration and interoperability. Such complex systems can facilitate relationships between public and private administrators, professionals, and citizens within a new city model defined as augmented building/city. The advantage expressed by models with a high capacity of response and data cataloging is related to representing the urban/architectural model. The transformation of virtual models into construction and participation digital twin allows virtual machines to process traditional forms and properties into future elements.

Acknowledgements

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Survey and BIM for Energy Upgrading. Two Case Study

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Michela Meschini

Abstract

This research aims to deal with the theme of the survey applied to the BIM methodology in cultural heritage; in particular on those buildings that, although from different periods and construction technologies, require energy requalification. The study focuses on two cases in Umbria: Borgo Lizori, a characteristic historical settlement located along the Assisi–Spoleto olive grove, and the Palazzetto dello Sport in Bastia Umbra, a post–modern building designed by arch. Leoncilli Massi.

Keywords
cultural heritage, energy efficiency, BIM.

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Introduction

In recent years there has been a steady increase in demand for the rehabilitation of the existing building stock, both historic and more recent. Intervention on the built heritage has to face increasing challenges and opportunities, such as the recent tax reliefs issued by the government; the resulting expectations are related to sustainability, energy saving, as well as the availability of new materials and continuous technological innovations. In this context, it is essential to understand the building, its genesis and its technological characteristics. Particular attention must be paid during the survey phase which, in the most complex cases, is facilitated by the use of drones or laser scanners, which make it possible to obtain a digital clone in a short time but with high accuracy. The point cloud obtained in this way is then imported into the BIM environment; from here it is possible to reconstruct the geometric elements, classified into hierarchical structures, and explored with different levels of detail. This procedure was carried out in the two cases that will be presented here; they are two profoundly different cases, but from which emerges as the lowest common denominator the need for energy regeneration, the point of convergence of a methodological research path that starts from the survey and projects itself to integrate the multiple information in the BIM environment.

The Case of Borgo Lizori

Lizori Burg, a settlement located on the hill between Foligno and Spoleto in the city of Campello sul Clitunno (PG) and a UNESCO World Heritage Site, represents the first case study. The very first inhabitants of the area were the Umbrian, an Italic people from Central and Eastern Europe who came to the peninsula around 1000 BC. Subsequently, the place will take the name of the castle of Pissignano, derived from the ancient Pissinianum, or swimming pool of Giano. The first nucleus developed in Roman times along the Flaminia, while later the hilly one was formed, where a small Benedictine community was established, presumably around the eleventh century. Between the eleventh and twelfth centuries, the monks erected a wall around the inhabited center, which therefore took the name of San Benedetto Burg. Over the centuries, the burg was often disputed due to its privileged strategic position. The recovery of the Burg, which took place from the mid–seventies, on the one hand gave new life to a place that was abandoned, on the other it was an opportunity for the application of good practices: the local materials were recovered, put in place with traditional construction techniques, so much so that they were shown at the IUA World Congress in 2005.

Its triangular shape has the summit upstream, with towers originally arranged at the corners and on the two sides inclined in an intermediate position. The urban layout is quite characteristic: it has a compact terraced layout of buildings with parallel lots and a trend that sets itself on con-

Fig. 1. A global view of Lizori Burg.

tour lines, rapidly degrading along the slope. The village is in a perfect state of conservation and presents architectural forms in relation to nature, as well as purely artistic decorative elements.
As preliminary survey, a model was developed through aerial–photo modeling techniques, a technique that offers considerable advantages for dense patterns, such as the case study. It was possible to survey the whole village, and represent the roof shape in detail using a professional EVO 4HSE drone. The flying and the image acquisition phase lasted 8 hours. In this phase more than 20 marker were positioned on the ground to facilitate the aero–triangulation and to limit the cameras orientation error. The camera used for this phase is a LUMIX DMC–GH4 digital mirrorless with a single lens, on a Panasonic 14-18 mm optic. The software used for photo modelling is ContextCapture (Bentley).
Once concluded the input and marker georeferencing phase, it is possible to move to the aero–triangulation phase, where among the options it is possible to set: density of key points, choice of methods of similar photos and adjustments of focal distortions. When completed the cameras alignment phase, it was the time to produce the dense cloud choosing points' density, texture quality and the mesh parameters. Subsequently, the survey data were merged and geo–oriented through the 3Dreshaper software, thanks to which it was possible to extrapolate further data such as the land digital model and the built environment shape to hierarchize the point cloud.

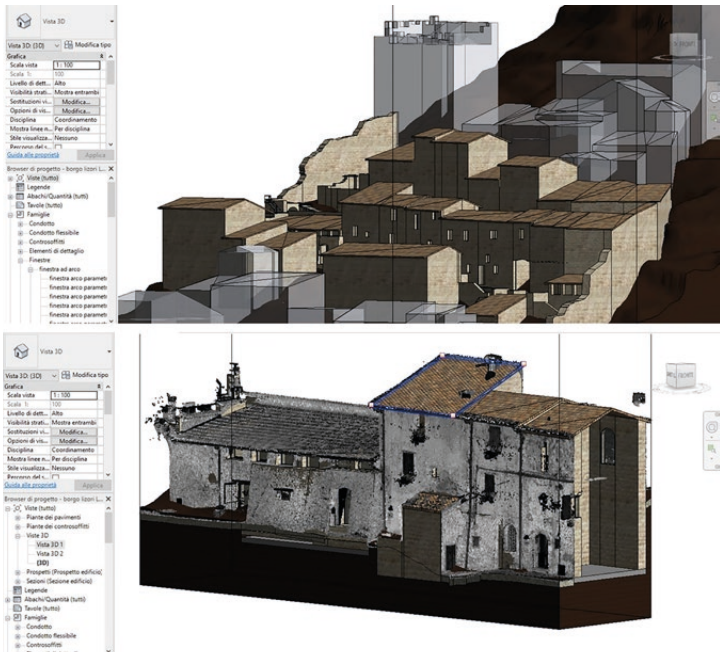

Fig. 2. Revit, different LOD levels of the BIM model.

By selecting the most widely used Autodesk BIM Revit software as a reference tool, operationally it was necessary to index the geo–referred data through the Recap software to ensure direct management in the identified digital environment. From the cloud of points is possible to move on to the interpretation of the shapes detected through the modelling of geometries. This are differently detailed in terms of scalar levels of detail, addressing the multiple issues related to the definition in parametric informational environment of singular and peculiar elements, such as those met in historical contexts like the case study.
Using 3DReshaper software, it was possible to export the BIM Revit model in FBX format and overlap it to the cloud of points from the laser scan, to calculate the variance, intended as the distance between homologue points of the BIM model and the relief. The obtained mistake is the sum of different factors and the average values are in the order of 5cm, an acceptable value connected to the vernacular character of urban space and the possible needs of a representative approximation.
The use of this platform has allowed the model to add a series of details relating to the structure of the individual buildings, ranging from the stratigraphy of the wall facings to

that of the roofs, passing through the types of heating system. This implementation of data has made it possible to carry out a series of analyzes on the current state of affairs from an energy point of view, allowing the development of a series of design strategies for the redevelopment of the individual element and, consequently, of the entire burg. In particular, the building envelope was studied, including both the external walls and the roof; a project was carried out for the inclusion of home automation, and the lighting was studied, including a study of both the internal and external environments.

The Case of the Sports Hall in Bastia Umbra

The Sport Hall in Bastia Umbra was designed by the architect Leoncilli Massi in the 1970s as a covered market for the S. Lucia area; later, following the granting of funds by CONI, the use of the building was changed to sport hall in what is now the Giontella area.
The building has an atypical truncated pyramid shape, with a rectangular base rather than a square one, and a basement that was originally intended to contain boxes for the open–air market. But if the pyramid works by gravity, Leoncilli Massi reverses the logic and inserts an exoskeleton, a characteristic element of the entire project. The structure recalls the themes of post–modern architecture, such as the colours chosen or rather the arch–window; and again, the fragmentary nature found in every corner of the building, where stairways, exits and entrances are inserted. Lastly, the misalignment, with the basement creating an 'L' on the east side. Almost forty years have passed since its inauguration on 16 November 1983, and the Sport Hall, although it has been selected by MiBAC as one of the most important works of contemporary architecture, presents a number of critical issues due to the technologies used at the time, such as infiltrations and thermal bridges, as well as more 'recent' problems such as parkour and graffiti. The survey was carried out using a laser scanner with a spherical camera; in this case, through the software installed on the mobile device, it is possible to see in real time the cloud of points that is gradually forming, as well as the positioning of the instrumentation. (fig. 4) The model that is created is geo–referenced. For simplicity's sake, the operations for importing it into a BIM environment, already seen in the previous paragraph, are omitted.
This led to a series of hypotheses which, on the one hand, resolve the technological difficulties, aim at energy requalification and, finally, restore the contemporary architecture. In particular, solutions were studied to eliminate water infiltration, redo the window and door frames and study thermal insulation. Finally, a proposal for a new external skin that does not distort the work but at the same time makes it contemporary.

Fig. 3. The Sport Hall in Bastia Umbra.

Fig. 4. Positioning of the laser scanner and its point cloud in the Sport Hall.

Conclusions

This contribution aims to compare two case studies, profoundly different, but which have in common the need for energy regeneration. Starting from the point cloud, necessary in these cases where the survey operations present objective difficulties, a first step was the implementation in a BIM environment; the research will be perfected with immersive experiences in an AI/AR environment, which will allow a further enhancement of the cultural heritage. Through the case studies, the research aims to highlight the centrality of a methodological workflow in its ability to manage and interpret data, which becomes fundamental for the knowledge and enhancement of the richness of our heritage of historical and environmental interest.

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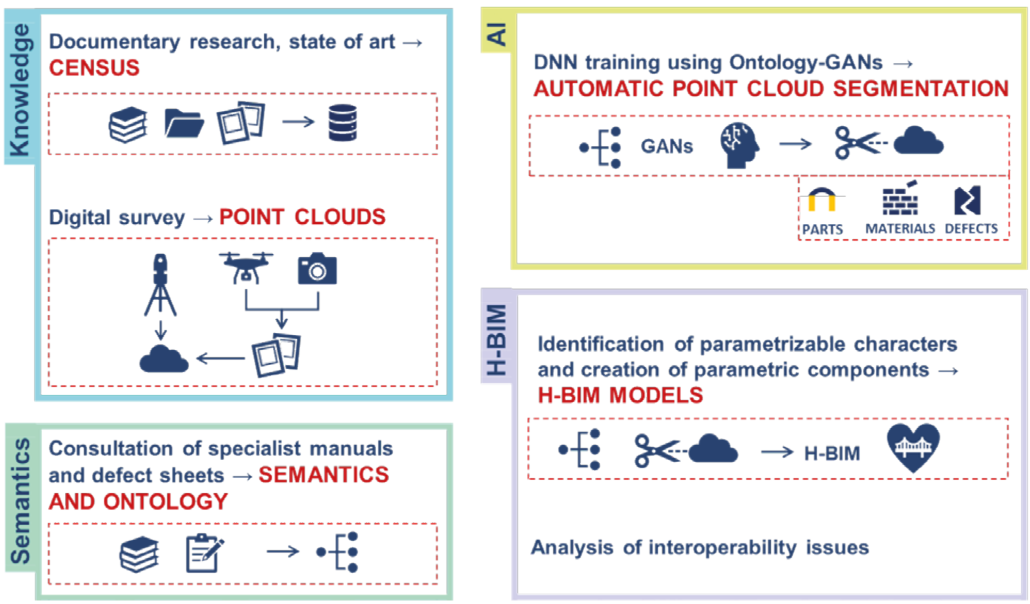
A Proposal for Masonry Bridge Health Assessment Using AI and Semantics

Raissa Garozzo

Abstract

Masonry railway bridges represent a historical built heritage to be preserved. This contribution proposes a new methodological approach for health assessment of masonry railway bridges based on the definition of image–based and AI–driven survey protocols useful for the creation of semi–automated H–BIM models. To do this, a heuristic approach is required with the integrated combination of techniques and methodologies belonging to different fields. As case studies the masonry bridges of the sicilian Circumetnea railway are chosen.

Keywords
railway masonry arch bridge, digital survey, archival research, artificial intelligence, GANs.



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Introduction

Masonry arch bridges are one of the most common structural typologies in the worldwide architectural heritage. In the nineteenth century, the design and construction of bridges had a great impulse with the railways' advent. While the function of the bridges has changed over time, due to the abandoned railway networks, their value as historical permanence of the past has increased over time, even enhancing the value of the landscape.
The architectural qualities of these assets make them testimonies of past theoretical knowledge and construction skills; the natural obsolescence threatens this key heritage due to neglect and lack of maintenance in the case of disused bridges. Therefore, a remarkable number of bridges have collapsed or failed worldwide over the past years. The stability and safety of still–in–use masonry bridges must be guaranteed, avoiding over–dimensioned intervention and, in the worst–case scenarios, demolition and reconstruction.
Hence the need for a strategy of expeditious health monitoring of masonry arch bridges, aimed at containing the potential damages caused by seismic, hydrogeological, and other vulnerability assessments. It is crucial to develop effective and integrated procedures to characterize the structural conditions, identify and prevent potential vulnerabilities of such historic assets studying their geometric configurations, construction techniques, and documentary heritage. In this direction the current Italian guides for risk classification and management, safety assessment and monitoring of existing bridges give pivotal suggestions.
H–BIM approach could be the starting point for management, conservation, and maintenance of these historical assets, as it gathers all present and past information on the artefact. Besides that, H–BIM could be used throughout the life cycle of a bridge, as a management supporting tool constantly updated. The knowledge base of such an information model is the point cloud, acquired with different methodologies depending on the characteristics of the case study.
Despite the tremendous advantages of this technology, one of the principal limitations is the time and training required to manually process the huge quantity of data that point clouds contain. In this regard, Artificial Intelligence (AI) techniques and semantic web could really help in the process. For example, ontologies could serve in helping neural networks in semi–automatic point cloud segmentation or adding semantic layers to H–BIM models. Also, the bridge's state of health is commonly assessed by visual inspection, and this is a time consuming, expensive, and laborious procedure.
Computer vision with Deep Learning (DL) techniques can support professional users in damage detection and classification. However, AI methods, based on the DL paradigm, require a significant amount of annotated data that, in this context, it is often impossible to collect. To make up for this issue it is possible to exploit data augmenting techniques to create synthetic data to enrich the dataset, through an approach based on Generative Adversarial Networks (GANs).
In this regard, this manuscript aims at proposing a new methodological approach to define image–based and AI–driven survey protocols useful for the creation of semi–automated H–BIM models for health assessment of masonry railway bridges.
To support the research purposes, the chosen case studies are the masonry bridges of Circumetnea, a still–in–service railway that almost encircles the Etna Volcano, passing through several towns in Etna's foothills.

State of Art

Automating the point cloud–to–Bridge Information Models (BIM) process can significantly reduce the effort and cost in masonry bridge inspections and management.
Recently, Zhao and Vela [2019] provides a pipeline for simple concrete bridges scan–to–BIM, integrating several procedures related to segmentation, surface model estimation, and classification of surface regions. Also Xu and Turkan [2019] underlines the need to identify productive approaches to inspect and manage bridges, proposing a framework that integrates BIM and Unmanned Aerial System Services (UASs) technologies. In León–Robles et al. [2019], historical–archival research and digital survey are used as a database to create a Historical (H)BIM.

The automatic or semi–automatic point cloud segmentation can considerably support information modelling. Kim et al. [2020] present a methodology for the automated concrete bridge component recognition using deep learning, while Truong–Hong and Lindenbergh [2021] introduce an approach to automatically extract the point cloud of each surface of structural components of a slab bridge. The researchers are showing an increasing interest in an effective pipeline for masonry bridges as well. In Riveiro et al. [2016], a method for the automatic segmentation of historic masonry bridges was achieved based on the combination of a heuristic approach and image processing tools adapted to voxel structures. Using these results, a methodology to automatically transform classified point clouds into IFC models for further applications is proposed by Sánchez Rodríguez et al. [2020].
Given this, a BIM approach supported by automatic and semi–automatic point cloud segmentation can help protect, managing, and enhancing historically rich assets, such as masonry arch bridges [Savini et al. 2021].

Methodology

The methodology proposed is structured as it follows:
Cognitive phase, aimed at knowing and documenting the case studies, was developed according to the following steps:

- Documentary research – it allows the understanding of the design idea and provides important indications on the artefact, especially regarding the geometric configuration and the relationship with the pre–existing structures at the time of construction;
- Integrated digital survey campaigns – it is aimed at acquiring the geometrical and material configuration of the bridges and is carried out by using TLS, SFM photogrammetry and the experimentation and validation of videogrammetry techniques;
- Census – it brings together all the information acquired during the cognitive phase in a geographical information system, allowing to understand the bridges analysed relation with the entire railway and the territory.

Semantic phase, aimed at designing a masonry arched bridge computational ontology that will be used as a knowledge–base for deep neural network training, needed of:

- Conceptualisation – it provides an in–depth survey of existing vocabularies and taxonomies. Then, identifying relationships and hierarchies between parts to choose the proper classes, subclasses, and property of the developing ontology is required. To do this it is crucial to conduct in–depth research into technical manuals and treatises, as it is analysing several case studies and their typologies, as reported in.
- Comparison of existing ontologies – it is useful to understand whether it is better to link to something existing or create a new ontology.
- Ontology development – for which a particular attention is given to the level of granularity, if it is as an extension from existing standards. Some levels of information to be added, for instance, are related to the semantic structure, construction techniques, and typical defects.
- Test phase – in which the developed ontology is used for training a deep neural network. In doing this, an attempt is made to understand if the chosen ontology standard fits well with the research purposes.

Artificial intelligence (AI) approach, which aims to train a neural network for point cloud segmentation and visual–based defect detection, both on the numerical models and images.

- Creation of a two–level GAN – it is composed by a first GAN that generates isolated objects corresponding to each ontology concept, and a second one that combines the generated objects according to the spatial information provided by the ontology, to generate realistic scenes. To create a synthetic dataset, it is necessary to start from real images. For this reason, a massive acquisition of pictures of the same typology as the case study is necessary.
- Training of the DNN with real and previously mentioned synthetic datasets
- Testing phase on existing bridges point clouds

Information Modelling phase, aimed at creating parametric components, starting from the segmented point clouds.

First Results

The case study chosen for the proposed experimentation is the Circumetnea railway masonry arch bridges. Built between 1889 and 1895, the Circumetnea is a regional narrow–gauge railway that connects Catania to Riposto, almost encircling the volcano Etna and passing through several towns in the foothills of Etna. The heterogeneity of the typologies (number of arches, materials, geometry) and the recurrence of the types, which include many instances, made them the ideal case study for this research. Finally, it is a heritage at risk, because some of the bridges have recently been demolished because of changes in traffic requirements.

Cognitive phase – The first step in the cognitive phase was an in–depth documentary research carried out at the State Archive of Catania, which holds 192 folders of original drawings and documents dated back to the timing of construction of Circumetnea. Plans and longitudinal profiles of the rail route, together with bridge projects and metric computations, were acquired digitally. This documentation allows the investigation of unknown construction and technological features, such as foundation typologies, and a better understanding of the reasons and the developments of the project. The documentary research was coupled with the digital survey campaign. The integration of several surveying methodologies, such as laser scanning, photogrammetry (ground and drone–assisted) and videogrammetry, was required due to the peculiarities of the analysis. A total of 37 bridges were identified along the route under investigation. Only 13 of these were accessible. 18 of them were photographed and only 11 were surveyed, using the above mentioned techniques (fig. 1). The census was conducted concomitantly with the previous two stages. The bridges were first detected using Google Earth and then loaded into QGIS, in order to produce a grid of attributes organised according to the position (latitude and longitude), number of arches, building materials, archival documentation and survey operations that were carried out.

Fig. 1. The result of the survey campain for a three–arch bridge in the municipality of Mascali (CT). The instruments used are: a NIKON D5300 (photogrammetry), Leica BLK360 (TLS), DJI MAVIC 2 PRO (UAV photogrammetry).

Semantic phase – The creation of a specific masonry bridge ontology started with the conceptualization phase. At the first stage, a multifaceted bottom–up analysis of the elements constituting this architectural typology, referring to well–defined thesauri and taxonomies, such as the AAT (Getty Research Institute) was conducted.

The actual conceptualization phase then began, based on the comprehensive text [Torre 2003], which helped in the semantic organisation. The element composing bridges are included in Physical Object, that could have Physical Property, such as materials, shape, and defects. Classes, as well as materials and shape, were obtained consulting manuals and historical documentation and through the case study observation. For defects, some inspection sheets previously produced for the Circumetnea under an agreement with our Department were consulted (fig. 2). Here, it moved to the comparison among existing ontologies; the analysis was conducted on CIDOC, ISO 21127 standard, which is the fundamental ontology for the management of cultural heritage information, and on IFC, ISO 16739 standard, open format for the management of interoperability.

To the author knowledge, there are currently no CIDOC extensions on masonry bridges. It is, therefore, interesting to explore the opportunities on such a diverse asset, which require a multidisciplinary approach for the safeguard of our cultural heritage. Nevertheless, the IFC–bridge is currently a project under development; also, using a single standard ontology as IFC to manage the semantic of built heritage in multiple applications could be an exciting challenge that simplifies information management and potentially bridging the gap between digital surveying, information modelling, and AI applications.

In the light of this, it was decided to extend the 'IFC bridge', acting on its granularity.

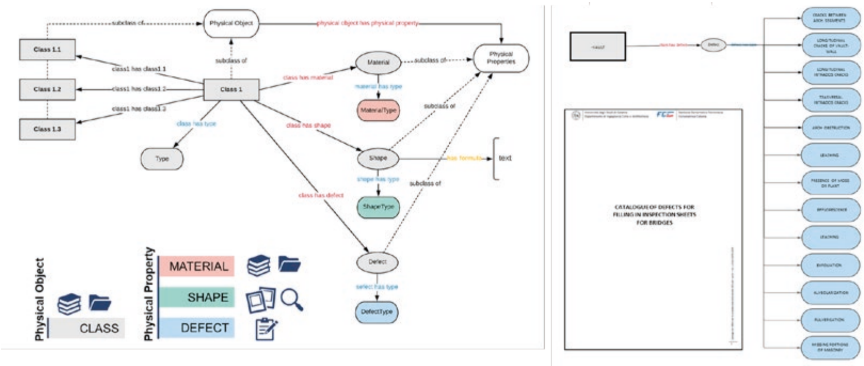

Fig. 2. The conceptualization schema (on the left); the detail of the defects developed part (on the right).

AI approach – At this early stage of the research, the necessary material for the creation of the synthetic dataset was acquired. A masonry arch bridge dataset was collected by the web, consisting of 10.446 images of 3.000 masonry arch bridges.
These data were built using a web scraping technique on Structurae.net, an international database and gallery of structures. Data collection was a key point in the training process, as a poorly built dataset could lead to bad performances or prevent the GAN model from learning. After images were scraped it took several days of manual data cleaning, erasing bad quality images, to obtain the final dataset used for the training. Images of aqueducts, drawings and plans, images with altered colouring, images that did not represent significant elements of bridges (such as statues and, more generally, decorative elements) were removed from the dataset. The images left after cleaning operations is a total of 7434 images.

Conclusions and Future Development

The results obtained at this stage of the research are encouraging, the conceptual formalization of the ontology added a new layer of knowledge to this valuable heritage. The experimentation will continue focusing on the integration of the ontology and, consequently, on the creation of the synthetic dataset and the segmentation of the point clouds. With regard to parametric modelling, an in–depth investigation will be carried out to identify a good pipeline to maintain a strong model fit with parameterisation of its components.

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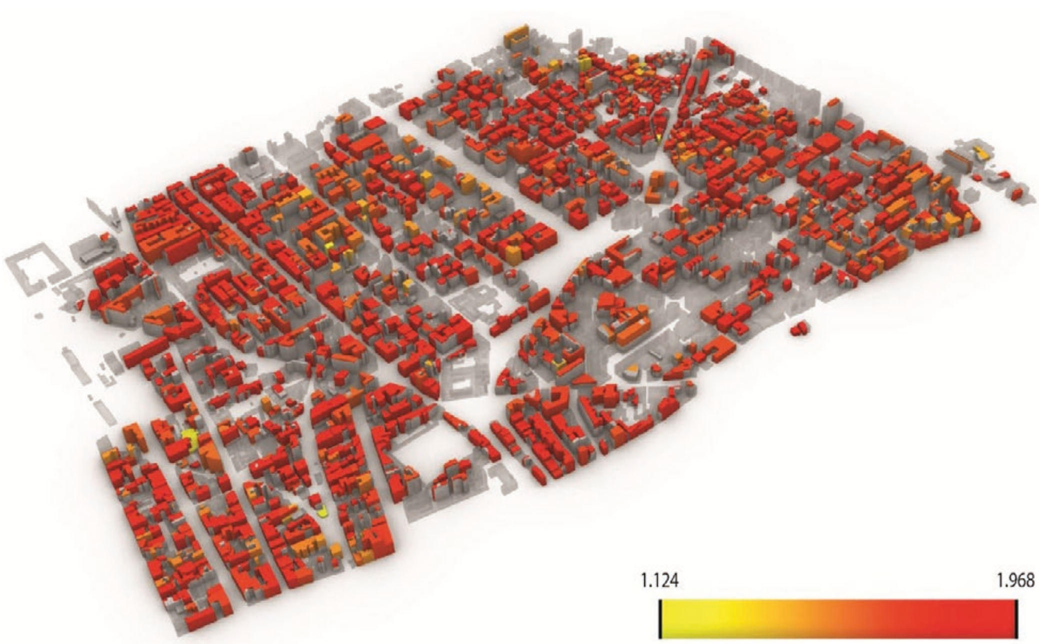
AI for AEC: Open Data and VPL Approach for Urban Seismic Vulnerability

Federico Mario La Russa

Abstract

This contribution provides an overview of the VPL evolution and an application case concerning the classification of seismic vulnerability indices with AI. This research aims to contribute to the scientific debate on the use of these technologies in architecture, deepening the themes of seismic assessment on urban and territorial scale. The whole experimentation was conducted using only the potential of Grasshopper's VPL and possessing, as basic knowledge, the main concepts of machine learning and supervised learning. The VPL is therefore an effective tool to introduce and disseminate the topics and applications of artificial intelligence within the AEC sector, effectively decreasing the gap between domain experts and programmers.

Keywords
open data, VPL, AI, seismic assessment, CIM – city information modeling.



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Introduction

Over the past few decades, the human–machine relationship has progressed significantly due to the evolution and deployment of increasingly advanced technologies. Among all of them, Artificial Intelligence (AI) has become prevalent in several application fields, including Architecture and Construction (AEC) industry. One of the main objectives in the AEC sector is to develop semi–automated solutions and workflows that can minimize repetitive and time–consuming activities, thus allowing professionals to focus on more valuable and relevant tasks. In this direction, progress had already been made through the widespread adoption of Building Information Modeling (architectural scale) and City Information Modeling (urban and territorial scale). These digital ecosystems usually do not natively possess tools and/or interfaces that allow professionals to apply AI to their models. Thus there are few applications in the field and mainly developed in the academic world where it is easier (for a generic domain expert) to develop computational skills and interface with other programmers. The gap between 'designer' and 'programmer' has been reduced with the introduction of Visual Program Languages (VPLs) within modeling software to develop computational codes. Their ease of use lies in their visual nature and in a vocabulary of 'components' where the main grammatical rule consists in the relationship between input and output.
The research aims to investigate what role Artificial Intelligence can play in the urban survey and City Information Modeling for the mapping of seismic vulnerability. For this purpose, the following research questions have been defined:

- Is it possible through a VPL to determine the relationship that links characteristics of building units with their corresponding seismic vulnerability?
- What are the limitations and potential in using a VPL like Grasshopper (GH) for Artificial Intelligence applications?

VPL Evolution and Impact in AEC Industry: History and Reflections

In the 1980s, there was a great diffusion of personal computers, but the average user did not have programming knowledge and this limited the impact of these technologies in different sectors. Programmers tried to improve the user interface but not always the efforts in this direction were successful. This condition led to researches aimed at using graphics to facilitate programming skills, leading to the birth of Visual Programming (VP) [Halbert 1984]. By eliminating syntax, the graphical method focused on workflow, making visual programming an efficient tool even for skilled programmers. The friendliness of this method was also demonstrated by cognitive psychology, as the human brain can process visual information using two hemispheres instead of one as in other cognitive processes [Myers 1986]. In accordance with Brad Myers, VPL can be defined as a "system that allows the user to specify a program in a two (or more) dimensional fashion. Conventional textual languages are not considered two dimensional since the compiler or interpreter processes it as a long, one–dimensional stream" [Myers 1986]. The first VPLs for geometry modeling purposes can be found in the late 80's: Prismis (nowadays known as Houdini) and ConMan [Haeberli 1988]. In the 2000s there was a new success of parametric design with a subsequent spread of programming tools (ex. GH, Dynamo, Marionette) for design purposes. The applications went far beyond that, as the new VPLs allowed the management of entire workflows (and data). VPLs for architecture began to be recognised as programming languages capable of facilitating operations that designers, engineers and architects used to carry out manually [Rutten 2012]. Together with the BIM revolution, these topics started to be included in the training of young architects [Boeykens et al. 2009].
Compared to traditional programming, visual programming has a very favourable learning curve in the short term. However, for more complex processes, VPLs are limited because they cannot keep up with traditional programming in the long term [Zwierzycki 2017].
Thanks to the community behind VPLs such as GH, it is possible to use a series of plug–ins that increase the potential of VPLs compared to their default setup. However, there is still a gap in the long term, even if it is smaller than the previous one. In recent years, there has been an increasing amount of applications in AEC regarding the use of artificial intelligence. A variety of plug–ins have been created that allow the transition to these new practices

within VPLs by reducing the knowledge required to apply them. These plug–ins enable the user to use Machine Learning and Deep Learning tools, enabling increasingly complex data processing practices. Applications range from design to optimisation in production processes. Although in some applications there is no need for textual programming implementations, VPL shows limitations in the long term.

Urban Seismic Risk Assessment: the Italian Methods

In relation to seismic vulnerability assessment at the urban scale, three majors schools of thought have been identified that aim to combine expeditious surveying with accuracy in assessment. These methods differ mainly in the type of data required and the accuracy of the analysis. In particular, there is an inversely proportional relationship between analysis extension and accuracy assessment (the more accurate the assessment, the closer to the architectural scale). Statistical evaluations focus on the determination of vulnerability with reference to different main characteristics of the buildings in order to analyse their distribution over the territory. Other analyses follow a mechanistic procedure where the structural behaviour is studied by simulating seismic actions on the building unit. As regards holistic analysis, it generally begins with an investigation of the urban growth of the fabric in which the building under analysis is located, then it recognises the construction components, maps the decays and analyses instabilities [Corradi et al. 2014; Caliò et al. 2018].

Methods and Workflow

Starting from existing studies on seismic vulnerability, the objective is to classify, through Artificial Intelligence mechanisms, the vulnerability of single building units using a few parameters easily obtainable from qualitative visual surveys. This approach is based on the assumption that each building unit is a living organism with its own genetic code made by all its parameters. In literature we find similar approaches at the architectural scale of BIM models [Tono 2018]. Therefore, it is essential to use programming tools that allow sufficient data granularity for their treatment from the territorial to the architectural scale and the use of Artificial Intelligence tools. The use of VPL based on CAD environment allows to easily interrogate the geometries obtained from the initial data, as well as to visualize the results of the analyses through thematic three–dimensional maps. In the specific case of seismic vulnerability at urban scale, the use of VPL as modelling and analysis tool facilitates the AEC sector professionals in the design phase thanks to the available plug–ins.

The research presents a workflow, developed with only the tools of visual programming (GH), to train a neural network using a dataset of seismic evaluations at the urban scale (statistical method). This approach belongs to supervised learning methods. In particular, a simple validation will be performed by means of a linear regression with several variables that identifies the relationship between indices and vulnerability values thus allowing the prediction of vulnerability in other urban blocks. The workflow can be summarised as follows:

- Downloading and importing the initial dataset;
- Data processing according to the Simple Validation scheme;
- Neural network training using the 'Dodo' plug–in;
- Model validation (coefficient of determination R2);
- Representation of the obtained predictions.

Case Study: the Historical Center of Palermo

To validate the proposed methodology, a dataset with the necessary characteristics was identified. The dataset comes from an open data work developed by the PalermoHub mappers community [1]. In this work, a seismic vulnerability analysis based on statistical methods was made for more than 1500 building units in two areas of the historical centre of Palermo. The whole dataset was created exclusively on open data available online from different institutions such as ISTAT and the Municipality of Palermo [Vitrano 2017].

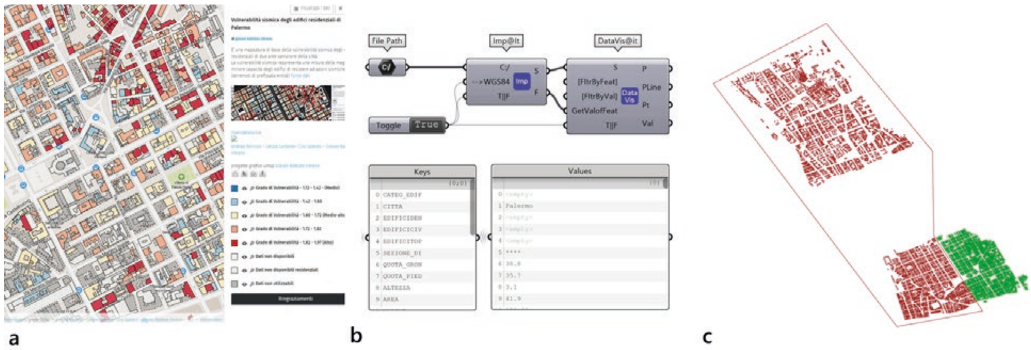

Fig. 1.
a) Initial dataset (webgis) of Palermo historical center;
b) VPL code to import geodata inside Grasshopper;
c) Training dataset (in red) and test dataset (in green).

The dataset is made of indices related to the period of construction, number of floors, construction material, state of preservation and the vulnerability of the building units.
The file (available for online viewing) was downloaded as geojson and converted to a shapefile using QGIS. The conversion into a shapefile enabled the import into GH via the 'at–it' plug–in. A code was then developed with the aim to filter the indices and vulnerabilities of each individual building unit contained in the input shapefile.
In the field of supervised learning, the method of the simple validation requires that the dataset is divided into two parts. The dataset destined to the training of the system usually constitutes 70-90%, the remaining part (30-10%) is destined to validate the training of the model of machine learning. In this case, the part assigned to training is 71.3% (DS1), the part assigned to validation (testing) is 28.7% (DS2). Within these two subsets, a filter was developed (via VPL) to separate the indices of building unit characteristics from the corresponding seismic vulnerabilities (fig. 1).
The open source Dodo plug–in [1] was used to train the neural network. Dodo allows to specify some significant parameters regarding the training process. In particular, the component 'Supervised Training NN' was used for the training of the neural network (it represents the phase of supervised learning). As input, the indices and the relative vulnerabilities of each building unit within the DS1 were given. The output was the neural network structure trained to identify the relationship between indices and vulnerabilities. Then 'Run Neural Network' component was launched giving as input the trained neural network and DS2 indices (test) to predict the vulnerability of DS2 building units.

Results and Discussion

The results of the predictions were used to create a representation of the buildings of the tested set DS2 (in blue) in comparison with the initial values (in grey) (fig. 1). Visual analysis of this 3D map suggested that the neural network identified the relationship between indices and vulnerability. An analytical verification was then made using the coefficient of determination (both standard and reduced) which confirmed this result, returning a value of 0.99 out 1.00. By graphically analysing data distribution, the neural networks managed to fit the test data almost perfectly (fig. 2).
However, the high values linked to the coefficient of determination are probably due to the statistical relationship between indices and vulnerability. The most significant limitations that have emerged from this experience are the 'black boxes' aspects of the component, and the absence of existing statistics that allow simple and effective comparison with other machine learning tools. Some potentialities emerged during this experimentation, such as the ease in implementing simple experiences and the usefulness of VPL as a learning medium for the main concepts linked to artificial intelligence towards the use of more robust frameworks (as Tensorflow and PyTorch). It is therefore possible to consider GH as a digital carnet where a domain expert in the field of drawing and surveying can sketch a prototype AI model to identify the problem. Once this is done, the model can be implemented working with AI experts or by the domain expert himself after a learning and training phase.

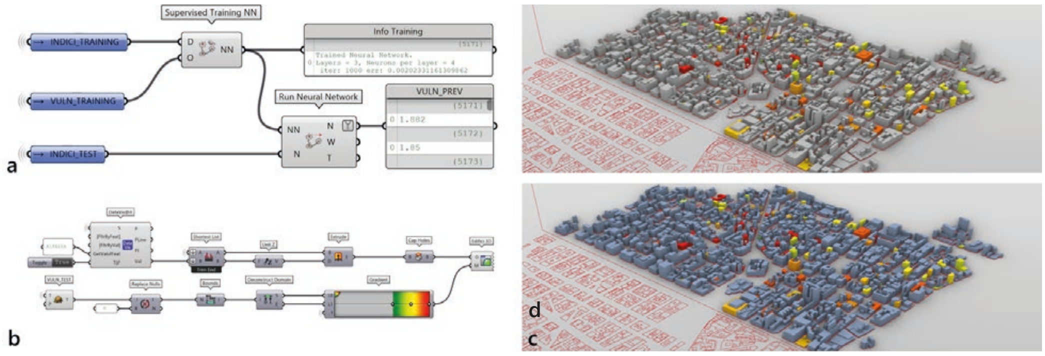

Fig. 2.
a) Training of the neural network with Dodo components;
b) VPL code to display prediction results;
Comparison of predicted (in blue) (c) vulnerability values and actual ones (in grey) (d).

Conclusions

There are still some open questions that constitute the next steps of the research. In particular, how to link the information produced in urban surveys to the classification of building types, how to predict the internal distribution pattern of building units using spatial syntax analysis (since it is not possible in many cases to access the interior spaces). Furthermore, from an economic point of view it is possible to envision a model that can support the prediction of the cost of seismic retrofit and/or demolition interventions.

Notes

[1] http://palermohub.opendatasicilia.it/ (15th February 2021).

[2] Dodo is a plug–in for Grasshopper developed by Lorenzo Greco. It is available on the online portal 'Food4Rhino' since 23/11/2015. Last version: 23/02/2019. Link: https://www.food4rhino.com/app/dodo (15th February 2021).

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V.A.I. Reality. A Holistic Approach for Industrial Heritage Enhancement

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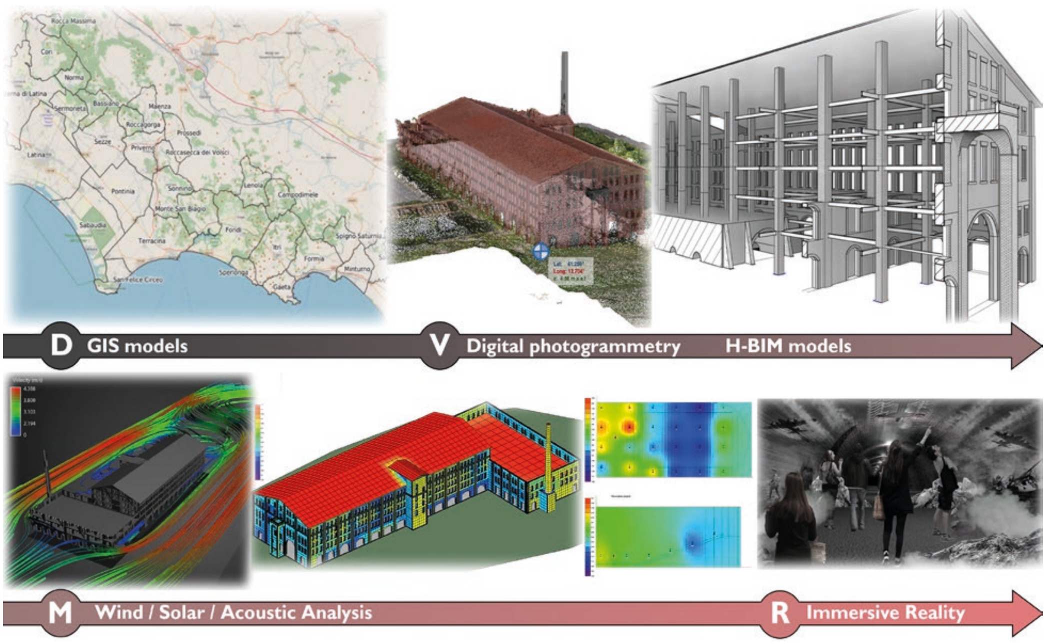
Abstract

The post–industrial heritage, characterized by heterogeneous, tangible and intangible factors, requires digital tools and a holistic approach to undertake the most appropriate enhancement process. Current virtual realities (Vr, Ar, Ir) allow the modeling of physical environments and the management and virtualization of a large and varied amount of data, thus helping to better understand the complexity of the real phenomenon. The paper proposes a method, named D.V.M.R. (acronym for Design, Virtualization, Modeling, Reproduction), which in four temporally consequential phases builds a tool capable of providing territorial, environmental, architectural and historical information of a case study. The method was applied for the design of a reuse of the brick factory, known as ex Sieci and located in Scauri in southern Lazio, owned by the Municipality of Minturno. The factory, which looks like a majestic cathedral on the sea, had in the past and still has a significant centrality in the social life of the local inhabitants.

Keywords
virtual realities, holistic approach, H–BIM, smart–service.



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Introduction

The European Union is increasingly convinced that cultural heritage can stimulate the sustainable development of nations in terms of liveability of the environment, social cohesion, well–being, creativity and employment . This statement is even more significant in the case of post–industrial heritage, characterized by factories, chimneys and clusters of volumes necessary for industrial production, which has shaped the skyline of many cities and marked the culture of many communities. In the past, factories have attracted families and created a modus vivendi, made up of social and religious sharing, customs and traditions, generating their own genius loci. In the industrial landscape, the factory is the most important landmark, the visual and symbolic attraction of the recognizability of a community and therefore of belonging to the place. Today, however, the material and intangible cultural heritage of disused industries, consisting of both architecture but also religious and secular traditions, idioms, anecdotes still alive in the population, appears shaped by architectural skeletons that usually occupy vast urban and peri–urban areas. Sometimes these sites are highly polluting, negatively impacting the environmental sustainability indices (ESI). The current situation requires a very complex process of enhancing disused industries which must be based on urban redevelopment interventions capable of restoring both the tangible historical value, in terms of architecture, but above all the cultural, social and economic value of post industrialized communities. Today, digital technologies are of great help to this end, due to their ability in modeling cultural heritage as a complex digital asset ensuring its understanding, consultation from different points of view and to the stakeholders.
Furthermore, the combination of virtual reality (VR), augmented (AR) and immersive (IR) based on a holistic approach is the most suitable procedure for enhancing brownfields. In fact, on the one hand, virtual technologies help paradigmatically in the reading and interpretation of heterogeneous territorial and historical data, the state of conservation and

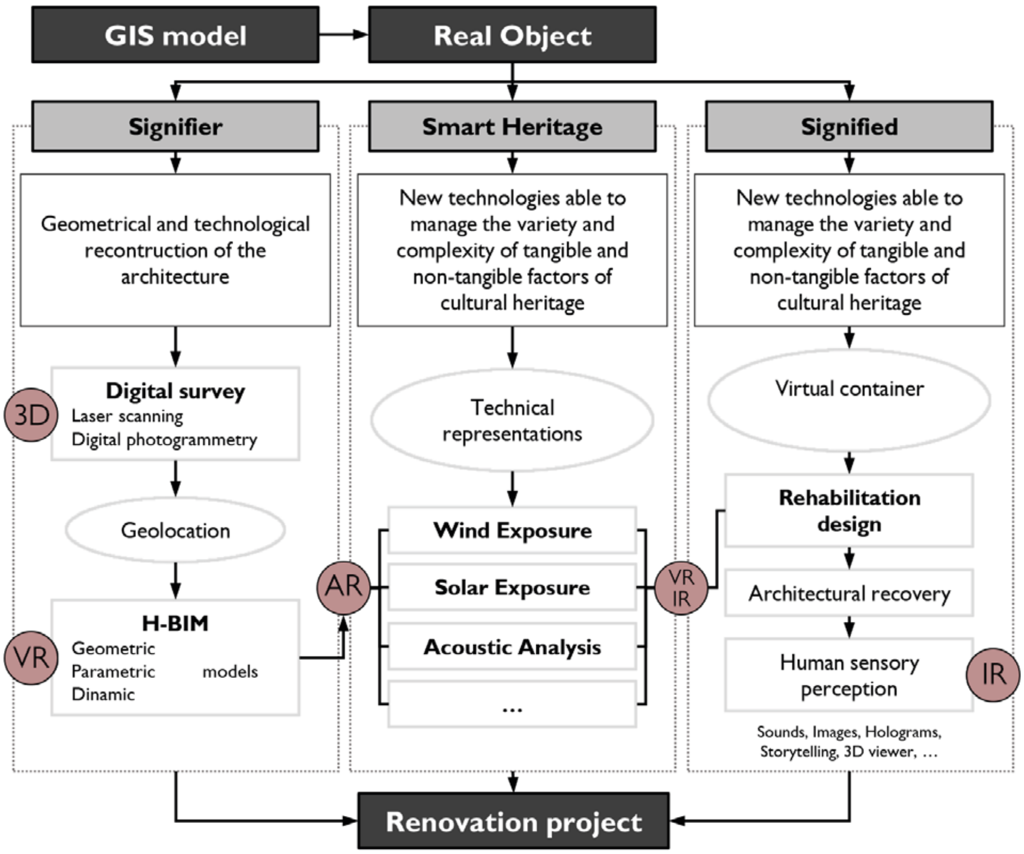

Fig. 1. Holistic Approach for Industrial Heritage Enhancement Workflow.

usability of the material and immaterial value of the asset. On the other hand, the holistic approach allows to have a complete overview of the phenomenon. This paper applies the new graphic language, based on the use of the informative, interactive and immersive digital model, defined as an 'smart model', combined with a holistic approach in the acquisition and management of heterogeneous data with the aim of defining the best practice in the enhancement of abandoned industrial places. To this end, the brick factory, called ex Sieci and located on the seafront of Scauri (southern Latium), was chosen as a case study.

D.V.M.R. Method: the Holistic Approach in VR–AR–IR Modelling of Cultural Heritage

Since their origins, factories have developed their own inherently holistic graphic language. The design of the factories, in fact, required the representation of both the 'architecture of space', in terms of the permanence of man and his needs, and the 'architectural space', responsible for housing the machines and their functional systems. Today as yesterday, the reuse of abandoned industrial sites, which sometimes cover several hectares of urban surface, need a new graphic language capable of visualizing, or rather virtualizing, the dimensionality and multiplicity of sites markers such as the territorial, historical and architectural factors. Nowadays virtual modeling, understood as VR, AR, IR, can dynamically and interactively manage large and heterogeneous datasets that are the informative, parametric and interactive structure of smart models. Such a complex data structure, ranging from spatial data to the smallest technological detail of the factory, must obviously also deal with the management of the relationship between each component and the functional sum of all the parts, thus following a holistic approach. In this perspective, the method proposed in the paper is able to virtualize the real object (referent) and the complex dataset associated with it, according to a holistic approach (fig. 1). The method has four temporally consequential steps, described below:

1. The Design (D) of a geographical information model, GIS, which returns the environmental and territorial context of the site under study as well as the consistency of the phenomenon of abandoned industrial sites (polluting/non–polluting, recovered/abandoned, public/private, etc.).
2. The Virtualization (V) (signifier) of the real object (referent), obtained thanks to 3D digital surveys (laser scanning and digital photogrammetry). The point clouds exported thanks to geolocation in parametric software (H–BIM), become the semantic structures of the informative models. In fact numerical, material, technological and historical data are associated with each graphic object, according to the most appropriate ontological model.
3. The Modelling (M) of intangible environmental phenomena (smart service). Thanks to IFC technology, the H–BIM model can be exported to other software capable of simulating for example the wind and solar exposure or acoustic analysis.
4. The Reproduction (R) of the intangible cultural value of the site (signified). H–BIM is a fundamental support for the immersive reality model because it is the box in which complete sensory experiences materialize through the reproduction of sounds, holograms, etc., thus helping people to be more aware of the cultural value of the site. IR also plays a key role in the decision–making process related to a post–industrial site rehabilitation project.

The D.V.M.R. uses GIS and BIM as VR models as they produce realistic 3D models within which it is possible to virtually navigate thus aiding the analysis of the entire real phenomenon. Furthermore, in DVMR, the VR models (GIS and BIM) become physical prototypes to be used in software for simulation and calculation of immaterial environmental phenomena, which for this reason can be defined as Augmented Reality (AR). This type of simulation is particularly important for analyzing and evaluating degradation phenomena on the facades of historic buildings and the design of functionality, through new and more suitable destinations in use. Similarly, in DVMR the VR models (H–BIM), are the box within which the immersive reality (IR), which ranges from entertainment, education, promotion and accessibility for people with disabilities, helps the perception of the intangible value of the asset. The D.V.M.R described above was applied in the enhancement process of an important abandoned industrial site in southern Lazio.

Case Study: Abandoned Brick Factory in Scauri

The brick factory, called ex Seci, located in Scauri in southern Lazio, was born on a small pre–existing industrial settlement, as a branch of the Albizi furnace in Remole di Pontessieve (Florence) located on the Sieci stream from which it takes its name. The factory is part of a very delicate landscape both for its natural features and the numerous archaeological and historical evidence present in the area. The main elements are the coast called 'Riviera di Ulisse', the archaeological area of the ancient Roman town called Minturnae, the Via Appia and the mouth of the river Liri (Garigliano) on the border between Lazio and Campania Felix. The plant covered an area of 5 hectares with about 50,000 cubic meters of buildings and was connected to the sea by a destroyed wooden walkway, which facilitated the loading and unloading of products, marketed by sea. The main body of the factory, one of the few remaining, is spread over three floors above ground and rests on a base defined by a series of round arches. The building has a clear neoclassical style characterized by empty/solid rhythmic sequences, further marked by a series of pilasters which define regular modules and shape all the facades. Each floor has, between the piasters, three openings (windows) separated from each other by masonry completely covered in brick. On the ground floor there are two Hoffman ovens, still well preserved, which almost entirely occupy the longitudinal layout of the factory. In the external space, some further smaller volumes complete the area together with the chimney still in fair condition today. The construction system is in load–bearing masonry and the building is entirely made of bricks to enhance the product for which the factory was born. Over the centuries, due to the bombings of the Second World War and the reduction in production, many volumes have been destroyed. Currently, in the eyes of ordinary people, the factory looks like a 'cathedral on the sea'. The centrality of the factory in the social life of Scauri is preserved by the locals who still today occupy the square in front with a weekly market, thus guaranteeing, albeit weak, a 'form of life'. The factory is currently owned by the Municipality of Minturno.

Application. Scan to BIM, Smart Cultural Heritage Services and Visitor Experience

The reuse project of the brick factory has required the application of the DVMR.
In the first phase, the Design (D) of the geographic information system through QGis was fundamental to analyze and understand the territorial context of the site. The GIS, in accordance with the ontological structure of the ISO/TC211 standards, collected data on three different territorial levels: a) the landscape, with the indication of the vulnerability and consistency of the industrial sites already existing in the territory (in terms of pollution, dimension, renovation, disuse, etc.); b) urban planning, with particular attention to the regulatory but also socio–economic aspects; c) area of the case study, getting of general, dimensional, technological, historical data, etc.
Scan to BIM: Virtual Reality (VR) for the definition of a geometric/parametric model: The Virtualization (V), in the second phase, performs the procedure known as SCAN to BIM. The size and internal spatial distribution of the plant suggested the use of a digital photogrammetric survey from a drone (returned with the DroneBase X1000 Mapper con fotocamera Sony Alpha ILCE –6000 16mmf/7.1, by double swipe flight plan at a height of 40 m from the ground) to reproduce the external volume and a laser scan survey (returned with Leika BLK 360 by the scans alignment of a specially designed grid) for the interior. Thanks to the laser scanner survey, the superfetations, the structural consistency and the state of decay of the finishes and structural parts were analyzed. Furthermore, through georeferencing, point clouds can be imported into an H–BIM system and the virtual reality model has been built according to the ontological structure of the UNI–11337–2017 standards (LOD, LOG and LOI). The virtual model of the factory 'Ex Sieci' is characterized by Lod 400/AS BUILT.
Smart heritage services for environmental analysis: Modeling (M) of natural phenomena in virtual environments, in the third phase, is an example of AR technologies. The HBIM parametric model exported, thanks to IFC technology, in a computational fluid dynamics software allows a multi–criteria analysis capable of evaluating the effects of wind on the facades of buildings. The

model can be imported, in fact, into a virtual wind tunnel, where the average wind direction and intensity are taken from the Annals, and the wind impact on the facades can be virtualized with sized voxels. In addition, taking advantage by geolocation, H–BIM performs energy analyses and shows the impact of solar radiation on the facades of buildings during the day. The visualization with false–colour of sunlight on the building walls highlights the surfaces with the greatest exposure to the sun, providing a significant indication in energy efficiency measures. Similarly, it is possible to virtualize in H–BIM the execution of different acoustic analysis scenarios, which are of great help in a re–functionalization process. Environmental analysis through Augmented Reality is a very helpful smart heritage service.
Immersive reality (IR) for the intangible cultural heritage: The last phase involves the use of H–BIM in the enhancing immaterial value of the place. The design of the ri–function of Hoffmann ovens, very complicated to manage, has combined the IR in two different approaches. One gate of the oven, with interactive screens, holograms and sounds, which recall the seascape in which the factory is located, aims to attract the interest of children to the natural landscape that surrounds the factory; the second gate, narrating the historical events that characterized the factory and the surrounding area during the Second World War, intended to attract the interest of adults.

Conclusion

The post–industrial heritage, which has marked the cultural and social life of many communities, today requires an impressive process of enhancement that must analyze all the different factors that come into play with a holistic approach. To this end, it is important to define a method that, on the basis of the potential of new technologies, is able to virtualise both the material and immaterial aspects. The method proposed with the abbreviation DVMR was conceived for this purpose and tested on a real case study, the brick factory located in Scauri. This first application, which required the acquisition and processing of many data, both territorial and historical–artistic, will be implemented with additional technologies, 3D viewers, with the aim of improving the sensitive perception in the enhancement of the intangible cultural value of the site.

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AR&AI education and shape representation

Visual Languages: On–Board Communication as a Perception of Customercaring

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Abstract

The year 2020 should have been one of confirmation of the continuous growth in the "cruise tourism sector": new ships for delivery, new constructions, and the design trend of the gigantism of these means of transport. If, at first, ensuring a correct perception of orientation on board these new ships were a complex challenge and not yet fully resolved, today with the outcomes of the Covid pandemic it appears even more and more complex.
The logistical communication of the past now seems to be no longer sufficient: the collapse of cruise bookings has introduced serious problems in the sector which must not only rethink new models of internal organization on board, but also reconsider how to regain the trust of potential passengers, frightened at the idea of getting on a ship.
This research introduces some reflections and proposals shared with industry operators and aimed at the reformulation of approaches and languages in order to bring potential customers closer to the Cruise Experience.

Keywords
visual communication, multimedia approaches, complex structures, cruise transport.

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May 2020: harbour cities change their perceptive profiles, transforming the usual view of the harbours of large cruise ships into a visual void, replaced by the silhouettes of the giants of navigation at anchor outside the port, as if they were ghosts in memory of a remote era. Venice is experiencing a return to the past, the waters of the lagoon become clear again and the perspective of the Grand Canal is finally free from the closures caused by the transits of "oversized" ships, to which this wonderful town resigned itself.
The pandemic makes evident the disproportions and overruns of the limit, the sizes of the cruise giants now appear in all their excesses, as does the crowd pouring into the collective spaces, that cause a real inevitable gathering; some cases of infections on board accelerate a process of disruption of the system, visualized and amplified by the media, which transmit images of health emergencies.
September 2020: Summer gives the illusion of an end to the pandemic and a consequent possible recovery of the cruise sector, which timidly reappears with advertising campaigns all aimed at reassuring potential users, through alignment with the restrictive anti–Covid measures.
Even if it has been a false hope and the resumption of the spread of the virus has blocked at the beginning the revival of the economic induced by sea travel, however the story has highlighted the substantial obsolescence of the communication systems that on board welcome and support passengers: panels and paper brochures, voice information and electronic touch screen devices, that is the combination of screen and digitizer, in order to allow the user to interact through the simple and immediate use of their fingers.
If for the analog component the potential and limits relating to application areas and reference targets are now clear and consolidated, the reasoning for touch screen instruments, until recently considered a definitely positive model of effectiveness, efficiency and balance of the cost–benefits ratio is different.
What intervened, on the contrary, to undermine this certainty? Simply the awareness of the health risk that occurs whenever several people touch the same surfaces with their bare hands: Sars–Cov–2 virus, in fact, can be also transmitted through the contamination of unwashed and / or disinfected hands.
Here, therefore, that the search for alternative forms of communication develops from a hygienic–sanitary emergency situation and the occasion of the crisis in the cruise sector represents an opportunity to experiment and mutate the techniques already in use in other cultural and geographical areas; not only but, it also represents an opportunity to update the contents, starting from the concept of customer–caring.
It could be said that the new frontier is given by the awareness that it is not a problem of solving a specific question that is different from time to time and not systematizable, but of undertaking a path to assure and protect the well–being understood in a global sense of those who use the cruise travel system; this proactive attitude translates into the formulation of a methodology of general value, which aims to draw up guidelines in compliance with certain assumptions, which are essentially the following ones:
• To convey a sense of attention to the passenger at 360°;
• Not to limit to signal attention to the Covid emergency;
• To promote the full knowledge of the medium;
• To promote a full knowledge of all its functional values;
• To incorporate hygiene behaviours into good practices on board;
• To avoid conflict with mandatory signs.
Above all, of course, it is mandatory to make the promoter recognizable, or to personalize the communication system, from time to time adapting it to the identifying characters of the specific shipping company. (MLF)
The design approach will necessarily have to combine – as mentioned – analog media with multimedia and assisted technologies; in particular, QR codes will be used, now consolidated in their wide–range use, and on–board communication will be then integrated through technologies based on Projected Augmented Reality, on an infrared light system detected through the integrated combination between hardware / software, as well as on holographic representation (fig. 1).

Fig. 1. Technology based on projected Augmented Reality that allows you to merge the real world with the virtual world. Each surface in the detected environment can become a possible screen.

These choices are motivated by the search to obtain a form of communication that might reach users in a way immediate and effective as possible, in order to always respect targets and purposes in a contextualized manner. It is essential that the result of the design choices is a system of documents of rapid perception and of univocal, simple and memorable understanding; alongside these requests, as for what concerns the present moment, a further request to be satisfied is given by the respect of a careful hygiene, where, consequently, no physical contact is foreseen, not even only tactile.
These are certainly alternative and above all updated modes, which offer a valid alternative to all systems based on the touch screen, which appear immediately obsolete and ineffective.
Overall, the Projected Augmented Reality represents a fusion between the real world and the virtual one with its effective and captivating perceptual yield, which is implemented thanks to a technology with latest generation projectors and the integrated combination of hardware and software, with the visible structured light, the "intelligent" scanning and the privileging of the point of view of the projector; the scanning of the visible structured light allows the alignment and correspondence "pixel by pixel" among the elements present in the real environment and the captured digital image, as if the latter had been taken with the optical parameters and the point of view of the projector.
The high–resolution projection of the image – automatically aligned with the objects present in the real world – thus assumes a significant importance, as it allows to transmit the information processed and converted into 3D maps directly on the real surfaces that become possible screens. Dedicated softwares therefore make it possible to apply procedural effects and projector control to produce captivating and engaging visual experiences through the creative and synchronized projection of visual and audio effects. Games of lights, colors and shapes automatically adapt to real surfaces, thus enhancing their scenic depth. Ultimately, this form of augmented reality uses the projected light to "increase" the contents to the reality without the aid of viewers or devices necessary for their vision, as is the case, on the contrary, in other forms of AR. This peculiarity allows its use in multiple areas of application: from the individual artistic installations to the promotion of the territory, from the urban redevelopment of "non–places" to being an integral part of wayfinding for orientation in real–life spaces as in public places and on cruise ships (fig. 2).
Furthermore, some contemporary communication systems of wide diffusion and use offer the starting point for a further series of application possibilities; above all, the use of artificial intelligence, with characteristics particularly suitable in certain situations and for targeted target audiences [1].
"Where did I park the car?" "What is the shortest way to reach the goal?" "Which is the most scenic route?"

In everyday life, the contribution of tools that interact with us on the basis of the principle of artificial intelligence as the realization of the human ambition to be able to create a relationship between man and machine, between automation and rational thinking, is not only consolidated, but even almost obvious. Computers and 'smart' devices provide us with virtual secretaries that simplify and support daily activities. (RT)
Naturally, it is a matter of distinguishing which type of automation can be usable and consistent with the communication and information needs necessary on board cruise ships; as is known, automation is structurally divided into two fundamental theories: weak AI and strong AI, defined by the scholar John Searle this definition allows to precisely parametrize and circumscribe the areas of action.
Very briefly, the differentiation between the two types of AI is based on the different action that 'imitates' the mechanisms of the mind, assimilated to computer programming: the stimuli that reach the brain lead to an immediate reflection of purposeful thinking (a 'reasoning'), from which a consequent and coherent action derives. The machine, therefore, has the purpose of imitating and simulating the reasoning produced by the human mind, at different levels, or 'limiting' the activity to the possibility of answering questions that derive from the careful and timely analysis of the data held by the tool, or trying to become itself a sort of autonomous intelligence, which not only learns from experience, but interacts with other non–quantifiable factors, such as emotions or the subjective way of expressing oneself.
It is quite immediate to understand how the type of interest here is the first, since the technological system, necessary for communication and information intended for cruise passenger, works on specific and repeatable questions, in a completely similar way to what happens with the 'virtual secretaries' which we are already used to: in fact, in the case in question, the applications requested from the machine, are limited to understanding and solving specific problems through answers directly derived from the information in possession.
From all the considerations that emerged, it is clear the need to bring together all the different categories of media, from the traditional analogue ones, to the more contemporary visual ones, up to the interaction with AI; the range of possibilities should make it possible to reach the widest target of users, regardless of the level of computer literacy, culture, age, possible disabilities and so on.
There are many possible examples to draw from: the attached images bring only a very small part of already tested implementations (albeit in other contexts), which could be revisited and introduced as a customer–caring system on board cruise ships. Lastly, it is recalled that the ideas and arguments contained in the text refer to the research in progress thanks to the partnership of Grandi Navi Veloci, to the collaboration with the Centro del Mare of the University of Genoa, with the PhD in Science and Technology for the Sea, as well as with some companies specialized in the research and implementation of the technologies described.

Fig. 2. Integrated on-board communication through the use of technologies based on Projected Augmented Reality.

Specifically, the collaboration with Grandi Navi Veloci led to the awareness of a necessary segmentation of the communication offered on board; if, in fact, the age group of the most widespread cruise target is undoubtedly literate and active from the use of devices and IT tools point of view, on the other hand it is also true that a communication based on an almost dialogic use of the "machine" could even cover also the less skilled users especially with multimedia. This, therefore, is the new challenge: the use of AI at levels of immediate understanding of information, to support each passenger with a virtual assistant in a targeted manner [2] (ER).

Notes

[1] In particular, a part of the study presented here is part of the project entitled: welcome on board: integrated habitat communication in cruise ships, funded by University Research Funds – University of Genoa 2019, responsible R. Torti.

[2] The research presented is the result of the joint work of the three authors; the individual contributions can be traced back to the authors by the presence of the initials at the bottom.

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Genetic Algorithms for Polycentric Curves Interpretation

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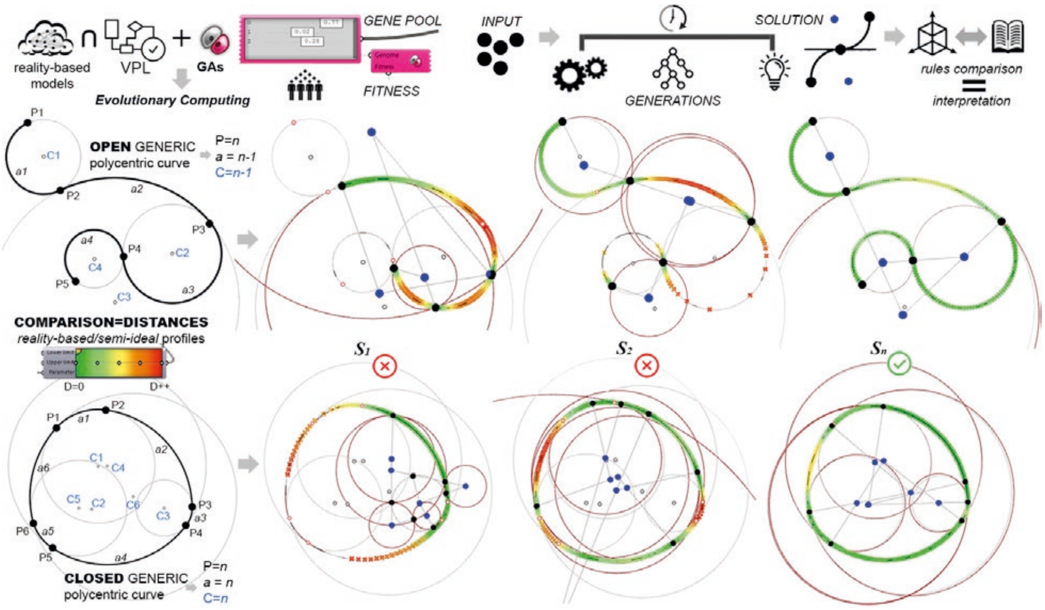
Abstract

This research work into Evolutionary Computing field aims at improving a dataset of algorithmic generative definitions able to return an optimized 'semi–ideal' curve that best fits a generic reality–based profile, starting from some of its points. This paper shows GAs_Genetic Algorithms applications especially with regards to study, interpretation and definition of generic polycentric curves. Current VPL tools (Galapagos–Rhino, McNeel) allow to test Evolutionary Theories for problem solving and decision making in architectural research field. According to a human driven approach, an operator defines GENOME, FUNCTION and FITNESS to drive the Evolutionary Solver towards optimized solutions. Some case studies from Historical/Existent Architectural Heritage are used to show how GAs can simplify the digitalization process and big data interpretation.

Keywords
genetic algorithms, evolutionary computing, geometry, PolyArc, cultural heritage.



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Introduction

This research work into EC_Evolutionary Computing field aims at developing a dataset of algorithmic generative definitions (VPL), to return optimized 'semi–ideal' curves that best fit reality–based profiles (generic polycentric curves from point cloud segments). This paper especially shows testing of GAs [Holland 1992] for vaulted systems study. EC is a subfield of AI aimed at iterative, continuous and combinatorial search for optimized solutions.
In architectural and engineering fields, it is possible to distinguish applications about optimization of architectural–urban design [Buffi et al. 2020; Canestrino et al. 2020, Palma et al. 2020], analytical–structural applications [Grillanda et al. 2017, Khan 2015], manufacturing complex elements–systems [Zaremba 2016; Coutinho 2010; Limonge et al. 2010], analytical–geometric applications to rebuild and compare shapes [Bianconi et al. 2018] and, more specifically, about ovals interpretation [Santagati et al. 2018].
Moreover, similar approaches are managed with different tools to optimize the curves and surfaces interpretation that describe historical architectural elements, according to stylistic features of cultural heritages and geographical contexts [Samper et al. 2020; Lanzara et al. 2019].
These approaches are also potentially aimed at supporting AI processes [Sim 2020]. This VPL algorithmic definition allows to construct all kind of profile starting from reality–based elements: the only input parameter is the points number. It is the main advantage of the process.

Methodology and Tools

Digitizalization of existent architectural elements is a process to provide a system of 3D models and related information (parameters/geometric variables, construction techniques, materials). About Historic Heritage, these properties can be extrapolated through a direct analysis of architectural elements (survey) or from specific treatises and historical manuals rules. The parameterization of pointed arches and polycentric curves (vertical sections), used to generate the revolution pointed domes, is one of tested approaches [Capone et al. 2019a]. Digital translation of geometric–mathematical rules simplifies the parameterization (geometric genesis) of complex architectural systems and allows to model variable and adaptable configurations [Capone et al. 2019b]. Another approach is based on VPL models built on reality–based profiles used as "input parameters", to compose the wireframe of the architectural element, providing a 'semi–ideal' model closer to the real element. Then, different approaches and tools (VPL/C++) were compared to identify ideal curves and surfaces that best fit point clouds segments [Lanzara et al. 2019].
We have applied these approaches to define generic polycentric curves, open or closed, from reality–based profiles using GAs. This contribute shows applications about closed symmetrical polycentric curves and open polycentric curves that could be domes profiles. Ovoidal domes can be generate as revolution surfaces or they can be shaped from curves network. The axes dimensions are not sufficient as input parameters to model these shapes. In fact, it is not uniquely possible to identify and to draw the specific oval that best describes a reality–based profile according to the lengths of its axes only. Starting from the same pair of axes, it is possible to generate infinite ovals and one ellipse [Dotto 2002, p. 14].
Current VPL generative–algorithmic tools (Galapagos–Gh component, Octopus–Gh plug–in, Rhino, McNeel) allow to test Evolutionary Theory (Darwin 1859) to support problem solving and decision making processes. According to a human driven approach, the parameters identification to define GENOME, FUNCTION and FITNESS allows to drive the Evolutionary Solver towards an optimized solution.
GAs calculates the optimal position of the end–points (GENE POOL) of a PolyArc (VPL component aimed at built a sequence of tangential continuous circular segments) along a reality–based profile to extrapolate a 'semi–ideal' polycentric curve. A direct comparison between the 'semi–ideal' curves (GA) and the ideal curves (rules) allows to establish which type of ideal profile best fits and decodes the reference curve. The number of points can

be random or deriving from a critical interpretation of the reference subject. Symmetrical distributions (entrances, chapels, mosaics, niches or structural–decorative elements) simplifies the decomposition of a PolyArc into its segments and allows to define hypotheses about the specific oval profile. If the curve is closed, the points number (GENE POOL) is the same of the arcs number; if it is open, the number of points is the same of the number of arches/centers +1.

The Evolutionary Solver combines points by minimizing the distance (Mass Addition)between reality–based curve and PolyArc (FITNESS) to optimize their overlap. FITNESS defined and tested to select the optimal solutions, allow to minimize the sum of the distances between the ideal curve and the reference one and the average distance between curves and they allow to maximize the identification of points whose distance from the reference curve is smaller or equal to a given limit value. A chromatic gradient distinguishes the points along reality–based profile according to their distance from defined 'semi–ideal' curve and/or the ideal configuration that best fits it: for a value of 0, points are green; for higher values, points are red.

Once the ideal circular segments of the PolyArc have been identified, it is automatically possible to extract the whole circumferences and the position of their centers for each circular segment. Finally, it is also possible to compare the defined 'semi–ideal' PolyArc and its distributive layout of the centers with ideal profiles (curves built starting from centers along diameters).

The main advantage of this definition is to use the points number as the only input parameter: the difference between closed and open 'semi–ideal' polycentric curves is to communicate this condition by simply using a Boolean Toggle (True/False). Therefore, a single definition allows to analyze, interpret and define a generic open or closed polycentric profile. Another important advantage is to use the same GENE POOL (points along reality–based curve) to generate different curves. The main advance, *in itinere*, of this research activity is also about study and definition of analytic curves, e.g. conics, only starting from points along reality–based profile.

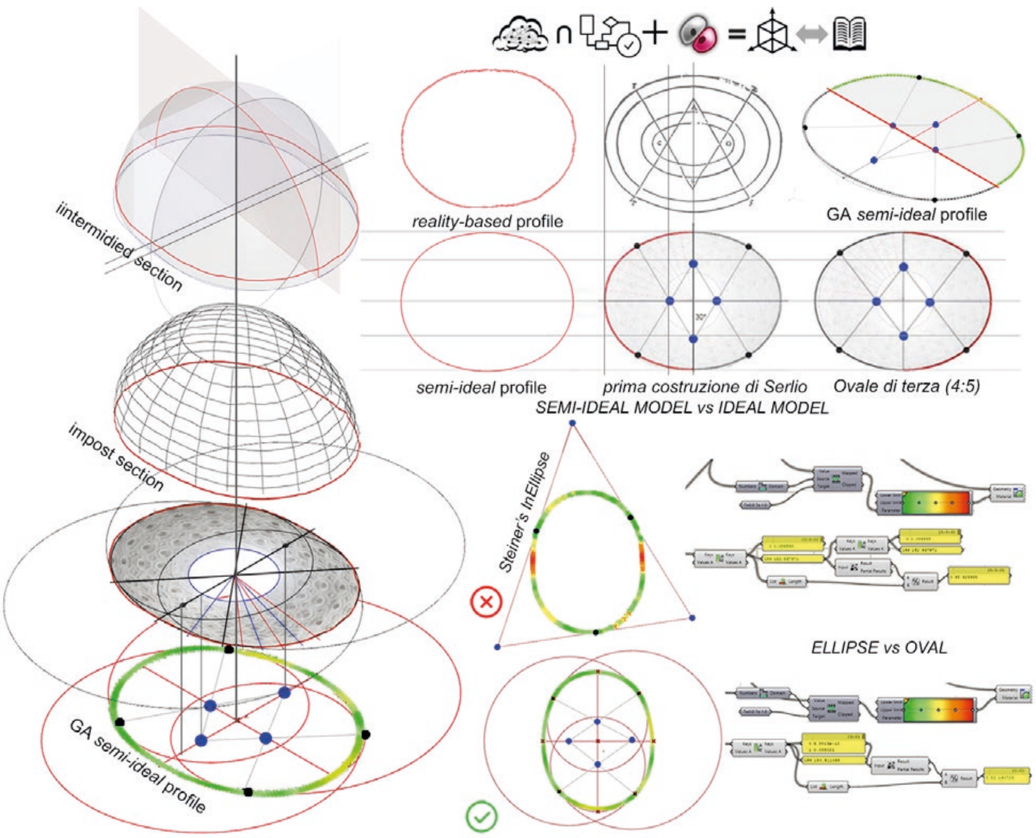

Fig. 1. GA to interpret and define CLOSED POLYARC – OVAL profiles (impost and intermediate sections) of the Church of S. Giovanni Maggiore's dome. On the right–top: comparison between 'semi–ideal' profile and rules; on the right–bottom: comparison between reality–based profiles, oval and ellipse, (authors elaborations).

Applications

GA for OVAL interpretation has been tested to verify the impost and the intermediate sections of the ovoidal coffered dome of the Basilica of S. Giovanni Maggiore in Naples.
A double symmetrical oval (four centers) is clearly recognizable with the naked eye by observing the extrusion profile of the molded frame crowning the drum and corresponding to the impost curve of the coffered intrados of the dome. However, the intermediate oval profiles are similar to ellipses.
Although ellipse and oval are conceptually and analytically different curves, for centuries they generate a "conflict" (Migliari 1995): the main reason lies in their formal similarity, often causing interpretative misunderstandings about the attribution of these shapes to geometric elements.
Figure 1 shows comparisons between 'semi–ideal' ovals, Serlio's rules (1584) and the elliptic profile that best fits the intermediate sections. Unlike the impost profile, the algorithm calculates a minimal difference between intermediate sections and ellipse. However, also the presence of lacunars would confirm the oval shape for the intermediate sections: in fact, oval allows regular offset.
About modeling of hemispherical pointed domes characterized by circular section, we have translated in VPL the geometric rules provided by Serlio and by Palladio; for polycentric vertical sections (curves composed by a series of continuous arches in tangency and curvature), the rules provided by Fontana and by Scamozzi; for pointed arches (different ratios between 'arrow' and radius), the rule illustrated by Vittone [Capone et al. 2019a]. Therefore, this comparative approach was tested on a series of revolution domes of Historic Architectural Heritage in Naples.
In particular, GA to interpret and build POLICENTRIC ARCHES was tested on the pointed dome of the Church of S. Caterina a Formiello to define the layouts of centers subtending one of its vertical section (without 'vertex').
By comparing Serlio, Fontana, Vittone and Scamozzi's rules and the reality–based sections, we can state that the reality–based profile does not match any of the constructions of historical treatises actually translated into VPL, neither the ellipse. However, the difference between reality–based profiles and ideal curves is not minimal: therefore, it does not depend only on structural problems or constructive irregularities, but also on different stylistic approaches (fig. 2).

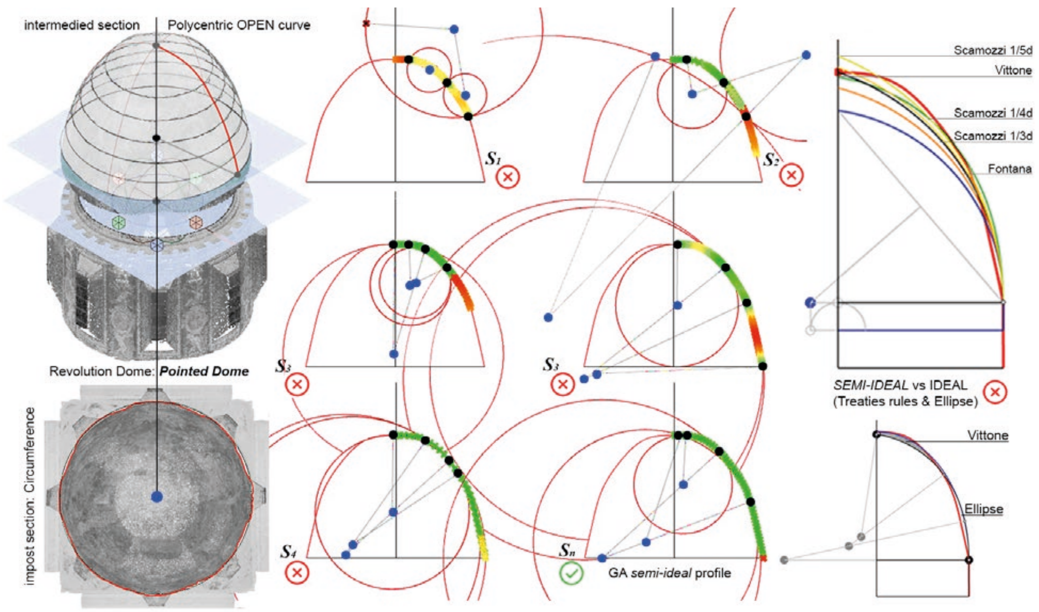

Fig. 2. GA to interpret and return OPEN *POLYARC* – POLYCENTRIC ARCH (vertical section/meridian) of the Church of S. Caterina a Formiello's dome. On the right–top: comparison between 'semi–ideal' profile and rules; on the right–bottom: comparison between reality–based profiles, oval and ellipse. (authors elaborations).

Conclusions and Future Works

The main progress (*in itinere*) of this study is to test GAs to interpret and define analytical curves (e.g. conics) and generic profiles characterizing also modern and contemporary architecture. In addition, other future advances can be about deepening the accuracy of the models, improving current VPL definitions and testing other types of algorithms [Gatti 2020]. The semi–automatic interpretation of complex elements simplifies their parameterization according to interoperable logics (VPL/BIM–HBIM). Furthermore, this approach is also aimed to test geometric–speculative approaches and to inspire studies with different goals.

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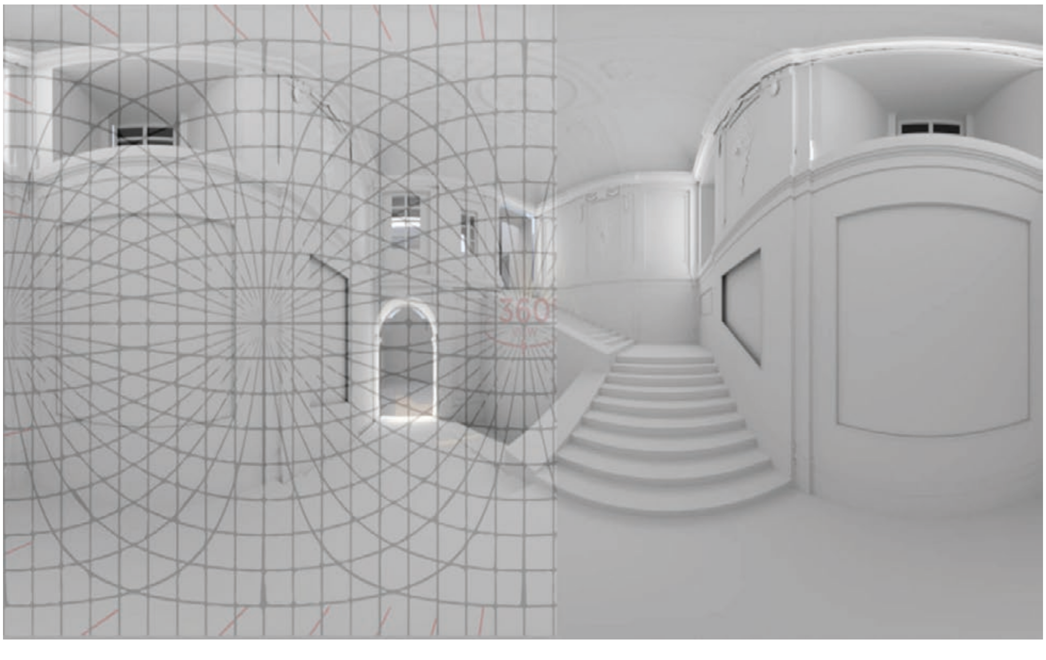
The Drawn Space for Inclusion and Communicating Space

Anna Lisa Pecora

Abstract

In the last twenty–five years, some studies have been analyzing the virtual reality potential for special education. They show the virtual environments as a valid communicative medium and a safe space where ASD people can experience new situations without limits of 'in vivo' experiences. Often, problems with space can complicate many aspects of everyday life. Referring to Hermelin and O'Connor's studies, the difficulties involving the autistic clinical frame are connected especially to perception deficiency, therefore the VR can become valid support, for people with ASD, improving relationships with space, with ourselves and with others. My study tries to provide a guideline tool for a human–centered VR design.

Keywords
virtual reality (VR), inclusion, autism (ASD), drawing, representation.



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Introduction

In recent years, the drawing disciplines, supported by the widespread of new technologies progress, play a fundamental role in the interdisciplinary mediation of the communicative field. Up to now, studies about special education and VR have been led by medical and psychological disciplines, disregarding perceptual aspects about the relationship between the user and the virtual space. Furthermore, a wrong interpretation of spatial configuration can provide various types of discomfort in both, typical and non–neurotypical users. If VR can mediate the relation with the real world, its visual codes must be managed with expertise, in order to provide a customized visual language on specific user needs. Therefore, the ICAR 17 disciplines can embody a valid guide to drive the perceptual process in virtual reality.

VR Spaces for Learning and Inclusion

In the last twenty–five years, the rapid development of virtual reality technology has improved the simulation quality, opening new applicative frontiers. Their communicative power lies in the potential to provide a perceptual realistic experience where it's possible to activate the same cognitive dynamics available in the real world. Therefore, in special education, the immersive experience should support the specific characteristics of the autistic perceptual system and its atypical responses to sensorial stimuli. Some impairments can create visual distortion complicating the reading of spatial clues; for example, they can inhibit the understanding of depth, dimensions, shapes and relative positions [Bogdashina 2015, p. 29]. Other problems can occur in recognizing the space limits or in the relation between the viewer's body and other objects. This problem can arise during a VR experience due to the specific characteristics of virtual navigation. Virtual reality uses panoramic images, also called 360 degrees images, as: photorealistic renders, photos or videos; therefore, since the frame limits exceed the visual field limits, the experience involves not only the vision but also the body, even in the simple head rotation. This way, the user turns from a static sight to a dynamic perspective [Rossi et al. 2019]. Usually, these relations between vestibular and visual apparatus help the wayfinding and the understanding of the space, but in autism, they can provide confusion and stress due to the disorder of the "afferent couple" phase [Russell 1994]. For this reason, the majority of the research about VR and autism, attempt to create a safe space where experience new situations without the limits of the physical world. Cultural heritage, for example, museums or archeological sites, often are uncomfortable spaces for autistic people, because they can provide overstimulation of senses, causing a painful and stressful experience for people with hypersensitivity. Using the potential of virtual reality, it's possible to communicate cultural information customizing the input data on the specific user needs helping, this way, the dialogue between the space and the viewer. Moreover, since the virtual experience involves the user in the first person like in the real world, the emotional aspects play a strategic role, enhancing the learning process with a playful incentive. In fact, most of the learning experience for special education use applications from the gaming world, without customizing perceptual inputs on autism needs. Therefore, the research lacks in details concerning useful aspects about the perceptive response to the stimulus coming from the designed virtual space. Most of the observed studies are visually overloaded and unfitted to the cognitive needs of ASD people. The majority of research, in fact, points out psychological and technical aspects without considering visual factors involved in the interaction between autistic people and VR. Trough the comparison between the scientific researches published about VR and autism, I identified four taxonomic categories in order to analyze the state of the art about this topic:
Usability tests: valuating ASD users' answers.
Life skills: learning of basic competencies useful in daily life.
Social skills: understanding of social situations.
Special education: VR application in schools environment, mainly for language learning.

Visual Clues Improving Space Perception

There is a huge difference between watching a real space and watching a drawn space. In the first case, space directly communicates its morphology without interferences, while, watching an image means to see a subjective interpretation of reality. Also, the virtual environment develops by a drawing action, therefore the perceived image is double filtered: first by the designer, who translates his personal view of the world in graphical signs, then by our brain, that, according to the personal experience, decode the figurative codes in a mental image. Thus, the final result depends on multiple factors, some depending on the person, others on the picture characteristics. Usually, we distinguish three main categories collaborating to the space interpretation and, in detail, to the depth: pictorial depth cues [1], physiological depth cues, motion depth cues. Jerald Jason adds another category: contextual distance factors, related to the environment and psychological influence on our perceptual behavior [Jason 2016, pp. 122-123]. He explains that: "perception and action are closely intertwined. Action–intended distance cues are psychological factors of future actions that influence distance perception" [Jason 2016, p. 122]. This aspect is particularly relevant if referred to autism where the answer to sensorial stimuli can be altered by an atypical behavior of the perceptual system. Moreover, this impairment can cause states of anxiety and fear, interfering in the right reading of depth cues. Consequently, designing a virtual space, it's important to take into account psychological aspects influencing physiological and projective factors when managing graphical signs. For example, the environment should be characterized by simplicity and clear spatial clues. Referring to this aspect, an example is one of the first experiments led by Sue Cobb and the VIRART team. There are no descriptions of the virtual environment, but, watching the published photos, it is possible to deduce some visual aspects interfering in the perceptual process. The VE represents a ski slope characterized by a simple framework where objects have basic geometries easily recognizable (fig. 1). The highly prevalent white produces a flat configuration where it's difficult to understand the perspective. For this reason, the use of some graphic depth cues is crucial: a curb on the right and a schematic ski lift on the left side, provide two linear clues that, converging toward the frame center, become important depth gradients. In fact, the angle of graphic signs on the vertical and horizontal axis is a key element for tridimensional perception [Arnheim 1997]. The distances and dimension reduction of ski–lift elements offer other depth gradi-

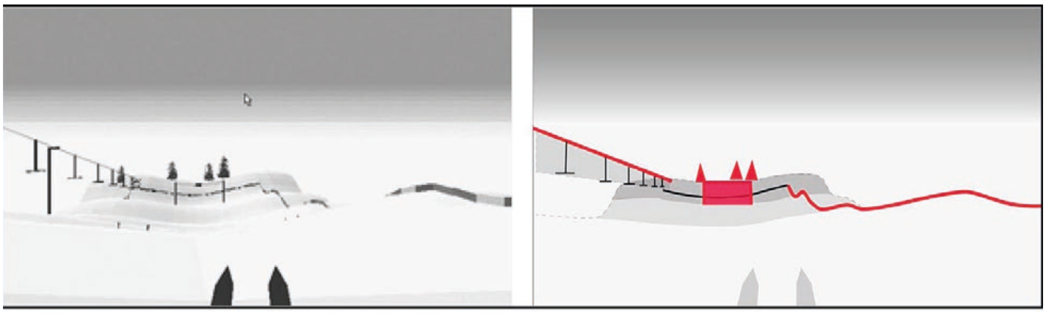

Fig. 1 . Cobb's experiment (1995). Frame of the virtual ski slope from the user's point of view and scheme with the main depth clues and target elements. Graphic drafting by Anna Lisa Pecora.

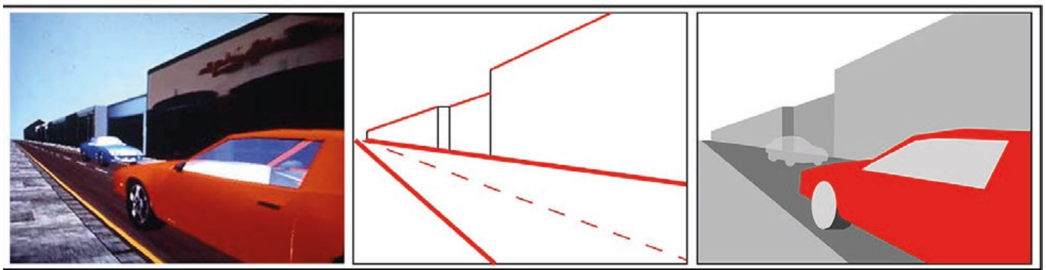

Fig. 2 . Strickland's experiment (1997). Street scene and scheme with the main depth clues and target elements. Graphic drafting by Anna Lisa Pecora.

ents in the observed image; acting in the same direction, they enhance each other because "the more the gradient is regular, the stronger their effect acts" [Arnheim 1997, p. 227]. We can find another example of communicating virtual space in Strickland's experiment, published in 1997; that is one of the first immersive experience for autism lead with an RV–HMD. It could be taken as a reference for its way to put in evidence target elements and depth clues. Strickland, describing the environment design, explains that: "The virtual world was a simplified street scene consisting of a sidewalk and textured building shapes. All motion objects such as people, animals, and objects in the sky were removed. Periodically one car, whose speed could be changed, would pass the child standing on a sidewalk. The contrast was kept low in the scenes with gray being the dominant color. The low quality of the headset screens provided a less detailed environment automatically. The cars, the focal point of the test, were presented in bright, contrasting colors […] red and blue" [Strickland Dorothy 1997, p .4]. Only later, another visual stimulus is introduced: a stop sign is moved to different parts of the tracking area during the later tests and the children are asked to find it and stopping there (fig. 2). In this kind of configuration, the environment works like a neutral background helping to focus on visual targets. Otherwise, the oversimplification of morphological spatial signs creates difficulties in evaluating distances. It's possible to improve the information about the spatial reference using some graphic solutions without exceeding in perceptual overload; for example, acting on the textures or using some objects like landmarks in the scene. Sue Cobb's experiment, in 2002, uses a grid pattern for the virtual cafè floor, that works like a spatial coordinates reference. Moreover, they found that watching part of the avatar's body, enhances the sense of embodiment and supports the understanding of the avatar's size during motion [Cobb 2002, p. 17]. The sense of embodiment, is related to "presence", also defined as "the sense of being there", "inside a space, even when physically located in a different location" [Jason 2016, p. 46]. Because ASD people frequently show proprioception impairments, they have difficulty feeling their body physically acting in the virtual environment as if they were performing the task in the real world. Giving the human height to the point of view, provides a familiar appearance to the framework improving the sense of presence and the willingness toward the virtual experience. For the sake of narration, I could only describe here a brief example of the guideline tool I compiled for designing an autism–friendly VR. The attached tables (fig. 3) show part of the developed tool.

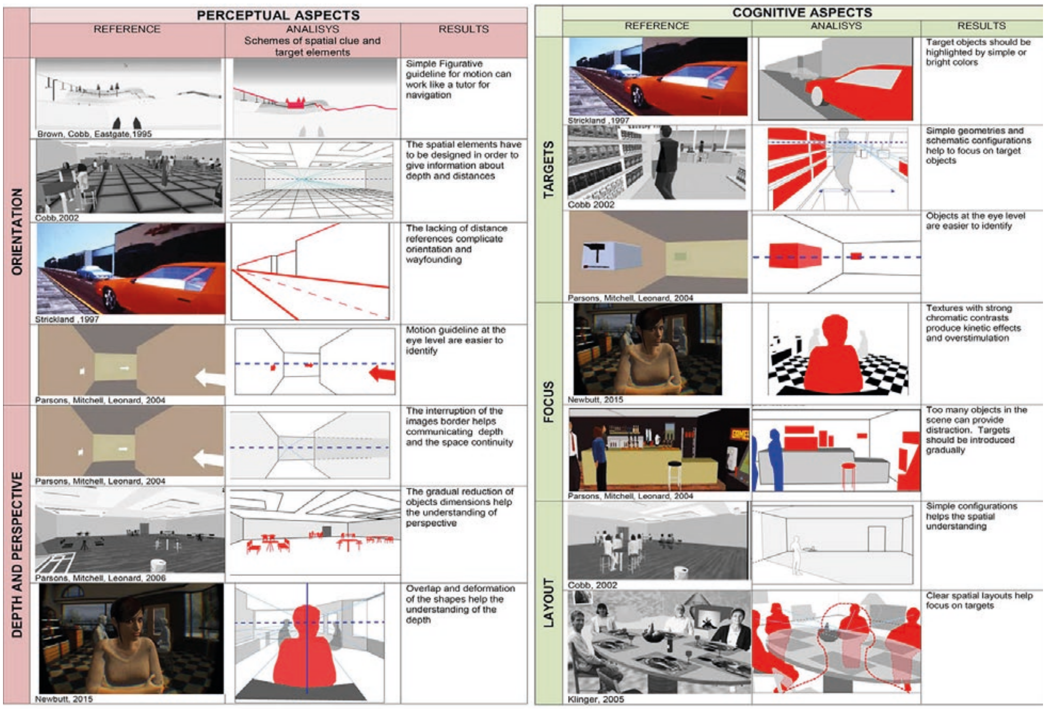

Fig.3. Tables. Guidelines for an autism–friendly VR design: perceptual aspects and cognitive aspects.

Conclusions

The physical space holds the complex theoretical and morphological relations between different elements as colors, lights, textures and patterns. So, only through the right graphic choices, their figurative configuration can be deeply understood. Setting the detail level, the chromatic and luminous qualities, the quantity and the value of graphic signs in the VE, become essential features to define the sense of immersion and presence and, therefore, the communicative power driven by perceptual inputs.

As Olga Bogdashina asserts, "filtering of an infinite amount of information is necessary to make the processing of information effective and conscious" [Olga 2015, p. 110]. For this reason, the graphic design for an "autism–friendly" VR has to provide essential information about the environment to reduce sensorial weight avoiding distraction. In fact, the representation path allows the process of "synthesis, communication and explicitation" of the space, necessary for decoding and subsequent learning its cultural contents. The relationship with environment can influence human abilities to the point of providing knowledge for non–neurotypical people as well as for anybody else. A right interpretation of spatial codes through drawing disciplines can provide a human–centered design of a virtual environment where architectural space becomes the medium for communication and inclusion. In future studies, the guidelines introduced in the present paper will be used to produce a prototype to test them with the user reference.

Notes

[1] So called referring to human optical system, elaborating images by projection on the retinal surface.

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Forms in Space. AR Experiences for Geometries of Architectural Form

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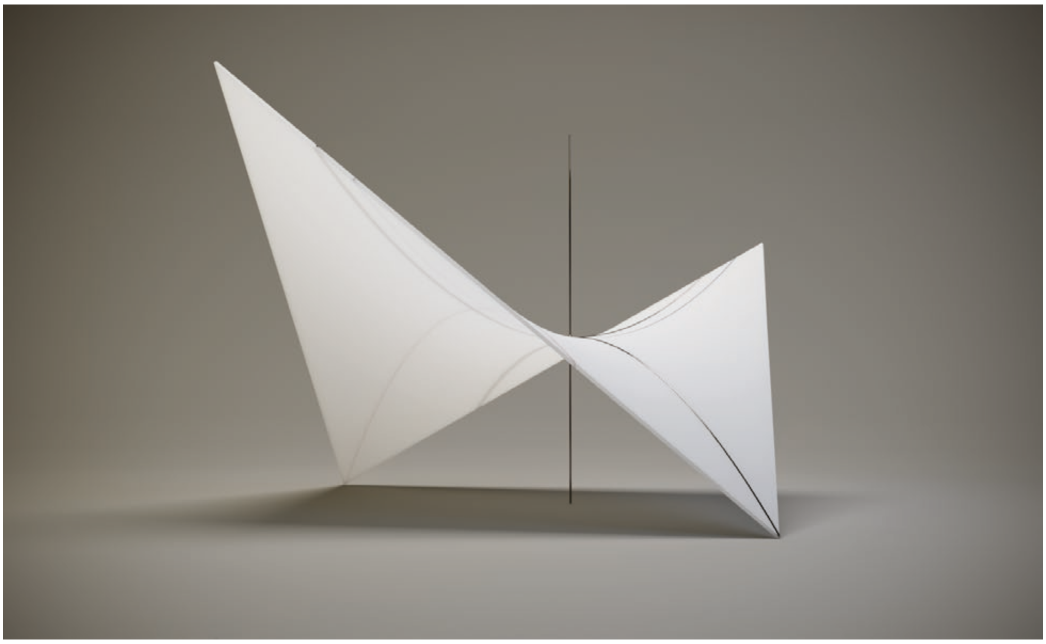
Abstract

Learning through the direct experimentation of models, in their variety of manifestations and hybridizations that we know today, is undoubtedly a very powerful aid in the acquisition of knowledge. Specifically on architectural form, this aid is even more important, because it helps not only to understand the form of existing architecture, but even more to imagine and design new ones. The research here presented, focusing on this double objective, cognitive and creative, proposes and experiments new ways of integrating and interacting with heterogeneous models – both physical and virtual – conceived for a *scenario* of musealization of the architectural form. A place where the user interacts and experiences the properties and peculiarities of form, in perceptive continuity between real and virtual space.

Keywords
descriptive geometry, form, digital model, augmented reality, projected augmented reality.



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The proposed experimentation intends to clarify, through Augmented Reality applications, the relationship between the properties of geometrical form and the architectural project. This idea is part of a larger project of the musealization of form aimed at investigating the close relationship existing between the geometric properties of form, its exploration through drawing and the architectural project.
The concept of 'model' is at the basis of this expositive idea. The tools to be used are those of synthetic geometry, which studies and communicates the form through drawing, i.e. using visual synthetic languages. The synthetic method is founded right on the 'constructive' character of descriptive geometry. This character is evident when referring to the geometry of space or of extension – using a definition given by Gino Loria in the early twentieth century – as the science that deals, in abstract terms, with repeatable procedures that can be reproduced in physical reality [Loria 1935, p. 77]. Therefore, the idea of construction, understood as a generative process of the form, is the privileged object of the exhibition that the museum intends to communicate, in terms of pure geometric speculation and in relation to the classical and contemporary repertoire of architectural projects. An idea that transpires, citing one of the most famous examples in architecture, from the formwork traces left on the concrete of the ruled surfaces in several works by the masters of the modern movement, which recount the evidence of the reasons of the form.

Towards a Museum of Form

Today, the possibility of operating in the virtual three–dimensional space of a computer has extended the experimentation field about the form, permitting to derive, with a synthetic method, properties that were impossible to investigate through the two–dimensional graphical representation. Thus, many geometric problems find effective synthetic solutions thanks to the use of skewed curves, curved or double curvature surfaces, unthinkable to employ until the last century, opening the way to new possible research developments [Migliari 2012, pp. 14-42]. Therefore, the three–dimensional digital representation renews the heuristic value of the 'construction' using the synthetic method for resolving geometrical problems, allowing the geometric control of properties that find application in different areas of design experimentation.
While three–dimensional representation expanded the cognitive possibilities around the form by the direct interaction with them, it also significantly contributed to promote its knowledge. In fact, the visual languages that today communicate the form describe, in exact and unambiguous way, the lines and surfaces properties. This twofold capability of the synthetic method, cognitive on the one hand, and communicative on the other, was the starting point that generated the idea of a musealization project of the form.
The idea at the basis of this project consists in describing the properties of lines and surfaces, through theoretical and speculative models, and to explain the relationships between these geometries and the form in the real space (natural or anthropic) but also in the ideal space, where the design idea originates.
The communication of form through the models belongs to the tradition of the mathematics and geometry schools since the early nineteenth century [1]. In continuity with this tradition, a dynamic use of these models is proposed, where chalk and stretched wires are replaced by three–dimensional representations made with contemporary forms of digital representation. Digital, physical models and their related hybridization, become a vehicle for the dynamic interaction and, at the same time, a privileged platform where the public can experiment and understand its design implications. In this context, Augmented Reality and Projected Augmented Reality applications play a role of particular interest due to their communicative potential.
The exhibition space has been conceived as a didactic laboratory on the one hand and as a research laboratory on the other. An implementable interactive platform capable of hosting a wide repertoire of shapes: lines, polyhedra and surfaces with which to interact through their respective properties. Geometrical, analytical and differential, these properties allow to identify, from time to time, the categories of affine surfaces and to know their genesis, symmetries, remarkable sections, etc. [Migliari 2009]. In addition, to show the geometric properties of the figures, the same models are intended to describe the morphological variety that can be achieved in design by using the same surface in different ways, according to its different portions (fig. 1).

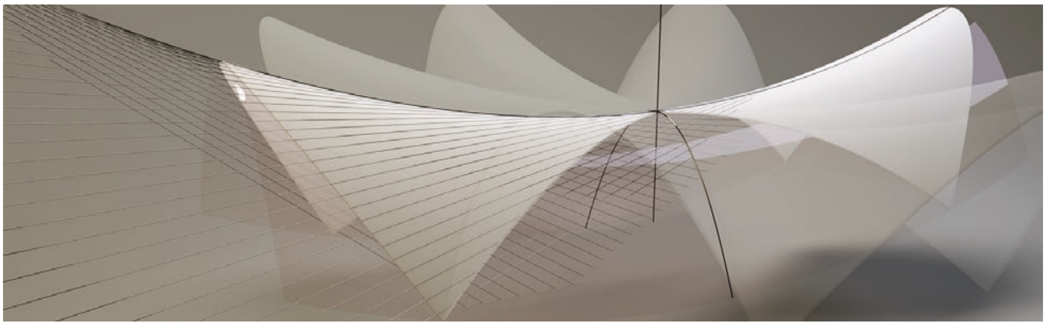

Fig. 1. Hyperbolic paraboloid and its sections in the Los Manantiales Restaurant by Felix Candela (Mexico City, 1956).

Therefore, the proposed models constitute an expositive prototype, with which to experiment the possibility of redesigning new ways of communicating the form that permit its three–dimensional exploration, revealing its peculiar characteristics. However, at the center of the exhibition project we do not find the final result, namely a surface or a curve, but the generative process that led to that particular spatial configuration, in other words its construction. The construction, understood as an existential demonstration of the form, is the foundation of the synthetic approach, i.e. graphic approach, with which descriptive geometry operates, univocally characterizing the *modus operandi* of architects.

Augmented Reality Experimentations

The extreme simplicity and technological advances implemented in everyday tools, such as smartphones, tablets, laptops, have made it possible to spread AR–technologies in every level of education, from primary school to university. The advantage of not needing for additional hardware such as visors or helmets typical in the VR field, makes AR–technologies particularly suitable for applications in numerous and heterogeneous sectors of scientific and humanistic knowledge [Voronina et al. 2019]. Many studies show that AR plays a fundamental role in pedagogical applications today, although their potential is still partially explored [Burton et al. 2011, pp. 303-329 4; Wu et al. 2013, pp. 41-49].
As part of the project aimed at the realization of a museum of the form, the experimentation of AR is one of the principal models through which to experience the properties of the form and the effects that these transfer into the architectural project. This type of representation offers the possibility of direct interaction with the digital model, allowing to operate with the abstract entities typical of the geometry of space: one and two–dimensional forms, that otherwise could not be realized in the real world, can be controlled in a representation on the edge between virtual and physical reality. The user operates with the form in order to understand its properties, that reveal their evidence in the finished form but, even before, in the generative process that led to it. According to this double need of fruition, the application focuses its attention on the representation of two states of the form: its construction process and its final configuration. The idea of representing generative processes and final configurations concerns both the pure geometric form and the one applied to the project. Depending on its geometric properties, this is declined in different ways, giving rise to a heterogeneous and morphologically varied repertoire of architectures, all referable to the same formal matrix.

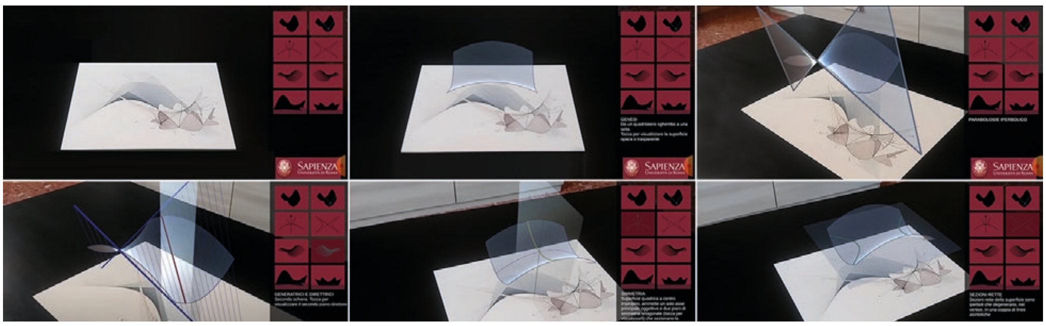

Fig. 2 Interactive model of the AR application for the exploration of the hyperbolic paraboloid properties.

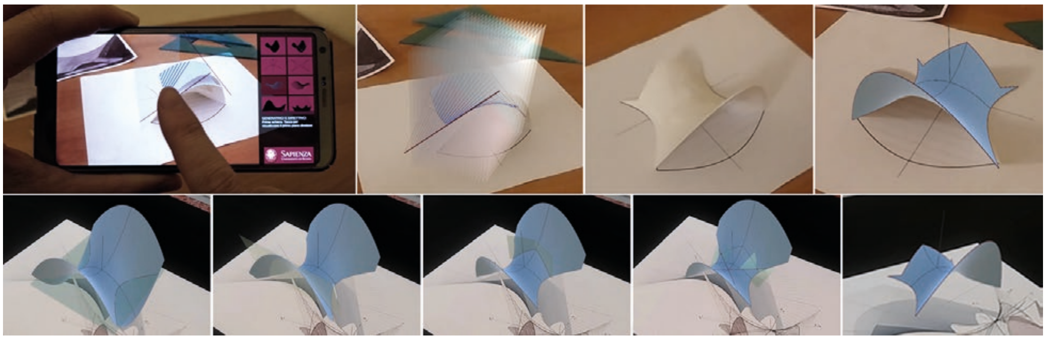

Fig. 3 Geometrical genesis of the Palmira Chapel (Felix Candela, 1958) starting by the hyperbolic paraboloid explored with the AR application.

From a strictly operational point of view, through the application the user can retrace the generative process of construction of the pure geometrical form, recognizing the properties in its final configuration and understanding how these properties are reflected in the architectural form conditioning the aesthetic and constructive aspects. It will therefore be possible to enjoy the model through the application by choosing the direction of the path to follow: from the geometric world to the architectural one or inferring the geometric properties of the form starting from its applications. This double way of reading favors the double objective: increasing awareness and ability regarding the geometric control of lines and surfaces feeding the education in geometry; increasing the knowledge by operating in space with the form, through a journey from the known to the unknown that leads to the derivation of new properties of figures [2].
The experimentation, still in progress, is oriented around the development of prototypal AR models, like that of the hyperbolic paraboloid and its applications (fig. 2). Developed in Unity 3D environment, the model is activated in virtual space through an image or a three–dimensional model (used as a Target), which provides the surface in different configurations resulting from its geometrical genesis (a skew quadrilateral or a saddle). This virtual surface can be explored by the user, who can classify it in different ways by combining its properties from a speculative geometric approach or from its applications in architecture. For example, from a synthetic point of view, this can be explored as a ruled surface whose generatrices and directrices are activated by contact with the surface itself. Otherwise, it can be considered as a second–order algebraic surface of which to derive the axes and symmetry planes and, sliding in contact with it, remarkable sections generically oriented in space. Moreover, it can also be classified from the point of view of differential geometry by ranging the osculating circles of principal curvatures. However, it is also possible to interact with the surface in question by sectioning it with notable planes, obtaining portions of surfaces that combine with each other, giving rise to a various morphological design repertoire, as in the case of some projects by Felix Candela (fig. 3).
In addition to this AR model type, the experimentation foresees that shape analysis is also enjoyed through hybrid models Projected AR type, in which 3D prints of surfaces are augmented in their information content through the video projection of their remarkable properties (fig. 4). In this case the physical model, reproduced with rapid prototyping techniques, is used for activating the AR projections, and for supporting projections themselves, which allow the user to learn the properties of the shape by directly interacting with the physical model.

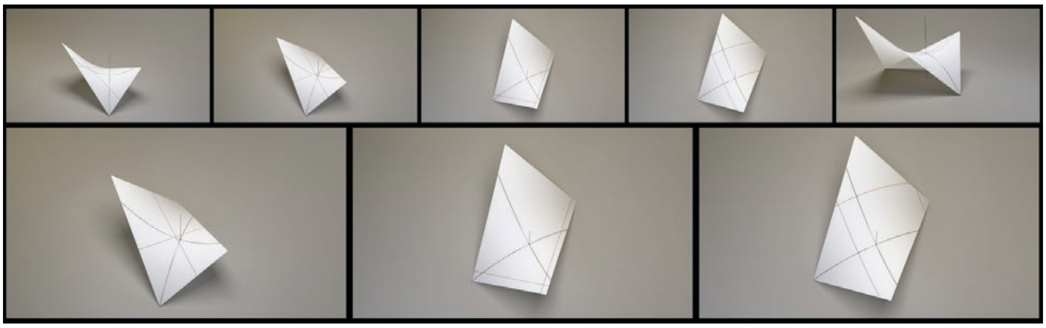

Fig. 4 Hybrid model of hyperbolic paraboloid through Projected AR application.

Conclusions

Representation has always had a central role in the genesis of the architectural project. The graphical exercise has always been an immediate expression of design thinking and a tool for the progressive elaboration of an idea that is nourished and grows through the repetition of its own representation, in a virtuous circle that accompanies the entire design process. Exploration of the form through drawing, namely by its construction, leads to increasing knowledge by passing from the known to the unknown, researching new properties of shape to derive. In this regard, the heuristic value of representation reveals its maximum expressive potential. Thus, the three–dimensional representation and its exploration constitutes a flywheel for research into architectural form, revealing its geometrical motivations in virtual space. The proposed experimental models, developed through *AR* and Projected AR experiences, describe the construction of form and show its properties, illustrating the potential of aggregation deriving from them. Potentialities that generate a wide and heterogeneous morphological repertoire of which several architectural projects are the expression.

Notes

[1] The project is inspired by the collections of mathematical models made in Europe between the second half of the nineteenth century and the early twentieth century. These exhibitions were aimed at "showing remarkable properties concerning the research topic investigated and showing some results that were progressively achieved in different fields of 'pure' and 'applied' mathematics: Descriptive and Projective Geometry, Analytical Geometry, Algebraic Geometry" [Palladino 2008, p. 31].

[2] The didactic purposes also include the implementation of learning tasks to verify understanding [Kaufmann 2003, pp. 339-345].

[3] The idea of knowledge as a passage from the known to the unknown is a founding principle of descriptive geometry. It was introduced by Monge in the first pages of his *Géométrie Descriptive*, where he illustrated its objectives and principles; today, in the field of digital representation, it still appears highly relevant [Monge 1798, p. 2].

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AR&AI in the Didactics of the Representation Disciplines

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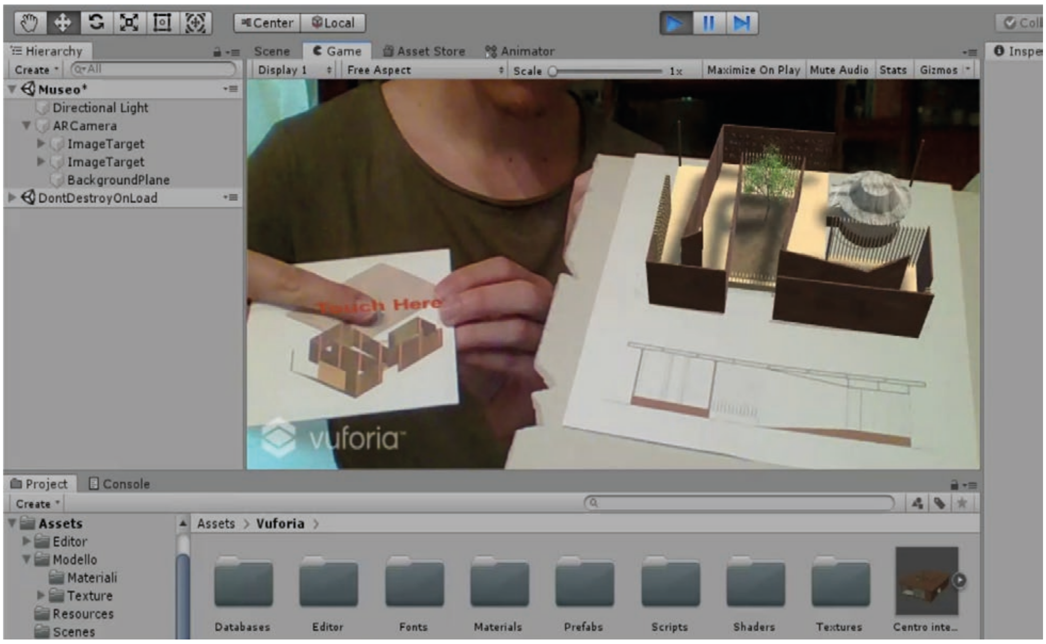
Valerio Palma

Abstract

The class of Digital Representation Techniques is an optional class for architecture and engineering students at the Politecnico di Torino. For the second year, the program of the class, focused on the theoretical and applicative panorama of technologies for digital drawing, integrates an introduction to the most recent developments in augmented reality (AR) and artificial intelligence (AI), two technological fields that are deeply influencing the interpretation of physical assets through digital models. The class requires students to produce different deliverables, including a research essay, graphic representation documents (plates or brochures), a video proving animation and editing skills, and a prototype AR application. The proposed contribution presents methods, objectives, and some of the results of the class, highlighting the interaction between the different digital representation techniques and deepening the critical aspects related to the introduction of new AR and AI technologies.

Keywords
augmented reality, artificial intelligence, didactics, representation, design.



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Introduction

AI and AR, considered in their significant synergies, have only recently attracted the interest of scholars in the fields of design and enhancement of physical assets. The connection with digital acquisition and modelling technologies makes them ideal media for recognition, communication, and interaction with physical space. In the transdisciplinarity of complex processes that characterize the design activity, the discipline of representation assumes a nodal role. On the one hand, in an increasingly effective way, digital models summarize the prerogatives of drawing and project enclosed in the Latin verb *designo* and in Alberti's *lineamenta*. On the other hand, the same models, suitably simplified, become data archives capable of communicating the complexity of reality, increasing the share of transmissible information.
Hence the importance of making these topics part of the research as well as of the teaching in the area of representation, as in the experience we have been conducting since last year in the Digital Representation Techniques class at the School of Architecture at the Politecnico di Torino.

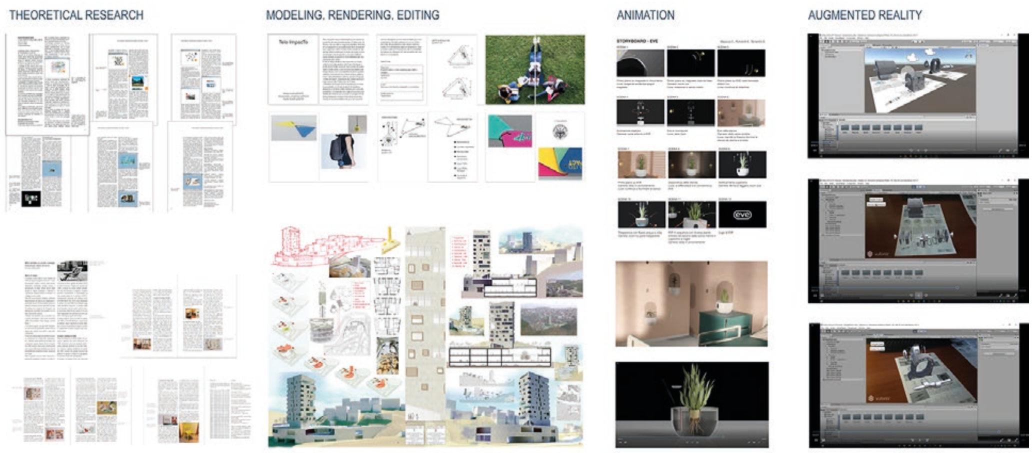

Fig. 1. Overview of the deliverables required from students.

Content and Experimentation of an Evolving Class

The Digital Representation Techniques class was created in 2006 as an optional class for the Bachelor course in Architectural Sciences. The aim of the class is to provide students with an up–to–date theoretical and applicative overview of the new and evolving trends in digital representation for project development and communication. In view of the interest shown by students, with applications for more than the 150 places available, in 2013 the course was elected as an optional Athenaeum class, extending the offer to the courses of Design, Territorial Planning and Engineering (this last including around twenty different specializations). The student composition has become increasingly diverse over the years, with engineering students exceeding 35% in 2021. This has led to new stimuli for us to explore new subject areas, tailoring experiences to the students' curricula.
In the past and current academic year, the class, taught by Roberta Spallone and co–taught by Francesco Carota, Riccardo Covino and Valerio Palma, has aimed at incorporating the inputs offered by the most recent developments in AI and AR technologies. For this reason, AI for computer vision was introduced at a theoretical level through specific lectures held by the teachers and by invited scholars who deepened the relations between computer graphics, computer vision, human–machine interfaces, AI and also telecommunications and 5G in support of virtual tourism. AR module has been developed at a theoretical and operational level under the supervision of Valerio Palma.
The theoretical contents of the class focus on the representation and digital communication of the project, and are organized between photography in its relations with rendering, reconstructive modelling, representation in contests, product communication, animation, design communication in websites. The operative contents include learning of rendering and

animation techniques, developed with Autodesk® 3ds Max and Blender software, video editing with DaVinci Resolve, and AR with the combination of the Unity® graphic engine and the Vuforia® Software Development Kit (SDK).
The attention of the teaching team to free and open source software (FOSS) as well as to the possibility of carrying out the proposed experiments with computers and devices commonly in use and at a low cost orient the pedagogical choices.
In addition to an in–depth study of the theory, the practice requires groups of students of different backgrounds to work on the digital model of a project, which scope is defined by their specific skills (i.e. architectural and urban projects, product designs, mechanical components, characters animation, etc).
The operations to be carried out on these models consist of rendering and animation, which flow into static graphic products such as plates or brochures, production of a video and, as will be discussed in more detail below, augmented reality experiences applied to the graphic works (fig. 1). The results of this last activity will be presented below, highlighting the interaction between different types of representation and digital communication.

Insight Into the Module of AI&AR

The module on AI and AR technologies aims at providing students with skills to deal with new digital tools and the ongoing changes in the use of information in representation and design. The way we structure our knowledge and the way in which the models become operational are deeply influenced by the possibility of producing and collecting an increasing amount of data [Batty 2016; Datta 2017]. The tools we bring to the students' attention support the understanding of physical space as a means for accessing information and ordering it. Both AI and AR technologies benefit from the growing computational power available and dedicated hardware and software on mobile devices. AI, which has undergone unprecedented advancements in the last years, has found practical applications related to computer vision in many different fields [Goodfellow et al. 2016; Pezzica et al. 2019]. AR applications have spread over the past two decades, and related development tools constantly increase the range of trackable assets and the effectiveness of digital superimposition against real–time images [Amin, Govilkar 2015; Bekele et al. 2018]. The physical form of reality is a sort of multidisciplinary platform, a shared grid (tangible and visible) on which to lay many information strata and different interpretations. Thus, the study of AI and AR allows us to reflect on the links between virtual and real, clarify the potential and limits of data, steer the tools towards more flexible, updatable, and scalable solutions.
With this in mind, starting from experiences that mainly concern the architectural and urban scale, we try to stimulate an even wider interest, which may involve the different disciplinary paths of students attending the class. The program section dedicated to AR deals with the current development status of these technologies (both hardware and software), also by

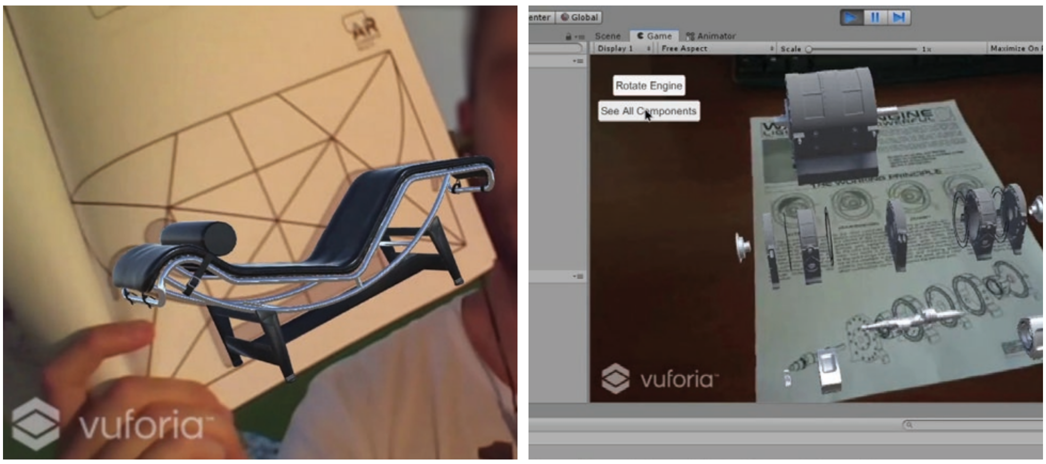

Fig. 2. AR exercises based on image tracking, developed in Unity and Vuforia. On the left: the object is superimposed against its design drawing. On the right: the user can start an animation to see the engine model disassembled; the figure shows the app preview in the Unity development interface. Authors: M. Ferraro, M. Marangone, D. Parente (left) E. Burati, A.L. Scardino, M.A. Valencia Zeballos (right).

Fig. 3. AR exercise based on image tracking, developed in Unity and Vuforia. The target image is printed on a mobile card to simulate an arm prosthesis. When the user reaches the virtual ball, the prosthetic hand grabs it. Authors: G. Brero, A. Porcelli, M. Pettiti.

Fig. 4. AR exercise based on image tracking, developed in Unity and Vuforia. The students presented a videogame in which the AR target image has to be reassembled before to se the 3D layer. Then, the user is challenged to search the correct viewpoint to find an hidden message. Authors: F. Rampolla, V. Mencarelli, D. Fiabane, M. Bosco.

presenting the research experiences conducted at the Politecnico by the teachers. Besides, we try to clarify both the potential of the technology and the critical aspects (*e.g.*, limits in interoperability). The theoretical part of the module deals with the most popular AR, AI tools for image recognition (in particular, AR image tracking functions and DL algorithms) and integrates insights into the role of fifth–generation cellular networks (5G) in future scenarios of transmission of information. The aim is to emphasize that technological advances do not only constitute quantitative leaps in data gathering but also require the transformation of the methods and models to organize digital information.

Objectives and Examples of the Students' Work

In the operational phase of the course (consisting of exercises) we provide the tools for building a simple AR application based on image recognition. We adopt the Unity video game development engine and the Vuforia AR kit, which are software with a short learning curve, requiring little previous experience with coding, and allowing free use for development. However, a broader landscape of competing products and development options is presented. Other practical indications are aimed at stimulating in–depth studies and experiments with particular AR or user interface functions, such as interactive elements, animations, other possibilities related to the integration of scripts and non–flat AR markers. Beyond the technical requirements of the deliverables, students are expected to conduct the exercises reflecting on two fundamental and connected aspects.

1. The first aspect is the link between real space and digital information (such as 3D models, graphic interface elements, databases). We expect students not to consider the real object just as the target for AR activation but as an object that can be studied through its digital model with the help of AR.
2. The second aspect that we ask to explore is the innovativeness of the developed application. In fact, in the case of digital representation, attention must be paid not to replicate uses of the model already available through other widespread technologies, such as virtual reality or simple on–screen navigation.

Therefore, we aim at continuity with the theoretical part, and we intend to highlight through practice the distinction between the excitement for novelty and more significant and long–lasting transformations enabled by technology.
Among the first year's results of this operational phase, several deliverables show good reception of the offered stimuli (the level of complexity depends on the students' choice to deepen AR or other topics in the program).
Some exercises emphasize the relationship between target image and model, letting the two parts complement each other, *e.g.*, by using a printed drawing to show the constructive geometries of a design object while the AR model, correctly scaled, shows the rendering (fig. 2, left). In other exercises with the simple image target system, students proposed interactive solutions, employing buttons and animations (fig. 2, right).
There are also more elaborate works. A team of computer and biomedical engineering students worked on a robotic prosthetic arm project (started in another class). They produced an application prototype that features a wearable target to simulate the use of the prosthesis. The exercise also included the interaction with other virtual objects, *e.g.*, for activating an animation of the arm (fig. 3).
Another team of cinema and media engineering students has instead created a gaming application that features the interaction between a website and the mobile device, proposing an enigma in which AR is used to change the point of view on a three–dimensional object (fig. 4).

Conclusion

It is difficult to speak of conclusions for a class that is constantly evolving. Rather, by recording the success of the new topics in terms of interest and results, new transdisciplinary perspectives can be outlined, opening up the possibility of developing master's theses and doctoral courses, as is starting to happen. In fact, a thesis in Design and Visual Communication has just been discussed. It combined the disciplines of Representation and Information Processing Systems in the realization of AR and VR experiences for the enhancement of the heritage of the Museum of Oriental Art (MAO) in Turin, and two more on the same topics are being prepared [1].

Notes

[1] This paper, the result of a teaching activity shared by the two authors, was written by: R. Spallone (Introduction, Content and experimentation of an evolving class, Conclusion) V. Palma (Insight into the module of AI&AR, Objectives and examples of the students' work).

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Limitations and Review of Geometric Deep Learning Algorithms for Monocular 3D Reconstruction in Architecture

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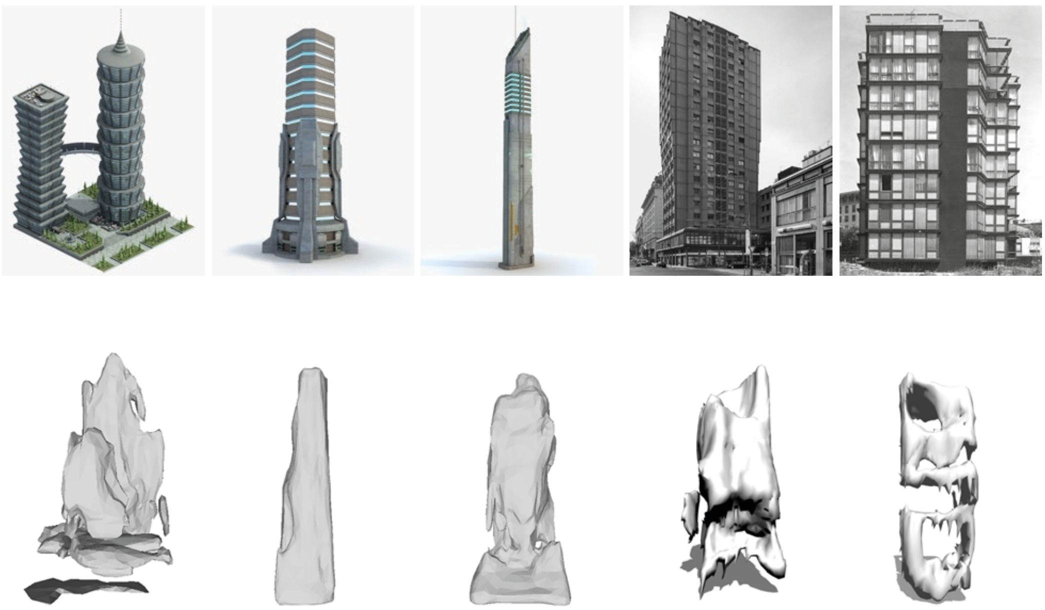
Abstract

This paper aims to test algorithms for 3D reconstruction from a single image specifically for building envelopes. This research shows the current limitations of these approaches when applied to classes outside of the initial distribution. We tested solutions with differentiable rendering, implicit functions, and other end–to–end geometric deep learning approaches. We recognize the importance of generating a 3D reconstruction from a single image for many different industries, not only for Architecture, Engineering, and Construction (AEC) industry but also for robotics, autonomous driving, gaming, virtual and augmented reality, drone delivery, 3D authoring, improving 2D recognition and many others. Henceforth, engineers and computer scientists could benefit, not only from having the 3D representations but also from the Building Information Model (BIM) at their disposal. With further development of these algorithms it could be possible to access specific properties such as thermal, physical, maintenance, cost, and other parameters embedded in the class.

Keywords
geometric deep learning, monocular 3D reconstruction, building envelope, architecture.



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Introduction

Currently, we mainly capture reality around us with static 2D media, such as pictures, or videos, in case we add the temporal component to it. For instance, architects represent their work with iconic pictures or render that convey their styles [Yoshimura et al. 2019], losing the sense of immersion provided by volumetric representations that can allow the user to explore the environment thanks to real–time rendering. Furthermore, when architects perform surveys, they capture the environment with methods that are prone to errors, motionless pictures, expensive laser scanners, or other methodologies for classifying and streamline workflows [Grilli et al. 2019; Matrone et al. 2020; Xia et al. 2018; Chang et al. 2017]. Today technologies aim to create a more immersive experience that can help in the long term to fill the gap between a 2D representation and the 3D physical space (in this paper, we won't consider temporal representations and others related to higher dimensional spaces [Rempe et al. 2020]). Thanks to depth sensors, lidar sensors, stereo imagery, it is possible to capture more information that helps us obtain 3D representations from 2D media like videos, panorama pictures, or even single 2D pictures. State–of–the–art (SOTA) algorithms are democratizing how we generate 3D objects from a multi–view or single view representation. For example, the so–called 3D photos produce a more immersive and dynamic representation [Kopf et al. 2020], allowing users and consumers to interact with their media thanks to the engineering use of the gyroscope in the devices.
The multidisciplinary inherited advancements in these technologies will provide better machine perception, a more immersive environment, and instant geometrical representations of objects and space [Keshavarzi et al. 2019; McCormac et al. 2016]. For example, nowadays, AR/VR experiences require an initial calibration process for the headsets. This is not instantaneous and requires an accurate scanning of the environment creating an adoption barrier for new users. Allowing an instantaneous representation of the environment from a single picture can benefit many applications, not only for AR/VR, but also indoor robot/drone navigation, especially within the building environment, where the environment is dynamic and subject to continue transformations. Such methods will allow easy authoring of 3D content, users will be able to obtain the 3D reconstructions of objects after taking a picture. The obtained reconstruction could be modiufied further as desired and would serve as a good, realistic starting point saving lot of effort. After presenting the importance of converting a monocular image instantly into a 3D model, we need to analyze the output formats produced: the file format [Ahmed et al. 2018], geometric representation, and dataset format [Gao et al. 2020] . Approaches like Mesh–RCNN [Gkioxari et al. 2019] produce 3D meshes by first identifying the objects in the image (Faster RCNN/ MaskRCNN [Gkioxari et al. 2019; Ren et al. 2017; Girshick 2015]) and then predicting coarse voxelized object, which is further refined to pr duce meshes. These meshes can later be sampled to point clouds where metrics such as chamfer distance and EMD can be applied. Other procedural methods have been taken into consideration and examined [Nishida et al. 2018; Liu et al. 2017]. Unfortunately, they lack flexibility, and they require considerable efforts during the initial stages to define a shape grammar that can produce the desired output. In this research, we tested and compared different approaches explaining their potential and current limitations in the Architectural Heritage. We tested: Mesh–RCNN, (figs. 0-1) Occupancy Networks [Mescheder et al. 2019], Pix2Mesh [Wang et al. 2018] and other solutions into the wild. These AI–powered techniques can blend digital and reality in a much more democratic way without expensive and bulky HMDs with multiple cameras. This paper experiments with new functional differentiable rendering frameworks like Pytorch3D (used in MeshRCNN) to explore 2D–3D neural networks. Moreover, working with 3d embedded semantics [Zhang et al., 2020], hierarchical graph network [Chen et al. 2020], it could be possible to encode shapes into images and learning their 3D part assembly from a single image [Li et al. 2020]. For example, after taking a picture of a façade, it would be possible to recognize its parts and regenerate a 3D model with windows, doors, balconies, and other sub–parts with associated information (BIM), and semantic properties ontologies. In this paper, an extensive review of state–of–the–art methods is presented to better understand current limitations and opportunities specifically for architecture.

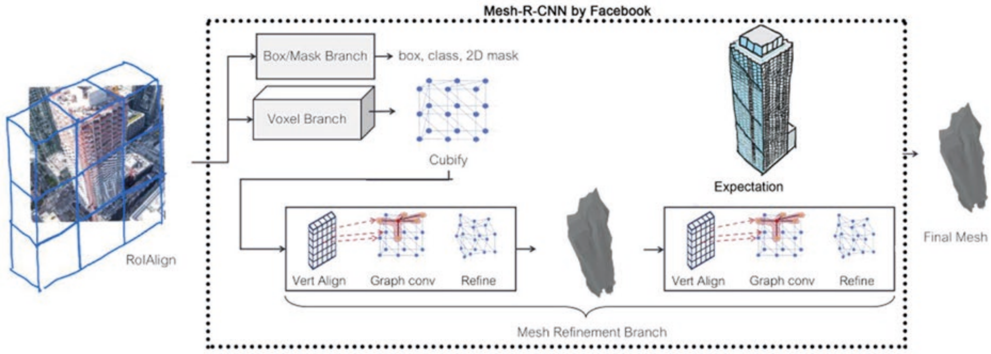

Fig. 1. Original from Facebook MeshRCNN – Adaptation to Architectural Field. (Testing Mesh–RCNN on the pictures of building envelopes).

Related Work

Methods for 3D reconstruction from single–image are complicated by the fact there could be many possible reconstructions when the object is not entirely visible; hence, most of them need to rely on strong supervision. Therefore, they use datasets such as ShapeNet or ModelNet [Wu et al. 2015] Other methods learn from images paired with aligned 3D meshes or require keypoint annotations on the 2D training images [Wu et al. 2016] and/or multiple views for each object instance, often with pose annotations. Shading becomes an important cue for 3D understanding, explored in numerous works over the years [Henderson et al. 2020]. Different methods have been explored in the past: mesh based such as N3MR [Kato et al. 2018], or voxel based like 3D–R2N2 [Choy et al. 2016] and MVD [Smith et al. 2018], or point based like PSG [Fan et al. 2017] and many others [Aubry et al. 2014]. These have issues in performing a complete task with objects not within the training distribution, so we wanted to confirm our hypothesis and stress these limitations [Henderson et al. 2020; Wang et al. 2019].

3D Reconstruction From a Single Image

Learning–based 3D reconstruction works are based on different 3D representations as presented before. While voxel representations prove to be computationally expensive, point cloud representations are demonstrated to be rotation and translation invariant, and computationally more efficient than voxels [Liu et al. 2019]. Moreover, mesh representations, better preserve the connections between distinct parts and are more suitable for fine–grain detailed representations. Modern implicit functions not only prove to be extremely efficient with their continuous and differentiable representation of the iso–surface with a binary value indicating whether a point is within the volume, but also more accurate for tasks such as reconstruction and 3D shape completion [Gu et al. 2020]. Nerf, Occupancy Network, DeftTef [Gao et al. 2020] have recently followed for this task.

Within the AEC, 3D shapes and objects preserve a common grammar and they are composed by a fixed set of components such as windows, doors, roof, floors, walls, and others. While the typology can change, the main elements in the building stay the same for most cases (except for some iconic buildings and pavilions). The philosophy of Hoffman and Richards influenced this research. In fact, they viewed object recognition tasks as a visual system decomposition of shapes into parts with their descriptions and spatial relations. In the same way, we propose that the best way of representing a building reconstruction is to assemble each component together, orienting their quaternions to perfectly fit an initial picture which was inspired by the CompoNet work [Schor et al. 2019]. In contrast to the approach, we aim to translate the assembly algorithm, specifically for an an architectural task. They used a generative neural network for generating 3D shapes from a 2D image, based on a part–based prior, where the key idea was for the network to synthesize shapes by varying both the shape parts and their compositions. Treating a shape not as an unstructured whole, but as a composable set of deformable parts, adds a combinatorial dimension to the generative process to enrich the diversity of the output, encouraging the generator to venture more into the "unseen".

They generated a plethora of shapes compared with baseline generative models using their custom metrics. The assembly–based synthesis was inspired by 3D shape assembly research that generates new shapes from a combination of various parts [Huang et al. 2020; Li et al. 2019] from a single image.

Conclusion

We saw that projects such as Mesh–RCNN lack the ability to perform well with unseen classes. This limitation of generalizing to unseen classes make these approaches challenging to adopt. Furthermore, the training of these algorithms required multi–GPU training(8 GPUs V100, for Mesh–RCNN) that not all the researchers can access. The current lack of a common balanced dataset (with intra and inter–class variance), or pre–trained models that generalize well to unseen data, are missing in the research community, and with this research we hope to stress the importance of the creation of such datasets and models. Another limitation is embedded in the metrics used to evaluate the performance of these algorithms: chamfer distance, EMD (earth moving distance), mAP and others offer good quantitative results distant from a recognizable representation that follows qualitative results. Finally, the creation of such dataset could provide new research on 3D shape explorations for architects using Generative Adversarial Network in 3D like ShapeGAN and 3DGAN [Kleineberg et al. 2020; Freeman et al. 2016].

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