Data, Models and Visualization: Connected Tools to Enhance the Fruition of the Architectural Heritage in the City of Padova

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Data, Models and Visualization: connected tools to enhance the fruition of the architectural heritage in the city of Padova

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Abstract

This contribution focuses on the relationship between informative models, databases and innovative visualization tools, as crucial inputs for the knowledge and management of cultural heritage and for the interaction with the design process. Along with the ever-growing development of survey, storage and analysis technologies, upgrading the representation tools can support the interpretation and processing of the new available information assets.

The Tu-CULT *research project has the purpose to acquire, store, process and disseminate data regarding the monuments of the city of Padua, studying how the information and communication technologies (ICT) contribute to the management of the architectural heritage and to the design of transformational scenarios involving the monuments. Specifically, we address the issues of digital survey and archiving, 3D information modelling, and multimedia visualization for a multi-level access to the collected documents and the developed scenarios.*

Keywords. ICT; database; BIM; cultural heritage.

1. Introduction

Architectural and urban design is a process of accumulation, integration, editing and communication of heterogeneous and complex data. Representation, as an interpretation and synthesis tool, is a key component of the design process: it allows to organize and understand surveys, to build sets of relationships across different disciplines and points of view, to identify and communicate the results of studies and projects. This role gains a particular importance in the fields connected to cultural heritage, as a fast technological advancement is continuously innovating the quality, quantity and detail of the available information. In the phases of collecting, processing and displaying these knowledge assets, representation can then take advantage of the potential of ICT, and clarify the scopes and limits of the new technologies. Because of its capability to deal with different scales and themes and to connect them, it can bring together various informative and critical media, and can provide strategies to manage architectures, cities and landscapes.

In order to achieve an integrated approach to cultural heritage, this research identified three contributions which have innovative features and are in a close mutual connection (Fig. 1).

1. *Informative models* are a first instrument. These are gaining a central role especially in constructive processes, and are changing the relationship between project and representation. Building information modelling (BIM) — at the architectural scale — and geographic information systems (GIS) — at the

territorial scale — bring an increasing attention beyond geometry, to build models that provide further information about the represented object.

2. Models can exchange data with *databases*, allowing to collect and archive the information on the architectural object. Populating a database consists of selection operations — from existing, ever-growing data sources and from new surveys — and management operations — to outline the relationships between the analyzed elements and to face the problems of huge dimension data as those of point clouds obtained by digital surveys.

3. Up-to-date visualization and communication *multimedia tools* can verify and support the accessibility of collected documents and design outputs. These tools include virtual and augmented reality interfaces, multilevel access software, multimedia installations, and other models allowing interaction and queries.

Through the integration of these disciplines in the design practice, the workflow gets improved and new connections between the project and its representation are introduced. It is therefore important to define the links between BIM, databases and new multimedia tools, and each specific contribution to the project.

The project entitled *Tu-CULT – "The Cultural Tourism knows no crisis: ground-breaking strategies to restore, preserve, guarantee multi-level accessibility and improve the smart use of the artistic and architectural heritage"* was funded by the Regione Veneto under the ESF program 2014-2020, and involved research fellows from the University of Padua and the University IUAV of Venice. Starting from this research experience, the paper analyzes the identified themes for the case studies of two monuments of the city of Padua: the church of Santa Maria dei Servi and the Basilica of Santa Giustina. It focuses on data collection, processing and representation, aiming to improve the use of the architectural heritage, and to implement strategic planning scenarios involving architecture and the urban context.

The research began with the collection of information — historical photographs and cartography, drawings, digital reconstructions... — through archive research, documentary analyses, and topographic and architectural surveys, that made use of photogrammetry and laser scanning technologies. In a second step, the available information was connected to interoperable informative models, employing BIM technologies. In a third step, a shared platform to upload and download the information from all the sources involved was provided. A website makes the database and the outputs accessible to users at different levels.

The research aims to investigate through a technical review which are the most appropriate computer aided tools to carry on this workflow, and what are the new languages, conventions and standards that assure a long-lasting possibility to share through different software and devices the digital representations produced — especially employing free and open source software (FOSS), to ensure interoperability and cost containment.

The analysis points out the potential of the three groups of instruments, as well as their interaction, demonstrating how new resources can produce a significant multiplication of the results.

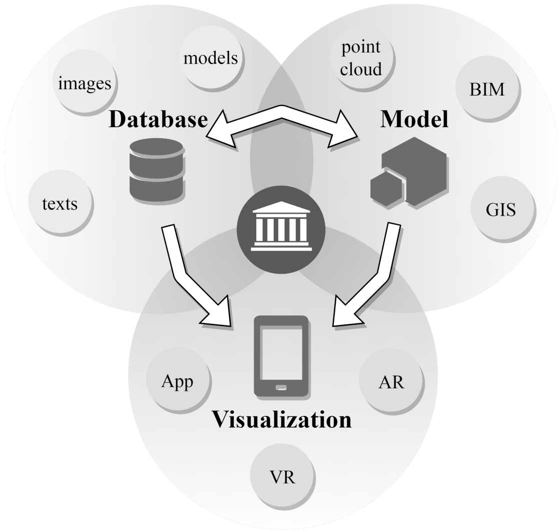

Figure 1. Scheme of the three connected contributions to the valorisation process analysed in this paper. The model and the database exchange information in a mutual connection, while the visualisation tools fetch the results and make them available in different formats.

2. *Background*

The *Tu-CULT* research project can be considered as a deeper investigation of the process applied to a previous study focused on the Eremitani Church in Padua (Borin and Pedron, 2014; Giordano *et al.*, 2014) which develops methodologies for the enhancement of cultural heritage in terms of preservation and communication referring to its historical and architectural data (Bortot *et al.*, 2017). The workflow set for the Eremitani Church constitutes a general process that can be applied to other cultural-architectural contexts. In the case of the *Tu-CULT* project, it was exploited and improved in order to achieve a knowledge base on two important religious buildings in Padua: the Basilica of Santa Giustina (Bresciani Alvarez *et al.,* 1975), a renaissance church that faces Prato della Valle; and the church of Santa Maria dei Servi (Zampieri *et al.*, 2012), built in the 14th-century and located in one of the main streets of the city, via Roma. These two case studies are very different from each other especially from the morphological point of view; this choice was meant to improve and verify the process as a standard and extensible framework for the architectural heritage.

A fast evolution of the technologies for capturing, editing and visualizing data is constantly updating the approach to the architectural cultural heritage, causing a multiplication of the file formats employed and a growth of the information that need to be interpreted (Cerutti *et al.,* 2015). One of the challenges in research and dissemination dealing with representation tools from ICT, is to understand how to produce an information that can be read, integrated and updated through time. Various solutions are based on making the contents available through web platforms, and these employ SQL databases to manage the information (Scianna *et al.*, 2016; Auer *et al.*, 2014).

Previous experiences — among others, the aforementioned *Eremitani* project and the *Visualizing Venice* project, see Giordano (2017) — suggest that the implementation of BIM in the studies that involve cultural heritage constitutes an indispensable backbone in order to achieve a real integrated framework. A BIM is a building model based not only on geometry but also on multidisciplinary information, which include all the links and the hierarchical relations between the elements. It can be considered like a shared digital representation of a construction with its physical and functional characteristics, based on open standards for interoperability.

Even though in literature the theme of BIM is more discussed with regard to new buildings (Volk *et al.*, 2013), the central role that it plays in this case is, nevertheless, confirmed by a series of studies since the definition of HBIM (Historical Building Information Modelling) as the reverse engineering process of mapping informative geometry on the point cloud with the advantages of accelerate the operation time, reduce the errors and exploit the opportunity to “develop detail behind the object’s surface concerning its methods of construction and material makeup” (Murphy *et al.*, 2009).

The complex system conceived in the present research — interlacing models, databases and visual user interfaces — intends to embed structured information, which requires appropriate tools for communicating, sharing and disseminating data: «considering the basic meaning of the term “communication”, as “sharing or exchange information, ideas, or feelings” we could assert that behind the act or the instance of communicating there is the way we share information. On the other hand, aside from its simplest meaning as “presenting again” the term “representation” includes the important features of knowledge, illustration and interpretation, as well as the communication of information, ideas, or feelings» (Giordano, 2017).

The value of such an interoperable digital representation is double: it is a tool for preserving geometrical and historical data in relation to digital survey and database and it performs the function of an informative communication tool applicable to several platforms with dissemination purposes.

3. *Discussion*

3.1. Survey

The first phase of the research was based on architectural survey. It consisted in the acquisition, the elaboration and the organization of data through technologically advanced instruments, preparing the ground for the modelling operations and the communication and fruition design.

The architectural survey project was organized in the following steps:

- developing operational strategies for detection regarding the choice of techniques (topography, photogrammetry, terrestrial laser scanning, etc.) and then planning the best positioning of the points from which to take photographs (internal and external) and to perform scans of the interior spaces, the exterior elevations, and the

urban context (Fig. 2);
- choosing the criteria for the organization of the photographic documentation to be acquired during surveys in order to be available for data processing needs;
- planning the accurate registration (chronological and thematic) of progressively carried out activities;
- collecting adequate literature references and historical iconography to support a critical reading of the construction phases of the monument;
- setting up three-dimensional representations based on digital data, according to the BIM interoperability protocols.

The three-dimensional survey project of the churches was carried out with integrated techniques of GPS positioning and topography for the main and secondary networks, required for subsequent terrestrial laser scanning activities. Photo-modelling was used to increase the geometric definition of the models, and to achieve a better quality of the photographic colorimetry, previously obtained by other techniques, and, furthermore, to have an additional digital comparison and verification model. The 3D laser scans were made with the Leica ScanStation C10 sensor (Leica Geosystems SpA) and were organized in two sub-projects for each church: a first one for the interior spaces, a second one for the exterior elevations and roofs. In the church of Santa Giustina, the more extended among the two case studies, the 3D laser scans made outside were 34, while 268 scan station were required to acquire the inside, due to the complex planimetric and altimetric articulation. The external spaces are similarly articulated also because of the numerous stratifications (demolitions and new constructions) that affected the monument over the centuries. Furthermore, the building is mostly embedded into the conventual fence, now partly intended for military use, so it was not entirely accessible for the survey purposes. The implementation of a complex network of control points (two-dimensional black & white targets, 15x15 cm) was necessary to cope with morphological complexities in external spaces. The accurate spatial determination of 2D targets, made using the 3D laser scanner and topographic sensor (TCR 802), was crucial for recording and systematizing all acquired point clouds.

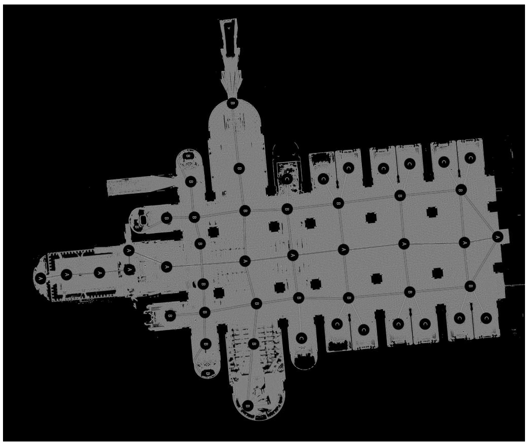

Figure 2. Top view of the ground floor of Santa Giustina — as seen in the complete point cloud obtained through laser scanning — showing the points from which scans have been performed.

In the church of Santa Maria dei Servi, the 3D laser scans performed were 19 in the external spaces and 47 in the interior ones. Although the same methodological approach was applied, the overall number of 3D laser scans was considerably lower than in the other church, because of the fewer internal spaces, their simpler spatial articulation, and because, due to its morphology, many of its external elevations are embedded in adjacent buildings.

Beyond the geometric acquisitions with these technologically advanced but highly consolidated and widely used systems, some open-source 3D real time surveying systems were experimented. The combined use of ROTBmat ROS (Robot Operating System) and a simple Kinect sensor (Microsoft) had made interesting results since its first applications, for operational usability and metric accuracy. These encouraging results prompted the research team to continue the experiments of the ROS + Kinect system in the attic of the church of Santa Maria dei Servi. A part of the attic was chosen where scanning problems were encountered with SFM and 3D laser scanning techniques, due to the difficulty of moving cumbersome and heavy sensors, the time needed for these actions, and the acquiring data.

From photographic documentation to 3D laser scan results, all digital or digitized material has been archived to allow for better control of reliability and verifiability of the research, at any time. The numerous acquired data were systematically edited to be stored in a database, subdividing the point clouds into lightweight files. The whole architectural survey process was conducted with criteria of verifiability and repeatability by third parties (scholars, visitor users, technicians, other researchers) who could draw on systematic and well-archived information of various nature in their approach to architectural heritage rich in information, thus avoiding having to start from scratch.

3.2 Modelling

The modelling phase, included in the process of protecting and enhancing the cultural asset, elaborated the input data from surveys and historical documentation, and prepared the development of digital applications. Here the models acted as an interoperable data exchange tool with both the cloud points and the database, generating an organized workflow that made available a multidisciplinary set of information in a relational space. In order to develop this framework, a primary activity was the development of a language to connect models and databases. In this case, a visual programming language (VPL) made possible to execute specific data exchange operations, including the reading and writing of geographic data, the indexing and management several of copies — or *instances* — of an object and the creation of links to access the database through the BIM environment (Fig. 3).

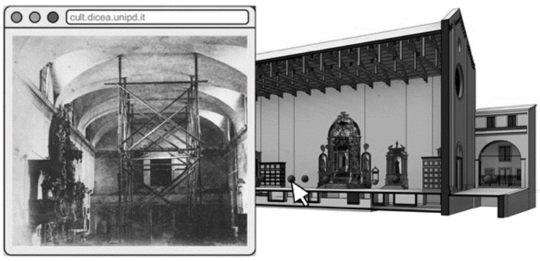

Figure 3. All the instances in the model are linked with the object in the database. The image shows an example of integration of historical photos in the BIM: spherical entities with an URL link refer to the images and allow to visualize them in real time.

In this way, the BIM models form a database extension, providing the latter with the opportunity to express the information contained in it through three-dimensional digital representations. In addition, since the BIM authoring software is based on parametrization, it allows to create a catalogue of typologies related to the created objects that enriches the database itself. The modelling of parametric geometry allows an accurate and flexible generation of various dimensions and the automated adaptation to other components (Apollonio *et al.*, 2012). In this way, the tool is validated as a suitable device for the study and an understanding tool to support the architectural representation. Within this framework, numerous types of architectural objects belonging to the two churches have been identified and catalogued, dividing them by categories — doors, windows, vaults, domes, columns, pilasters, buttress, capitals, cornices etc. —: "The objects of different categories vary in semantic meanings and inherent behaviours" (Apollonio *et al.*, 2012). Figures 4 and 5 show some examples of how these solutions allowed not only to reduce of the modelling times, but also to create a practical typology catalogue of architectural elements.

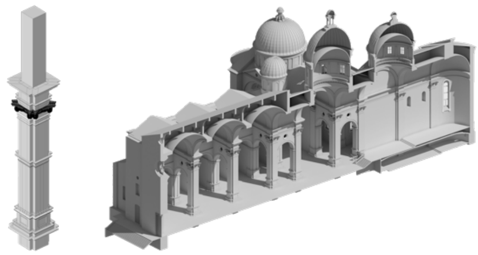

Figure 4. The image shows the system adopted for the construction of the pillars of Santa Giustina. Crossing the various data, we identified a repetition of the decorative architectural elements that recurs in the complex ornamental structure of the pillar. Therefore, referring to each side, there is a single family that contains the decorative architectural elements, but depending on their position in plan the elements can be considered present or not, compiling a set of parameters.

The potential of the BIM technology made possible to implement the organization of information within the interoperable platforms (preferred in open source environment) in order to ensure considerable flexibility. The content has been organized and made available to the public user through ICT (Information and Communications Technology) applications. Such tools can, for instance, express what has been discovered during the reconstruction of the historical phases of the churches, starting from the data (metrical surveys, archival documents, paintings, engravings) and arriving to the models (Figs. 6, 7, 8). "The technology would suggest new ways to think about the narrative of the past" (Staley, 2014).

Figure 5. Exploiting the potential of the BIM tool an interesting cataloguing of parametric objects has been created, they are virtual entities of the structural stubs and have been used as a "negative" surface to realize the vaults and domes.

The study of the communication tool suitable for this purpose is not trivial, even if some aspects of the practice are becoming consolidated, in fact, others need to be further developed. Some others, however, demonstrate to be obsolete nowadays, due to the continuous and rapid development of the technologies linked to computer systems. This is particularly relevant when applied to the tools and the techniques dedicated to the divulgation of historical and cultural information, where it is essential to evaluate which system is the best for fixed purposes, taking also into account that a technologically advanced system is not necessarily the most suitable practice.

Figure 7. Mobile app that takes advantage of Augmented Reality. It allows to view on the spot projects that have never been realized for the façade of Santa Giustina.

3.3 Database

The employed methods to gather and edit information on the buildings, their content and their surroundings gave access to a vast and complex documentation, that was recorded into different file formats.

We developed a framework to store and organize files, with the following main objectives:

- ensuring a long-term accessibility of the collected information;
- setting up a highly interoperable information model;
- offering management, visualization and query tools at different user levels.

The tool aims to keep track of every status of data processing and updating, and makes files accessible through a web server. The archive stores text, image and 3D graphic files, along with a related set of metadata.

With the aim of making the whole system standardised and widely compliant to other archive standards, the Dublin Core Metadata Initiative set was chosen, to describe the archived objects and their relational structure (Giordano, 2017). This schema shows advantages in managing heterogeneous documents and in web applications (Kakali *et al.*, 2007).

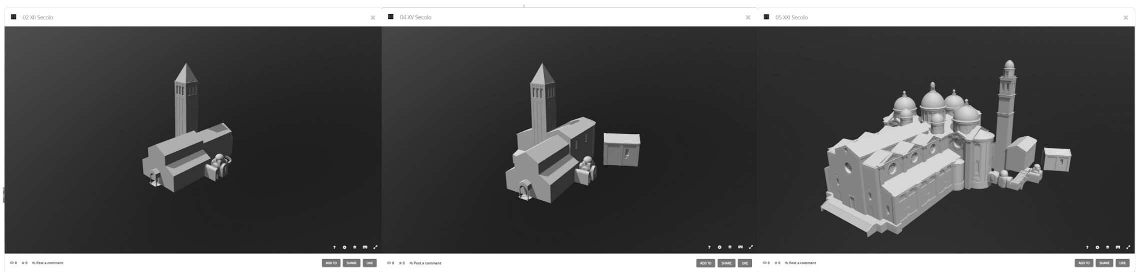

Figure 6. An interactive tool to see the model in the various historical phases that characterize the church.

Figure 8. Mobile app that takes advantage of virtual Reality. It allows to display the historical phases of the church of Santa Maria dei Servi while pointing to the internal elevations.

Several sources feed the information asset related to each database entry, depending on the associated file type. Bulk updates are possible through VPL tools applied into the BIM environment, allowing to get semantic information from the 3D models. Through GIS software, geographic properties can be calculated from geolocated elements, point clouds and topographic surveys (Fig. 10). Furthermore, many scripting tools can automatically inherit a selection of metadata already embedded within the uploaded files, such as EXIF informations about digital photographs.

The structure of this digital archive is composed by a database, a web server, and web interfaces for both admin and public users, and it makes extensive use of FOSS tools. The database was developed in PostgreSQL, a Relational DataBase Management System (RDBMS) available under open source licence. It supports the PostGIS extension, to manage geometrical and geographical data through query and editing functions. This permitted to connect the database to the open source software QGIS, which is a first access level to the resources on the administrator side, particularly focused on the geographic attributes, their editing and their visualization on maps.

The Django framework allows to manage the database through the Python language, and to create user-friendly administration web pages at the same time, based on the structure of the database itself. This second access level is suitable for a non-technical use by authorized user who can expand the archive through structured forms, i.e. adding files, geographic markers and specific metadata. The software and languages to host the application on a web server are also FOSS resources.

Original templates to generate web pages were programmed into the Django framework, to offer a third access level to visiting users, according to the DB contents which are chosen for a public availability. The responsible design of the web interface allows for a use on both PCs and mobile devices.

The website features an essential graphic design to make it easily accessible for different users, and suitable for different contents (Fig. 9). The *Tu-CULT* logotype is a synthesis of the research title and it contributes to the dissemination objectives through recognizability and ease of reproduction in different contexts.

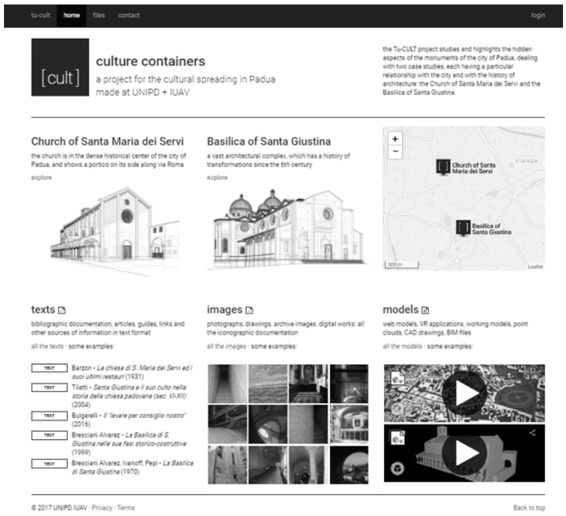

Figure 9. Screenshot of the website linked to the database (http://cult.dicea.unipd.it)

The various multimedia representation tools connected to the database are meant to pursue the distinction of user targets. We chose the free service Sketchfab for the web visualization of 3D models, due to its ease of use and fast implementation (Barrettara, 2013). The service can be integrated into web html code and can be shared through social network platforms, promoting the dissemination of results. An interactive interface allows to navigate the models using different devices, to enter immersive reality functions on mobiles, to check informations and move through predefined point of views (Scianna *et al.*, 2016). The database structure can connect the visualized models to their semantic definitions and to the related documentation, making more complex informative models available for advanced users (BIM files, GIS data).

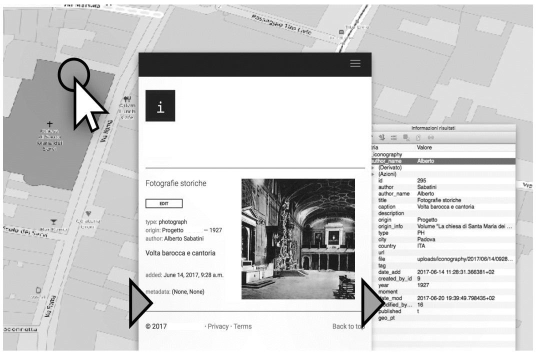

Figure 10. Representation of the double-way connection between the software QGIS and the web interface of the archive, made possible through the PostgreSQL database.

4. Conclusions

One of the most important outcomes of the research was the conjunction of compelling and scientifically accurate representations of the studied monuments with a dissemination and research platform which stores, connects and multiplies the results.

“The creation of the 3D model must be carried out by considering the requirements of BIM technology. The model is not only a virtual representation of the construction. It is a vital part of the project, where the different elements of the building become advanced objects with parametric intelligent” (Barazzetti *et al.*, 2015 a). “The BIM can be intended as a central tool for the accurate investigation of the building” (Barazzetti *et al.*, 2015 b). Similarly, when the BIM model is referred to cultural heritage (HBIM), it becomes a historical database embodying a powerful tool of conservation because it allows to understand and enhance the information (easily accessible by historians, architects, engineers and other professional figures). Furthermore, through these content, it allows to activate devices (mobile or fixed installations) that can be accessed by the “generic public”, who demonstrates to be interested in it and to have the will to engage with these types of contents. This main goal, expressed since the very beginning of this project, is not based on the “artistic show” of the adopted system, but rather on the expressed desire for clearest and simplest to use systems, considering that these tools are directed towards a wider audience, and not necessarily to a specific sector of specialists.

The wide use of FOSS resources ensured the economic sustainability of the development of the project and supports the future maintenance and improvement. These tools confirmed also other expected efficiency criteria, including a wide software compatibility and the chance to implement standard data formats, providing scalability and interoperability to the developed framework.

Further developing steps concern a better interaction between the database and its contents, to activate an exchange semantic information with the connected BIM and GIS data, although a seamless integration of these schemas is still to come, and many compatibility issues have to be addressed (Tobiáš, 2015).

On the user side, implementing crowd-based solutions — i.e. improving the mobile device compatibility of the interfaces through apps — can enrich the archive of up-to-date contents and add new informative layers. Taking advantage of the flexibility of the database, other functions can be added to the web services and apps, such as interactive 3D models, or geo-localization and micro-localization based real-time queries.

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Authors bio statement

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Valerio Palma is a PhD candidate in Architecture History and Design at Politecnico di Torino, where he is enrolled in the FULL Interdepartmental Centre. He holds a master's degree in Architecture and Urban Design from the University of Roma Tre (2016). He has been a research fellow at the ReLOAD Lab of the University of Padova (2016-2017), dealing with interoperable digital models for architectural cultural heritage. His work focuses on the use of quantitative models for the analysis of urban transformations.

Federico Panarotto graduated in Building Engineering at University of Padua. After having participated in several research projects, he is now a PhD student at the Department of Civil and Building Engineering at the University of Padua. He participates in teaching activities at the Drawing and Representation Laboratories (LDR) and is interested in three-dimensional computerized modelling and BIM (Building Information Modelling). He is the author of books, numerous papers in scientific journals and conference proceedings.

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