Parametric planning for the restoration and rehabilitation of architectural heritage

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Abstract

Over the last decade, economic, financial and social issues have undermined the construction industry, leading to a worldwide crisis. Restoration and energetic rehabilitation have become increasingly more common within the construction industry. Notwithstanding the fact that it has a significant architectural heritage, Italy has proven not to be ready to face demanding projects regarding the rehabilitation of historical buildings. Therefore, numerous construction companies have missed out an important source of income and have left EU Structural and Investment Funds untouched. The reasons for these Italian problems include: the lack of long term programming; shortage of quality control systems as well as the lack of team work.

The aim of this paper is to show that the use of BIM – Building Information Modeling – can solve many of the aforementioned problems connected to rehabilitation projects. In fact, the efficiency and benefits of this kind of approach towards the analysis, management and planning of rehabilitation projects have proven to be significant. In order to prove the efficiency of the BIM, a study was carried out to compare the cost-benefits of both a standard as well as a BIM survey when surveying a historical building. With the aim of this research in mind, the team decided to survey the castle of Francolise, in the province of Caserta.

The aim of this article is not to show how BIM surveys work, but rather the actual efficiency of the BIM survey when used to survey historical buildings. Before starting the analysis, it is important to underline that protocols – which could define the usage of the BIM for existing buildings – have yet to be created.

Foreword

The European Union has promulgated a public procurement directive, expressly requiring the modernization of public contract regulations. The document, asks the 28 Member States of the European Union to use BIM for public contracts and design contests founded by the EU: *"...for work contracts and design contests, Member States may require the use of specific electronic tools such as of building information electronic modeling tools or similar..."*.

If on the one hand, many countries around the world (such as Finland, UK, Germany, Korea, Japan, etc.)use BIM as a standard surveying tool, with it having now become a keyword in the construction business, along with the words *Mobile, Field and Lean;* on the other, regulations for the use of BIM have yet to be issued in Italy. The lack of any form of BIM regulations has not affected Italian businesses, due to the fact that BIM surveying is not as widely used as standard surveying. However, in order to allow Italian companies to operate in the rest of Europe and extra-European territories, issuing regulations is a necessary step.

The role of BIM in architectural rehabilitation

Architectural rehabilitation aims to rehabilitate an existing building while keeping its intrinsic and extrinsic properties intact[1].

Although they are subject to the norms UNI 10838-10914/1-11150 (1-2-3-4) and 11151, rehabilitation processes require a revision of the technical instruments and regulations. In order to do so, every different case requires an analysis in order to rehabilitate the building taking into account its unique features. Moreover, rehabilitation projects also require a careful management, planning and programming.

A rehabilitation project in addition to respecting issued norms, also aims to preserve the characterizing features of the building. Over recent years, software such as BIM have helped construction companies to reduce the duration of projects, while also saving both time and work.

Building Information Modeling allows users to: firstly shape, inspect and check the parameters of a certain 3D model which matches the real life building; secondly, carry out a structural analysis, produce accurate data and drastically reduce planning issues; finally, reduce the risks connected to unforeseeable factors by simplifying any managing procedures.

1. De Joanna P., *Il recupero edilizio nelle aree protette. Norme e strumenti di programmazione, progettazione ed esecuzione*, Franco Angeli Editore, Milano 2010.

Introduction to BIM for integrated planning

Nowadays building processes are fragmentary and based on paper documentation, which contains all the project information (technical, contractual and administrative). Due to the use of paper documents, mistakes, omissions and miscommunications are still quite common and can lead to problems in the client-supplier relationship such as: delays, unplanned costs, lawsuits.
Building Information Modeling is a solution to many of these problems. Firstly, it does not require paper made documentation; secondly it allows to generate, modify and manage digitally the 3D model of a certain building; finally, it carries out a unique, implementable, up to date 3D model, which can eventually help prevent data loss, misunderstanding and redundancy.
This result can be achieved by creating shared BIM, a digital representation of the physical and functional characteristics of a real building[2].The3D model is made up of three-dimensional objects such as doors, walls, windows, stairs, roofs; the building's mechanical, physical and logistical features; elements within the building are connected by associative rules.
Parametric integrated planning is widely used for projects relating to new constructions, but its use for existing buildings is difficult and still being studied. If on the one hand, the use of BIM is helpful in new projects which deal with modern factories and contemporary building complexes because of their standardized features, on the other, the unique technological, geometrical and physical characteristics of pre-existing building's make the use of BIM more difficult. This obstacle can be overcome by using integrated and parametrical planning along with laser-scanner data. It is therefore possible to create a three-dimensional point cloud. The point cloud can be then modified and updated and the elements which do not match the modern standardized components within the BIM library can be added.

Parametrical planning for architectural heritage: BIM surveying

To validate the hypothesis, the team objective was to show the benefits and advantages of using BIM software. In order to do so, the Castle of Francolise was chosen as a case study, and the study group decided to carry out a cost-benefit analysis between the two different kinds of survey: the direct and the BIM survey. Some variables were analyzed using the two methods in order to compare them and define which method would prove to be more convenient in terms of costs, quality and precision.
However, this paper does not focus on surveying operations, which have been considered irrelevant elements.

The medieval castle of Francolise

The castle of Francolise is a medieval building in the city of Francolise, Caserta, southern Italy (Figure 1) and was built during the second half of the XIII century.
It is made up of four floors connected by two stairs, with a total surface of 1450 square meters. Although the second floor preserves the original materials, laminar wood has been applied for safety reasons to the other three.

The direct survey

The direct survey was conducted using standard instrumentation: tape measures, spirit levels and plumb bombs. The angles and edges were matched with measure points, which resulted in many triangular shaped schemes. Furthermore, the vertexes – which were not possible to define during the measurements – were found with a trilateration process.
This survey was completed in four days deploying two different work teams: one made up of three people who measured the inner walls; whereas the other, made up of two people, measured the outer walls. 48 sketches were produced.
The data collected was digitalized using AutoCAD. One team member was able to draw four sections and four facades taking into account technical drawing standards. This phase was finished in eight working days (Figure 3).

The BIM Survey

The BIM survey is quite different from the direct one. An important difference is the way the team members operate in a 3D space: not only did they use horizontal reference points, but they also took sloping position measurements. The points found were then put into a x, y, z coordinate system.
The BIM survey gave different results compared to the standard one, notably regarding the speed, which was extremely higher than the traditional survey. When surveying the inner area, the work team used a "Faro Focus 3D" laser scanner, which took 84 pictures per scan, with a resolution of 2Mpx, thanks to a CCD sensor. The laser has a 120 meter range, 122.000 points per second speed, and finally an

2. Osello, A. *Il futuro del disegno con il BIM per ingegneri e architetti*, Dario Flaccovio Editore, Palermo, 2012, p. 35.

Figure 1 – The main facade of the castle.

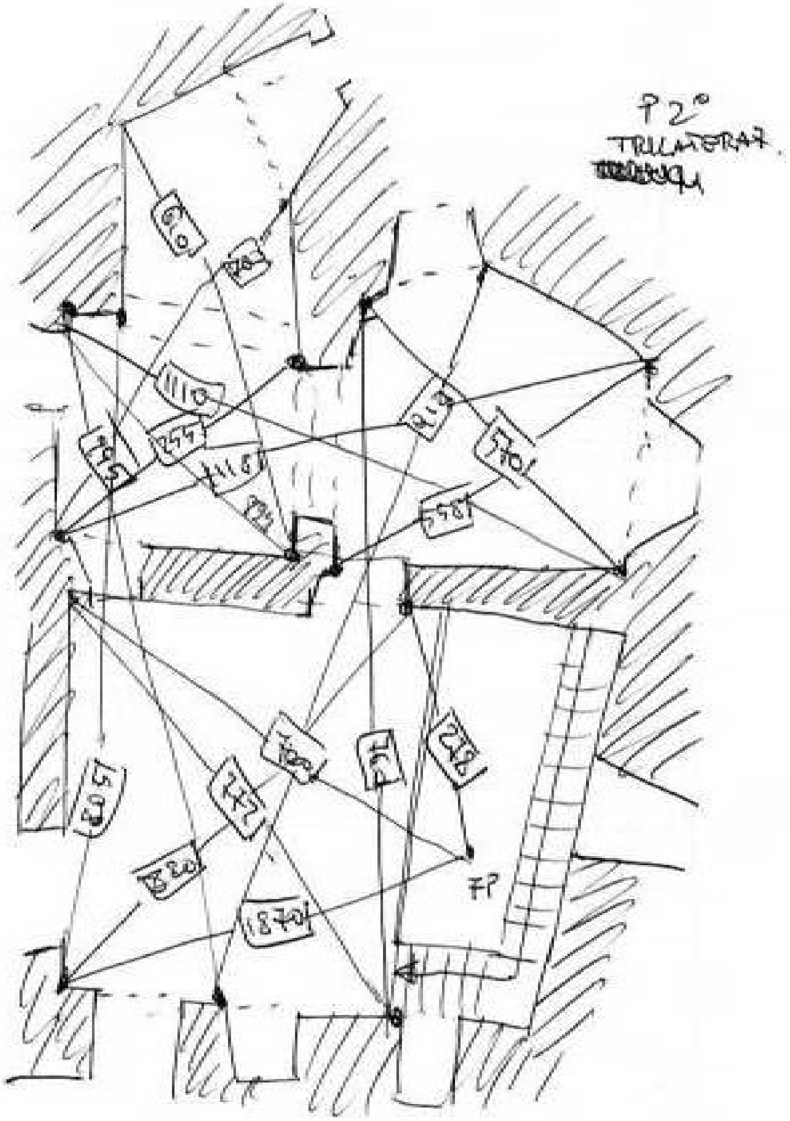

Figure 2 – One of the 48 sketches produced.

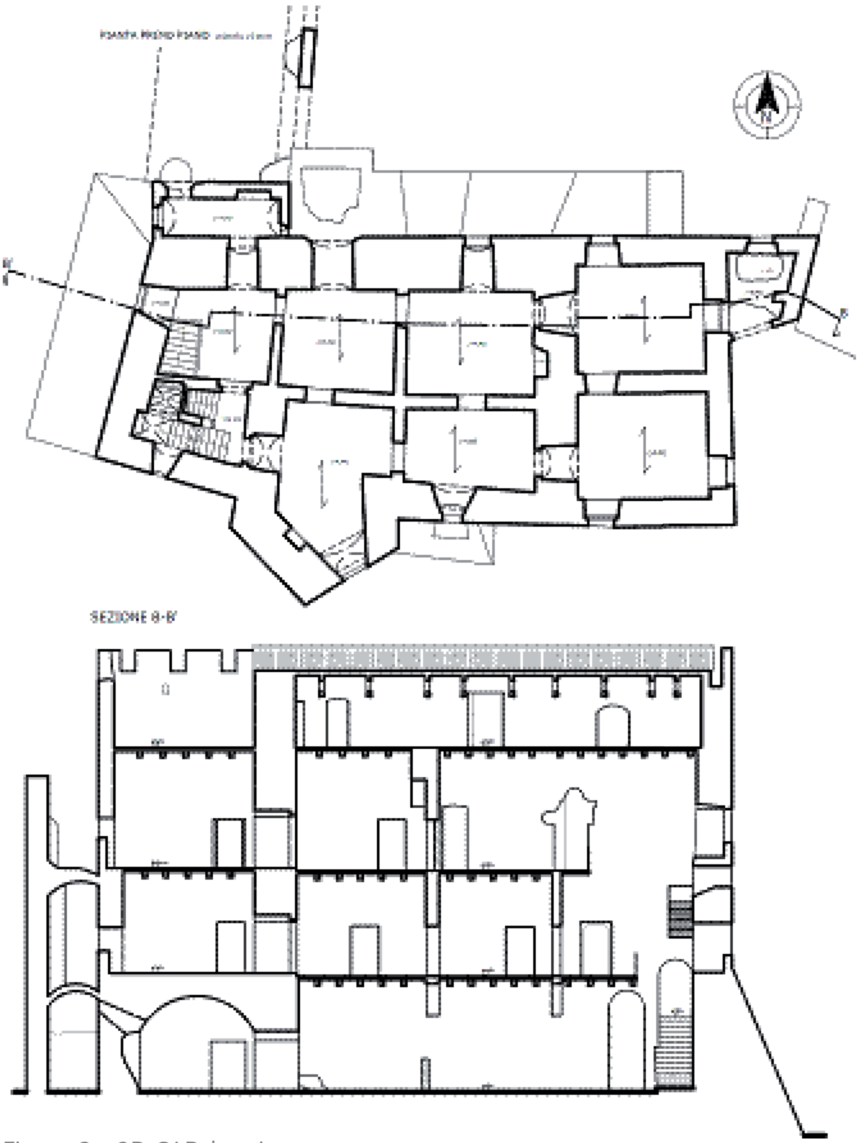

Figure 3 – 2D CADdrawings.

average error of 2 millimeters for 25 meters.
Due to the proximity of the objects to the laser, the resolution was set to 1/16; 4xqualityfor the inner spaces; scan duration: 2 minutes and 23 seconds; whereas for the outer spaces, the resolution was set to 1/8; quality 4x; scan duration 3 minutes and 44 seconds. (Table 1) A total of 36 scans - 29 for the inner spaces and 7 for the outer spaces (Figure 4) - was made by one team member in one working day.

The following phase was the most laborious and demanding. By using the homologous points present in the common areas, the scans taken were aligned to one another using the Faro Scene 5.1 software. This process was heavily simplified using software recognized targets. Furthermore, in order to prevent the hardware from overworking, the point cloud was decimated by deleting any unnecessary information. This task was completed in one working day by one team member.

Table 1 – Laser-scanner settings.

	Outer spaces	Inner spaces
Resolution	1/8	1/16
	1 pt. every 12 mm from 10 m	1 pt. every 24 mm from 10 m
Quality	4X	4X
Speed (pt./sec.)	122.000	122.000
Duration (sec.)	224	143
Number of scans	7	29

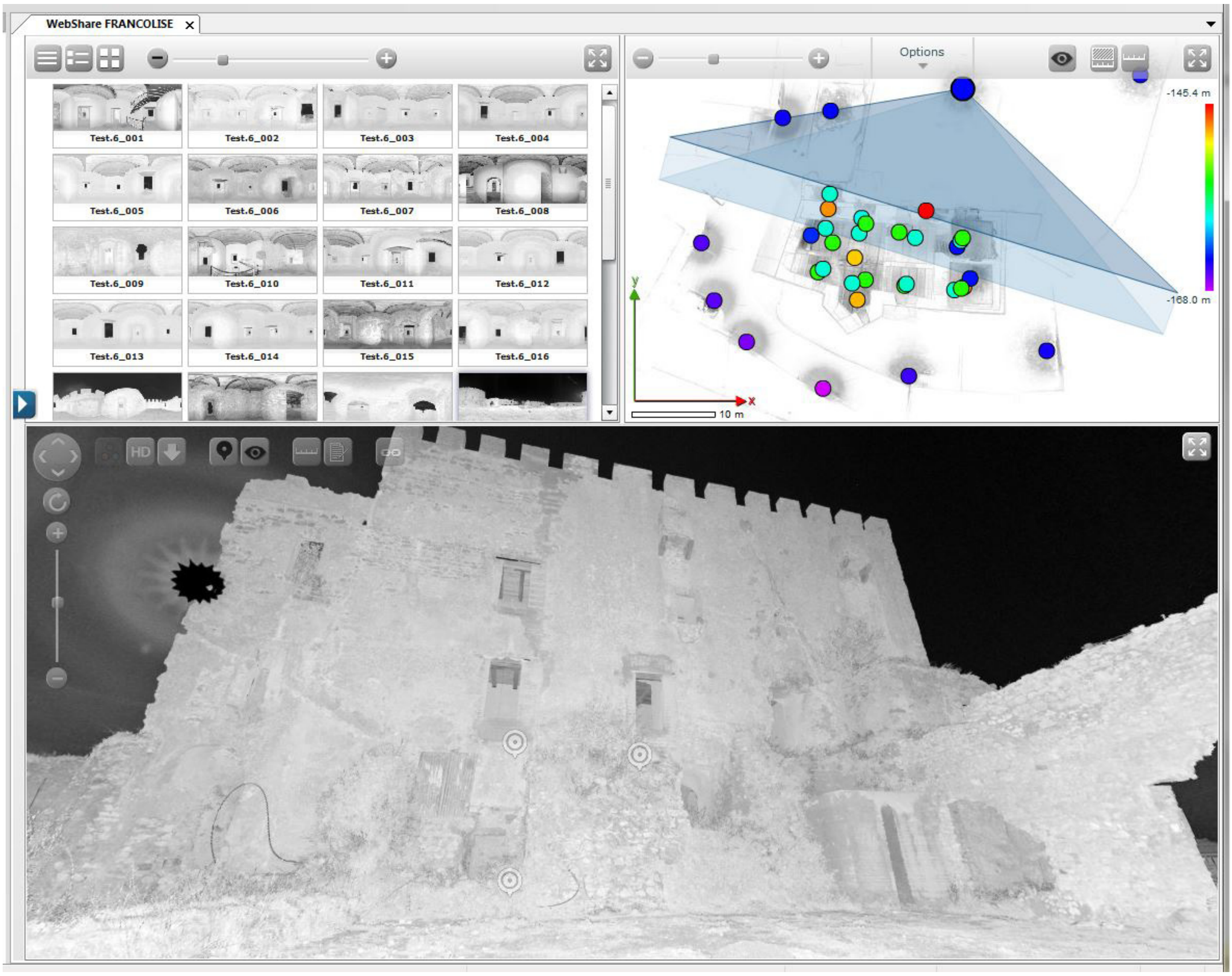

Figure 4 – Overview map with scan positions.

The point cloud model generated (Figure 6), along with representing the real building, is a database that eases the restoration plan. In fact, thanks to the IT model, users can both inspect and modify the different elements of the 3D building model, minimizing the chances of making mistakes. Furthermore, the model can also be metrically, geometrically and colorimetrically interrogated.

The BIM model of the castle was drawn with a parametrical modeling. It is not relevant to describe the data elaboration step by step. The software used for the model elaboration was Revit Architecture 2013. After setting the castle position coordinates, the point cloud was opened (Figure 7) and the levels defined (Figure 8).The graphical output properties and castle editable features (density, resistance, tensile strength) were then assigned.

If on the one hand, the objects found in the software library can be applied in the case of a new building modeling, on the other, in the case of pre-existing buildings such as the Castle of Francolise, the uniqueness of the elements of the castle did not permit the use of library objects. For example, the outer walls of the castle do not present the same shape in the different diagrams.

In order to make this issue irrelevant, after having taken the point cloud as a guide to the drawing, the outer walls were volumetrically modeled and the thermal and mechanical properties appointed (Figures 9 and 10).

Regarding floors, the process was more laborious because corresponding BIM elements were created to match the castle floors: for example, BIM models were created for plywood and concrete reinforced floors and the mechanical and energetic features were assigned to different components.

Editing the floors and modeling the castle was laborious. If on the one hand, in order to edit the floor, the team created BIM elements for each type of floor (plywood/concrete), assigning to each floor specific mechanical and energetic features; on the other, although allowing the team to set different parameters for the castle structure itself (such as thermal conductivity, porosity, etc.), due to the fact that the whole castle is made

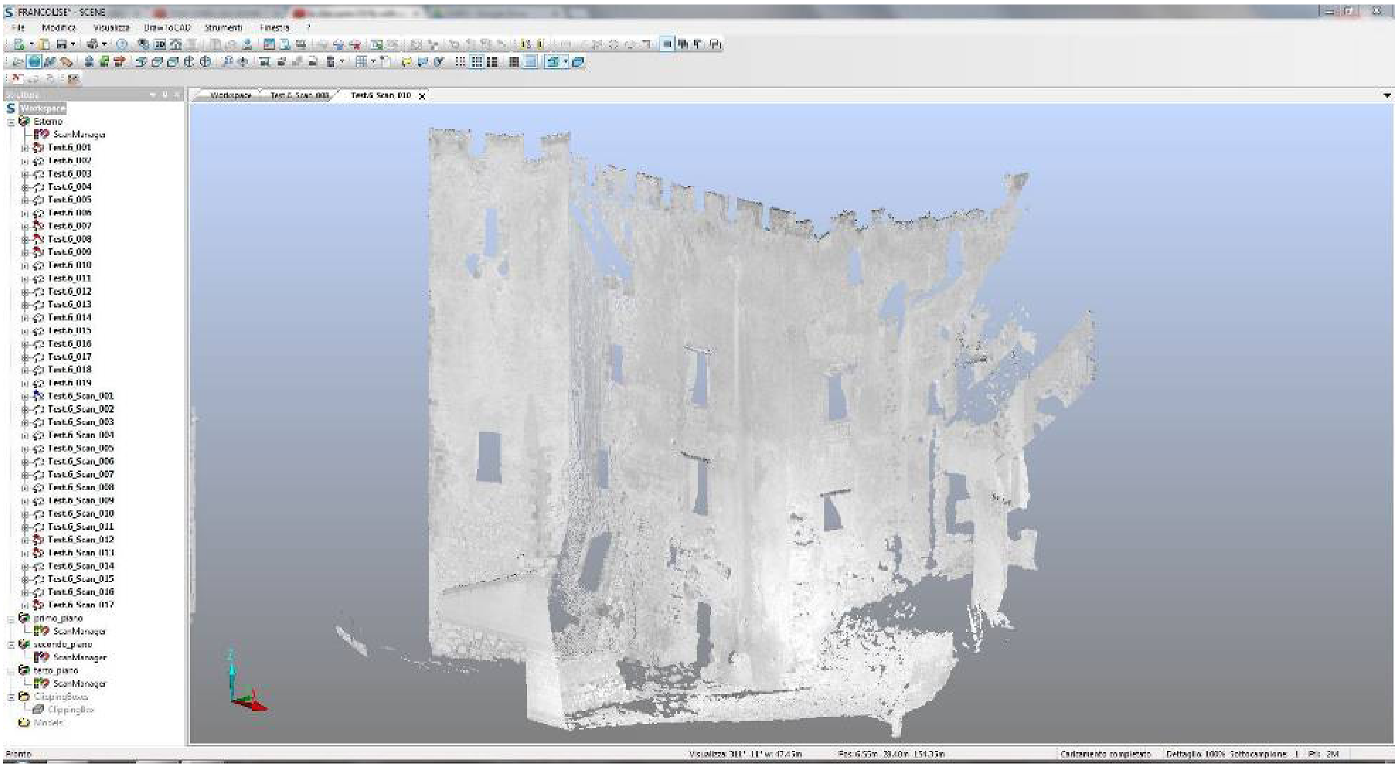

Figure 5 – One of the point clouds of the castle.

Figure 6 – The 3D model of Castle of Francolise.

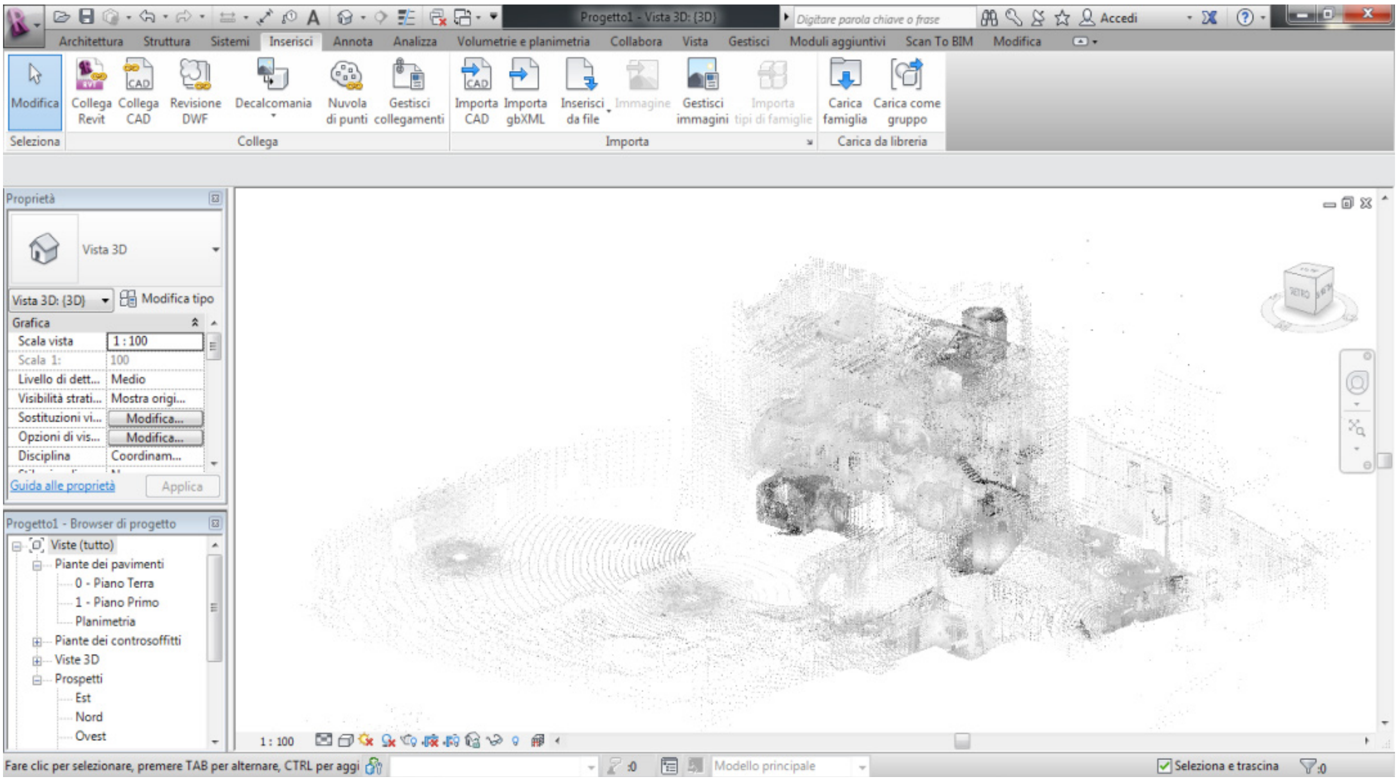

Figure 7 – The point cloud model used in Revit Architecture 2013.

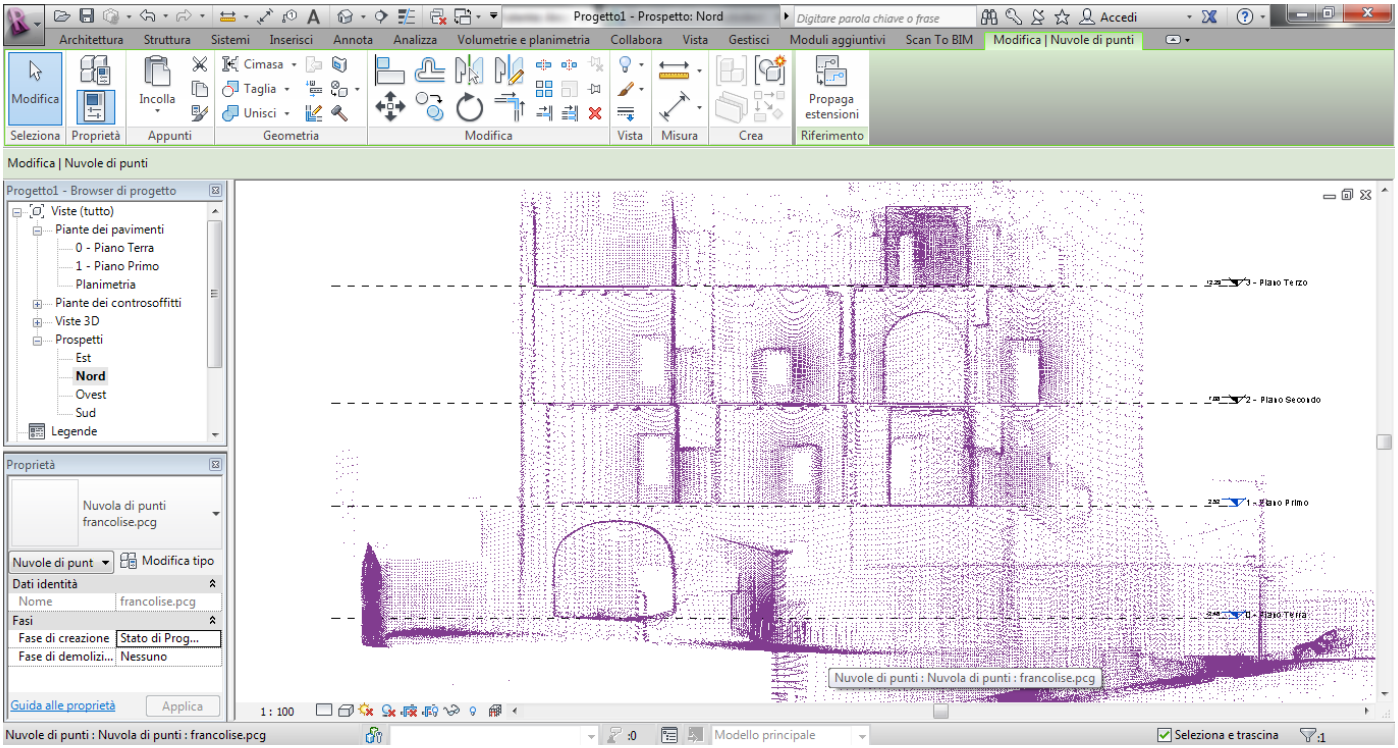

Figure 8 – Marking of the different levels on the point cloud.

up of load-bearing walls, the software only allowed to set the general limestone and tuff mechanical characteristics, the reason being that Revit was created for steel and reinforced concrete structures. Therefore, the BIM model could not be immediately analyzed. However, it was possible to transfer the 3D model into a calculation software that would prevent the user from creating another 3D model.

Overall, the castle of Francolise BIM model (Figure 11) was realized by one team member in six working days. The first observable benefit is the possibility to obtain a variety of 2D graphics in just a few seconds.

Furthermore, it was possible to automatically draw up tabs

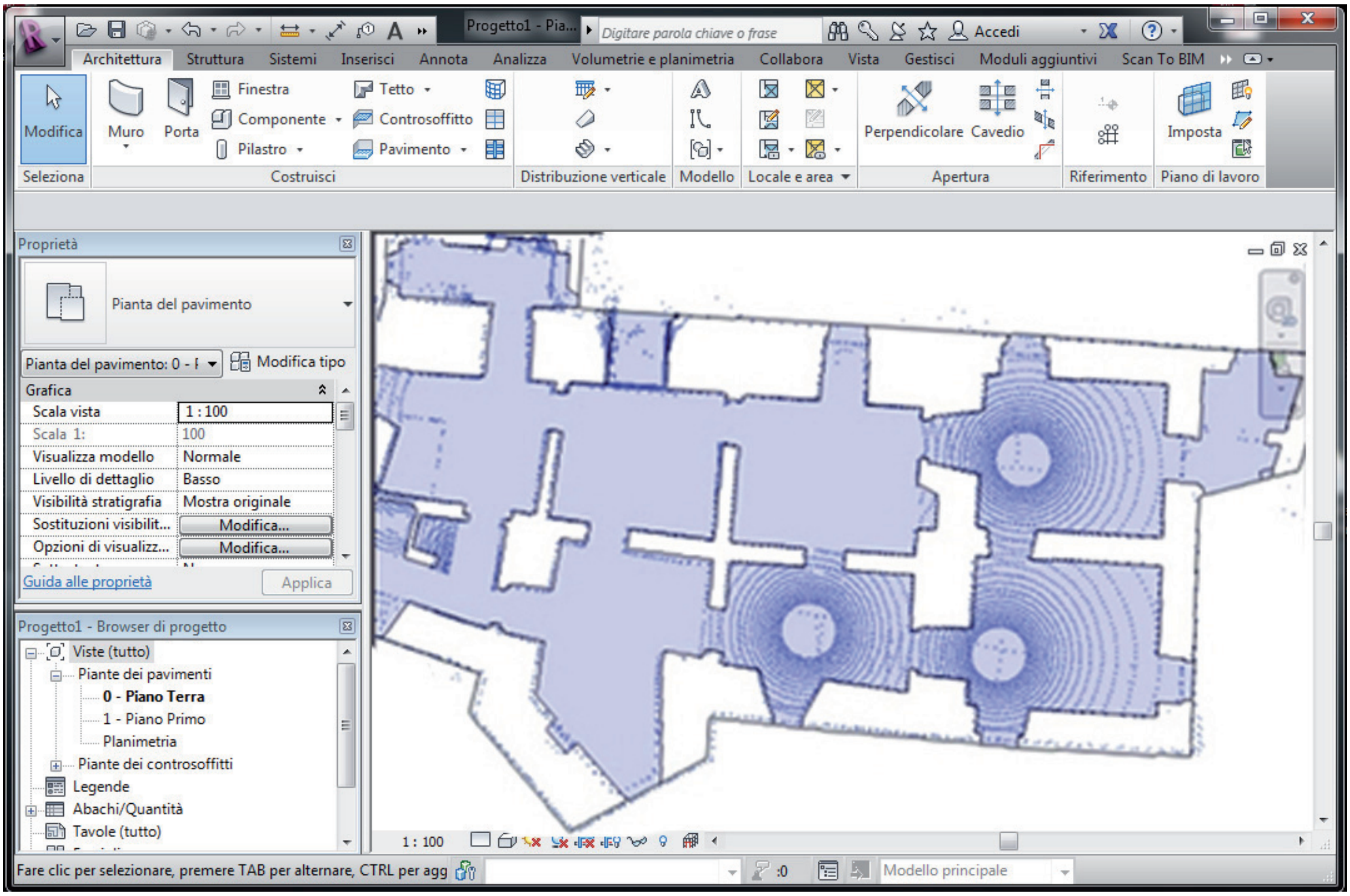

Figure 9 – Modeling of the walls.

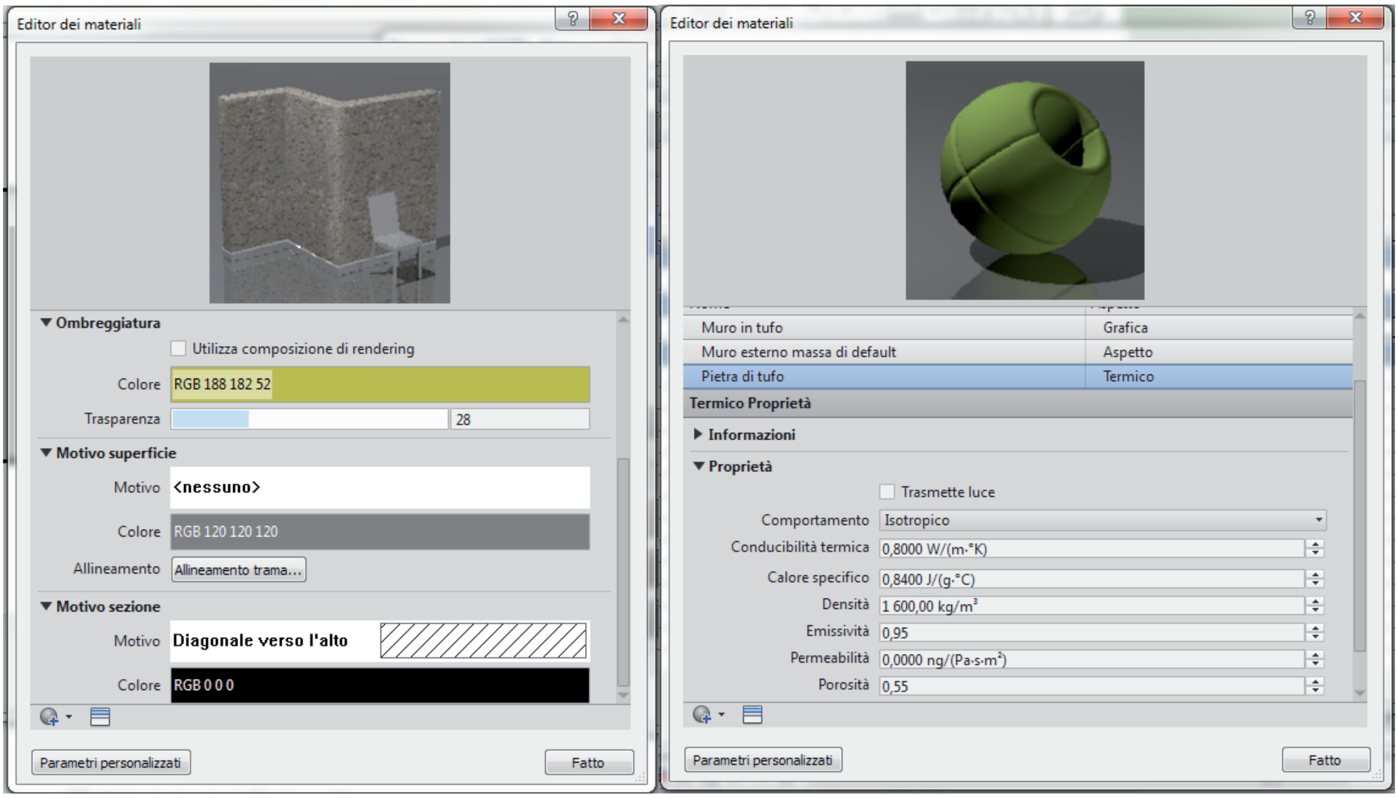

Figure 10 – Setting of the thermal and graphical features.

and charts concerning surfaces, quality of materials, exc. Moreover the model can be implemented and modified anytime, and can give different output, for example about the energy cost and its impact.

Analysis, comparison and results

The case described highlighted some interesting aspects. The data elaboration time between the BIM Surveying and the direct one is significant. A major role in this case was played by the "Focus Faro 3D". In fact, whereas the traditional survey required the employment of five team members who completed the job in four working days (20 men-days), the BIM laser-scanner survey was completed within just one day. The result is astonishing, with a man-day saving ratio of 95%.
The following metrical data elaboration produced different results concerning the quality and quantity of the information. If on the one hand, the traditional process due to a restrict number of 2D infographic models which were also subject to discretization, only allowed a limited number of drawings and sections to be created; on the other, the BIM surveying, after a preliminary processing phase gave a 3D model which is not comparable to the results that the 2D graphics produced: for example, the 3D models gives the user a faster analysis.
The direct survey final phase was finished in eight working days. It gave the team four diagrams, four sections, and four perspective drawings. Whereas the creation of point clouds using BIM surveying took one working day. The final result is significant also in this case: time reduced by 87% .
If on the one hand, the direct survey had now come to an end, the BIM Survey was still being carried on. The 3D point cloud helped create a BIM model which was completed within six working days. Differently from what happens with a standard survey, in this case it only took few steps for the team to get 2D graphs such as diagrams, sections and perspective drawings. Furthermore, tabs and charts relating to the main aspects of the building, such as surfaces, quality of materials, exc. were rapidly drawn when needed. Finally, the model was automatically implemented and modified, responding to every single change made, for instance about the energy cost and its impact.

Conclusions

The parametrical planning study carried out and the application of BIM surveying to architectural heritage have led to several observations. The castle of Francolise laser-scanner surveying and the following parametrical modeling, proved that the objective of this research paper – which is included in a series of studies concerning the energetic and technological requalification – is correct.
In fact, it is possible to apply the BIM methods to both architectural heritage as well as pre-existing buildings. Although requiring implementations and tests, the BIM

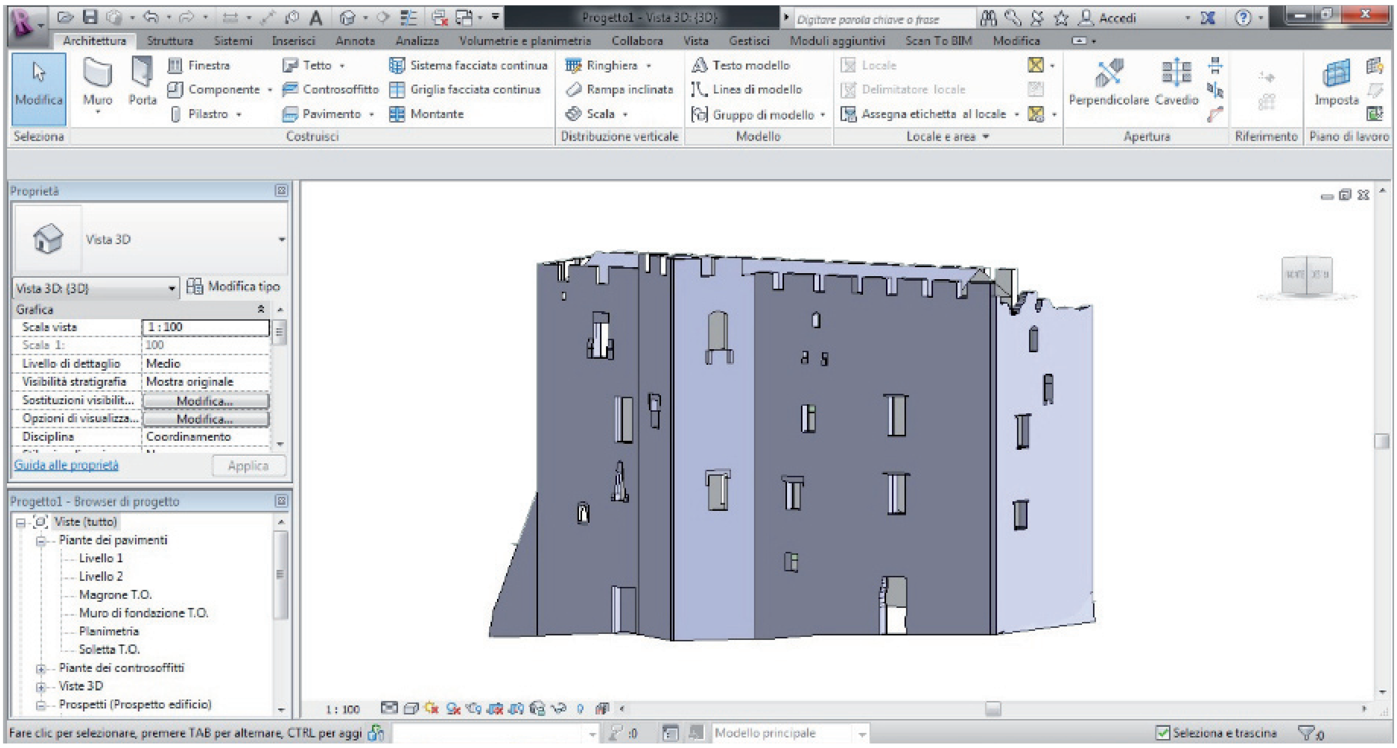

Figure 11 – The bim model of the Castle of Francolise...

method gives users an evident number of advantages both for the construction of new buildings as well as for the rehabilitation of pre-existing ones.
In order to support this thesis, the team carried out a comparison between the application of BIM Surveying and direct surveying. The BIM method proved to better than the traditional one in terms of the productivity and quality of the work.
A further observation concerns the economic aspects of the traditional and BIM surveys. The costs linked to traditional surveys are only made up ofqualified technicians fees.
On the other hand, BIM survey costs are higher due to the technological equipment (laser-scanner) needed and employment of specialized technicians who can elaborate and model point clouds. On the other hand, the BIM Survey reduces the man-days factor by 70% compared to the traditional survey. On the whole, the BIM method is more convenient: it reduces costs by 20%.
The quantity of information obtainable from the output of the final products of the compared methods is another important factor. The traditional survey only produces a limited number of 2D CAD elaborates, whereas the BIM Survey produces a3D building information model. It consists of a real building infographic prototype. This model brings many benefits to its users, who can easily obtain an unlimited number of connected diagrams, sections and perspective drawings; charts regarding materials; tabs regarding material specifics; characterization of constitutive elements; etc..
Although bringing many implementations, there are some limits connected to the parametrical planning of architectural heritage. Although the Castle of Francolise modeling was not complicated due to the absence of ornamental elements, and the number of irregular elements within the castle structure was not relevant; in this case, the team was able to inspect a different building, characterized by particularly complex features - such as a church or acourtyard –where there would be many more issues.
Altogether, in order to improve the BIM of architectural and structural elements (capitals; gates; pilasters; cornices; etc.), online libraries have to be implemented by creating different groups of elements whose lengths, widths and physical-mechanical properties could be freely edited, according to the users' needs.
It has been shown that when applied to architectural heritage, the BIM Survey could become an important tool for local administrations. Administrators along with experienced technicians could create a "cultural heritage smart catalogue" connected to historical buildings within territories under their jurisdiction.
This architectural heritage smart cataloguing - which would consist of a database containing BIM models of buildings in need of renovation - would simplify issuing design contests, minimizing risks of interference and failures. The current organization has, in fact, proven to be inefficient: local administrations are not able to spend at least half of the ESIF (European Structural and Investment Funds)received from the European Union.

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References

Azhar, S. *Building Information Modeling (BIM): Trends, Benefits, Risks and Challenges for the AEC Industry*, Leadership and Management in Engineering, American Society of Civil Engineers Library, Reston, Virginia, 2011.

Ahmad, A.; Demian, P.; Price, A. *BIM implementation plans: A comparative analysis*, in: Smith, S. *Proceedings of 28th Annual ARCOM Conference*, 3-5 September 2012, Edinburgh, 2012.

Barba, S.; Fiorillo, F.; Corder, P. O.; D'Auria, S.; De Feo, E *An application for cultural heritage in erasmus placement. Surveys and 3D cataloging archaeological finds in Mérida (Spain)*, in: *4th International Workshop "3D-ARCH'2011", 3D Virtual Reconstruction and Visualization of Complex Architectures*, Trento, 2-4 marzo 2011.

Cappochin, S.; Maistri, D.; Torre, A. *Efficienza energetica in architettura. Metodo BIM (Building Information Modeling) e metodo CasaClima per la progettazione di edifici a basso fabbisogno energetico*, Gruppo24Ore, Milano, 2011.

D'Auria, S. *Metodologie e strumenti per la progettazione: il BIM*, in: Di Ruocco G., D'Auria S., Falcone I., Nivelli M., SabainiGama M. (a cura di), *Lezioni di Architettura*, CUES Edizioni, Salerno, 2012.

D'Auria, S.; Barbato, D. *Standardisation of the design processusing BIM software*, in: Gambardella, C. (a cura di), *Le Vie dei Mercanti. Heritage Architecture Landesign*, Atti del XI Forum Internazionale di Studi Le vie dei Mercanti, 13-15 Giugno 2013, Aversa-Capri, Italia, La scuola di Pitagora editrice, Napoli, 2013.

De Joanna P., *Il recupero edilizio nelle aree protette. Norme e strumenti di programmazione, progettazione ed esecuzione*, Franco Angeli Editore, Milano, 2010.

Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM handbook. A guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, John Wiley & Sons, Hoboken, New Jersey, 2008.

Gallaher, M.; O'Connor, A.; Dettbarn, J.; Gilday, L. *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*, National Institute of Standards and Technology, Building and Fire Research Laboratory, Gaithersburg, Maryland, 2004.

Gleason, D. *Laser Scanning for an Integrated BIM*, Lake Constance 5D-Conference 2013, 28-29 ottobre, Constanza, Trimble Navigation, 2013.

Lo Turco, M. *Il BIM tra rilievo e progetto: l'utilizzo delle scansioni al laser scanner in ambiente parametrico*, BIM Academy, 2013, http://www.bimacademy.it/2013/11/il-bim-tra-rilievo-e-progetto-lutilizzo-delle-scansioni-al-laser-scanner-in-ambiente-parametrico

Randall, T. *Client Guide to 3D Scanning -and- Data Capture*, UK BIM Task Group, Londra, 2013.

Turner, B. *Building a few million points. Leveraging high definition laser scanning for BIM*, in: *Structural Engineering Structural & Design*, zweigwhite, Fayetteville, Arkansas, febbraio 2011.