Collaborative design for existing architecture: the Building Information Modeling as a frontier for coordinated process

Simone Garagnani
University of Bologna, Italy.
simone.garagnani@unibo.it

Roberto Mingucci
University of Bologna, Italy.
roberto.mingucci@unibo.it

Stefano Cinti Luciani
University of Bologna, Italy.
stefano.cintiluciani@gmail.com

ABSTRACT
Building Information Modeling (BIM) has been considered as an emerging collaborative strategy since its introduction, meant for AEC industry and heading to benefits in terms of costs and design quality during the whole building lifecycle. BIM approach, originally developed for new projects, can be successfully applied to existing contexts using TLS surveys to collect point clouds and turn them later into smart digital models, taking advantage of new technologies and methods. This paper addresses these themes paying attention to issues and opportunities, considering BIM as a paramount tool to collect and manage data destined to multiple disciplines.

KEYWORDS: BIM; laser scanner; AEC digital tools; architectural modeling; collaborative design

Introduction

After interactive Computer Graphics was born in the 60's of the last century (Sutherland, 1963), CAD tools started to spread in the AEC professional practices beginning from the 80's, replacing traditional paper drawings with digital ones (Bermudez and King, 2000). Ever since, digital drafting and computer modeling have gained attention more and more and nowadays CAD systems have evolved into more refined design tools, while the construction process has shifted to a revolutionary new approach, in which projects are now modeled using 3D higher-level entities that can be modified working on a few parameters instead of assembling standard primitives as it happens in simpler CAD systems. This opportunity was actually known all over the academic community since the 70's (Eastman, 1976), thenceforth materialized by commercial software intended for 3D models able to describe buildings as complete, consistent objects databases, in order to avoid any possible misinterpretation.

Today this coordinated process, known as BIM (*Building Information Modeling*), is strongly supported by several computer programs improved in order to reach higher quality and better team communications with always up to date reliable documents, leading to optimized scheduling with error and cost reduction. This features imply considerable versatility along the whole building lifecycle: models can be modified during the design process, allowing decisions favoured by different choices comparison, even in a late stage of development or during the construction phase as well, always assuring respect to the original design intent (Rundell, 2005). Therefore, BIM has not to be considered as a set of software to produce drafts and models but, on the contrary, as a pipelined process among designers, managers, engineers, architects and contractors (Eastman, Teicholz, Sacks and Liston, 2011). In fact BIM foundations (and advantages) reside in the completeness, detail and "*self-consciousness*" of the building's model, authored by tools offering the features needed to generate *smart* objects aware of their role and not comprehensive of their geometric appearance only.

BIM strategy applied on existing buildings

Even if BIM promises are not yet fully realized, benefits offset some limitations or inconsistencies. This is already true for new buildings, where different actors are encouraged to collaborate and to exchange information through digital models, however BIM approach can bring advantages dealing with built edifices too.

In fact it represents a complete tool aimed to assist those professionals who use computer models, made of evolved objects, as a common workbench to perform restorations, maintenance interventions, renovations or simply information archiving on Cultural Heritage. In these contexts, BIM technologies can be integrated with facilities management to improve space allocation with optimized occupancy use, reducing operating costs, as well as aiding technical maintenance and providing quick and easy access to the existing building's parts and inventory, projecting future operating costs in regular maintenance.

These tasks are commons in BIM domain, which can be basically applied considering two different scenarios:

the original project was already generated using BIM modelers and any further modification (*as-built*) has properly been stored into a single digital model;

the existing building has to be completely remodeled as a new project, since there is no previous digital representation at all;

Put aside the almost improbable first case, especially referring to historical buildings, the second one is particularly articulated: in order to generate a proper BIM model from scratch, paper drawings or existing CAD files resulting from traditional surveys can be used, otherwise BIM representation can be produced taking advantage of digital photogrammetry or TLS (Terrestrial Laser Scanning), converting somehow high fidelity point clouds into smart objects later.

This last scenery comes up again in two possible circumstances: either point clouds are used to build up part of edifices only made of smart objects, leaving uninteresting boundaries as acquired geometry not converted and expressed by points or polygons, or specific software can be run to obtain straight point clouds translation into graphic primitives, even in real time, covering the whole building. Dealing with these aspects, some scientific studies have been seminal for advanced development in reconstruction field (Früh, Jain and Zakhor, 2005). Those works ended in today's software that can identify surfaces and translate them into B-rep geometries using portable TLS devices (Chen, Kua, Shum, Naikal, Carlberg, and Zakhor, 2010). In any of these cases, translation of collected laser scanning data into BIM entities can be crucial for renovation projects, because of its attitude in capturing existing conditions quickly, accurately and efficiently.

High precision surveys on materials deterioration for example, followed by information storage into smart models, allows production of frameworks in which data can be filtered for operators with specific duties in restoration, together with powerful documentation systems able to memorize records for future interventions (Garagnani, Cinti Luciani and Mingucci, 2011). This is particularly useful dealing with monumental sites and Cultural Heritage preservation, a field in which the need for not ambiguous and durable database systems is extremely important, especially when documentation is arranged following semantic and topological relationships (Gaiani, Benedetti and Apollonio, 2009) useful to share information through paper sheets or mobile viewers such as PDAs or tablet PCs.

Fig. 1. Sant'Apollinare Nuovo in Ravenna (Italy), a case study on BIM remodeling from digital point clouds.

From point clouds to BIM model

The architectural organism is a complex environment, made of parts coexisting together. So complete surveys have to deal with different aspects involving geometric descriptions, materials documentation, structural analysis, plants tracking and so forth. The best way to sum these kinds of data up is represented by digital 3D modeling performed by high definition survey techniques, both range based and image based.

Acquiring dense point clouds assures a not ambiguous way to represent real space in computer virtual environment, introducing abstractions imagined as real components' simplifications. Huge numbers of vertexes can be easily captured then processed in order to store metric data, even if millions of scanned points are still relevant entities to manage in computer memory, task more complicated by metadata linking if alphanumeric documental archiving is needed.

The connection between BIM and point clouds resides in smart segmentation of registered vertexes. In fact a laser scanner output is basically a non structured set of points in which elements differentiation and topology are not considered: using that points to isolate building's element is the first step to translate clouds into objects. This operation brings advantages in term of lighter, memory saving models, made of entities that can be related to each other. For example, moldings can be isolated from host exterior walls and translated into objects generated extruding profiles, which in turn were derived from point cloud sections. If any sort of intervention contemplates walls editing in length, smart moldings will follow walls in their new dimension, as they are topologically interrelated in their BIM "self-awareness" (i.e. moldings know they are connected to walls). The same happens for editable windows and doors following walls, arcades coupled to columns, beams to pillars and so forth. On the other side this deep conversion into BIM elements could be useless for building's portion not subject to interventions, so point clouds could be left in model as collected geometry; in this case, decimation and oversimplification would be required to allow concurrent coexisting of as-built and easily editable smart objects without superfluous memory consumption. This kind of "*as-built reverse engineering*" demands models that are ultimately intended for human manipulation, since thousands of collected points are not meant for users' direct simulation or smart modeling purposes, activities that imply the need for accurate inference of geometric and topological information, expressed in terms of component features and interconnections ignored by laser scanners. In fact analytical software needs elements well defined in their geometric and implicit data aspects, in order to evaluate their behaviors compared to surrounding conditions maybe surveyed through assays or building monitoring by means of sensors settled to measure various factors.

BIM translation into smart object can be effective isolating planes from noisy point clouds through proper threshold values: a wide number of algorithms have been proposed for either interpolating or approximating an unorganized set of points on a surface, in order to obtain simpler geometry. When this process is automatically carried out, it could be roughly interpreted in the same way as typographic OCR was introduced to "read" from paper sheets by means of programmed recognition of handwritten or printed fonts in order to digitize them in text files. In this specific field, commercial state-of-the-art computer programs are very few since critical points seems to be recognition of very complex morphologies, which modelers can only manage if expressed with parametric constraints not easy to set up automatically.

Autodesk Revit Architecture, a set of software widely used in practices all over the world, has been one of the first BIM-related computer programs to adopt TLS management since its release 2012 (Garagnani and Cinti Luciani, 2011); first imagined as an aid to building's remodeling, Autodesk improved the module and current efforts are focused on automatic point cloud feature extraction for terrain surfaces, floors, walls and windows. This technology preview, named "*Point Cloud Feature Extraction*", is fascinating even if some glitches and bugs still have to be addressed and results have to be often corrected by human operators. IMAGINiT's *Scan to BIM* is a third party Revit plug-in well known too, even if very limited if compared to Autodesk's module.

In 2011, Leica ported his AutoCAD's point clouds management plug-in, CloudWorx, to Autodesk Revit and to Bentley MicroStation but still without automatic feature extraction. Since then (but only from SelectSeries 2 version) point clouds could be imported in MicroStation only as reference geometry with very limited use.

In fact TLS output imported in BIM software usually remains either orientation geometry in form of points, edges or polygons used as snap vertexes to manually generate smart objects, or building's portion representation used as boundary context for limited interventions where smart objects use is destined to intervention area only.

It's important to consider TLS devices help acquiring visible objects only, which have to be completed by knowledge on surrounding conditions (structures hidden in walls, plants covered by floors or ceilings, material degradations, etc.) with assays performed by critic specialists belonging to different disciplinary fields: this is a costly step in terms of time and resources but it's necessary in order to author complete digital models. (Fig. 2)

Sant'Apollinare Nuovo a case study on Cultural Heritage preservation

In order to collect data from TLS surveys intended for BIM virtual building modeling, suitable for editing, data archiving and simulations, all critical aspects documented before were tested on Sant'Apollinare Nuovo, an important historic church in Ravenna (Italy). This is one of the most important examples of early Christian Byzantine architecture in Western Europe, erected by Theodoric during the first quarter of the 6th century, with an apse and atrium typical of ancient Basilicas and sidewalls covered with colorful mosaics.

Investigations were performed using Leica C5 *time-of-flight* laser scanner equipment: once registered with Leica Cyclone software, joint point clouds were used to trace planes and edges while single elements were generated in Autodesk Revit Architecture by mesh approximation: in both cases data transfer from raw laser scanner output had to be carefully verified in order not to loose information due to excessive vertexes decimation or bad manifold importing in Revit. Semantic splitting and elements topologies not stored in point clouds (metadata making object to be "*intelligent*") had to be specified later, isolating exterior walls, floors, ceilings, nave's arcades and aisle's columns. Basically, Sant'Apollinare Nuovo was remodeled using smart objects mostly by hand, keeping laser survey as a sort of background for objects sizing and assembly, once solved some issues.

Imported point clouds in fact are not fully identified as snap points (even using Leica's CloudWorx plug-in) so a C# script compiled through Revit's API (codenamed "*GreenSpider*", Garagnani 2012) was run in order to isolate main edges of some scanned components, recognized later as native reference primitives by Revit. Once generated the BIM model, Sant'Apollinare virtual building was ready to be analyzed by means of simulation software engines, in order to study how sunlight interacts during different times of the year with mosaics, producing glittering effects. Radiance information captured by Leica C5 was also useful to define tiles positioning and historic layering through centuries, but this potential was not provided natively in Revit. However, the detailed BIM model of this important building allows dynamic structural simulations too, in order to monitor conditions and to prepare emergency intervention plans in case of earthquake damage, as recently happened in Northern Italy. These tasks, belonging to heterogeneous disciplinary fields, were performed using several different software, so interoperable file transfer had to be inquired in order to find the best interchange format; Industry Foundation Classes (IFC, recently updated to release 4) proved to be a good abstraction, even if careful validation (using the piece of software Solibri) is still required (Slattery, 2006). On the contrary, Green Building Extensible Markup Language (gbXML) acted as a versatile conduit between software tools and analytic engines saving a great deal of tedious building morphology recreation. (Fig. 3)

Conclusions

As described in this paper, BIM foundations are located in "*self-aware*" components (*smart objects*) and their cross-related topology management, assembled in complex building's models driven by factors very different from unstructured laser scanning devices output. Although BIM process has been developed mainly for new buildings design, it can represent as-built conditions too, since it allows always up-to-date documents, easy editing and project alternatives comparison in renovations or restorations workflows.

As TLS equipment is becoming cheaper and cheaper, range based surveys collect dense 3D point clouds, which provide designers with the basics to organize BIM models intended for restorations, maintenance interventions, renovations or simply information archiving. However point clouds have to be properly segmented and used as reference geometry to obtain *smart* elements in BIM software, following either automatic or manual approaches.

Models authored this way are made of components intended as metrically variable "*self-conscious*" objects, programmed to interact with each other following precise rules.

Lesson learned in BIM application on Sant'Apollinare Nuovo case study is that of *state-of-the-art* commercial and experimental academic software still not allow correct automatic feature extraction from laser scanner output without human intervention, even if their evolution is promising and software houses are investing funds and resources in their development. In the end, BIM seems to be profitable if applied to as-builts, offering a wide range of opportunities and tracing a still evolving scenario in which professionals dealing with existing building can find a cultural exchange common tool aimed to introduce higher quality and order in AEC interventions.

References

Bermudez, J., King, K. 2000. Media interaction and design process: Establishing a knowledge base. *Automation in Construction*, 9, 37-56.

Chen, G., Kua, J., Shum, S., Naikal, N., Carlberg, M. and Zakhor A. 2010. Indoor Localization Algorithms for a Human-Operated Backpack System. *3D Data Processing, Visualization, and Transmission 2010*, Paris, France.

Eastman, C. M. 1976. General purpose building description systems. *Computer-Aided Design*, 8 (1), 17-26.

Eastman, C. M., Teicholz, P., Sacks, R., Liston, K. 2011. *BIM Handbook. A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, Second Edition*. Hoboken: John Wiley & Sons.

Früh, C., Jain, S. and Zakhor, A. 2005. Data Processing Algorithms for Generating Textured 3D Building Facade Meshes from Laser Scans and Camera Images. *International Journal of Computer Vision*, 61 (2), 159-184.

Gaiani, M., Benedetti, B., Apollonio, F. I. 2009. Standard di acquisizione e strutturazione di modelli digitali per sistemi informativi di aree archeologiche: il caso di Pompei. *DISEGNARE IDEE IMMAGINI*, 39: 60-73.

Garagnani, S., Cinti Luciani, S. 2011. Il modello parametrico in architettura: la tecnologia B.I.M. di Autodesk Revit. *DISEGNARECON*, 4(7). Retrieved in August 2012 at http://disegnarecon.unibo.it/article/view/2298.

Garagnani, S., Cinti Luciani, S., Mingucci, R. 2011. Building Information Modeling: la tecnologia digitale al servizio del progetto di architettura. *DISEGNARECON*, 4(7). Retrieved in August 2012 at http://disegnarecon.unibo.it/article/view/2297.

Rundell, R. 2005. *Revit: parametric building modeling: Part 2. Why parametric building modeling matters*. Retrieved in May

2012 at http://aec.cadalyst.com/aec/article/articleDetail.jsp?id=150779.

Slattery, K. T. 2006. A Course in Building Information Modeling for Construction Students. *Proceeding of the 2006 ASC Region III Conference Downers Grove, Illinois.* Edwardsville: Southern Illinois University.

Sutherland, I. E. 1963. Sketchpad: A man-machine graphical communication system. *Technical Report*, 574, Boston: Massachusetts Institute of Technology.

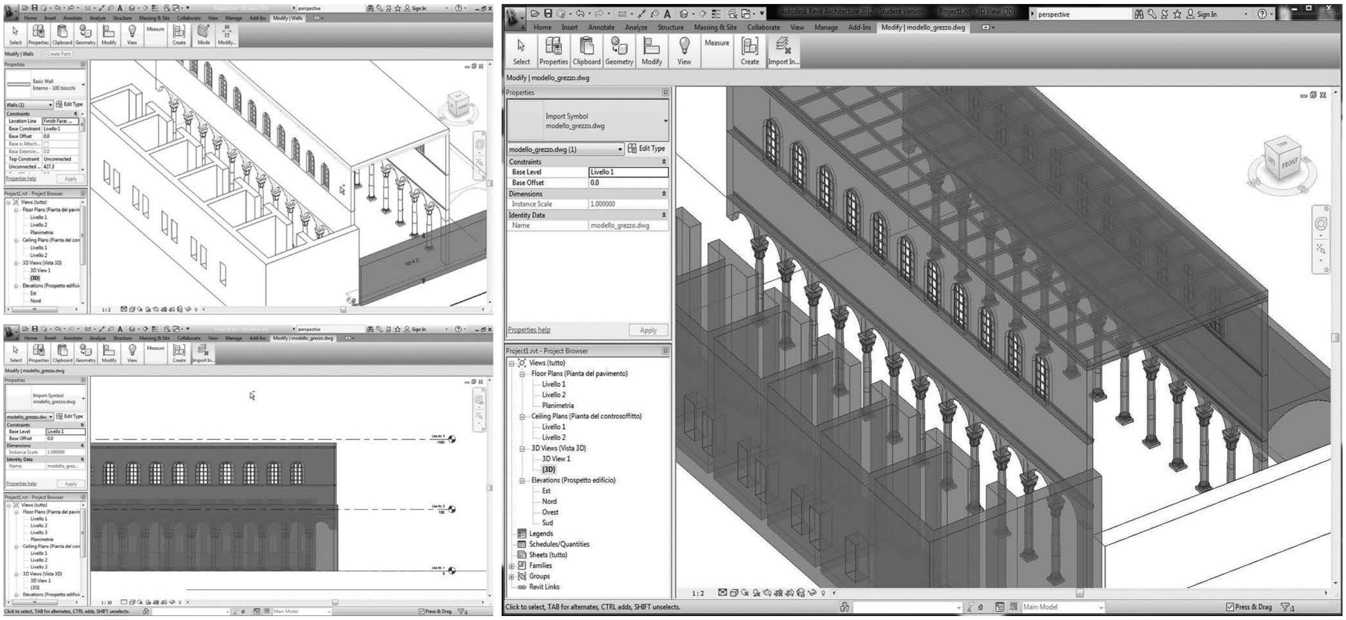

Fig. 2. From scanned point cloud to BIM in Autodesk Revit Architecture: acquired morphology has been translated into "smart" objects, lighter than the original point cloud and easily interchangeable among different software.

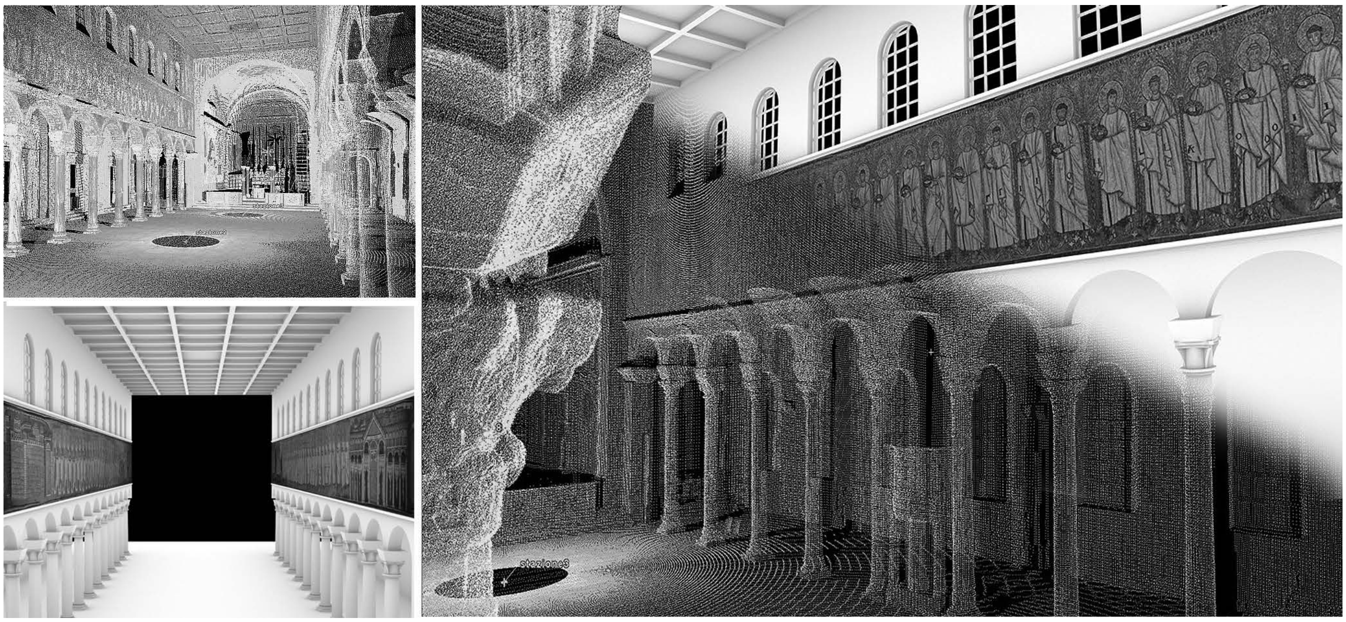

Fig. 3. Once a 3d model has been generated with BIM software, visual analysis is easier: this is the final registration of several point clouds representing Sant'Apollinare interiors, with important mosaics on walls.