

# Building Information Modeling semantico e rilievi ad alta risoluzione di siti appartenenti al Patrimonio Culturale

## *Semantic Building Information Modeling and high definition surveys for Cultural Heritage sites*

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### Abstract

Negli ultimi anni la tecnologia digitale dedicata alla progettazione degli organismi edilizi ha conosciuto avanzamenti di notevole portata, permettendo di raggiungere mediante il *Building Information Modeling* quei traguardi che erano stati solo immaginati, a partire dalla metà degli anni Settanta del secolo scorso. Il processo BIM, latore di numerosi vantaggi per i progettisti che lo implementano nel proprio flusso di lavoro, può essere declinato con successo anche alle casistiche applicative di intervento sul patrimonio architettonico esistente. La semantica tipica dei componenti dell'architettura classica, così pervasiva nel paesaggio storico urbano europeo, così come i caratteri propri del moderno o del costruito contemporaneo, incontrano nella struttura autocosciente degli "oggetti intelligenti" BIM un valido apparato di documentazione relazionale. Tuttavia la traduzione delle informazioni geometriche di precisione pertinenti l'esistente, acquisite utilizzando le tecniche diffuse di laser scanning e fotogrammetria digitale, costituisce ancora una criticità di processo che questo contributo vuole indagare, descrivendo un possibile approccio di metodo.

*In recent years, digital technology devoted to the building design has experienced significant advancements allowing to reach, by means of the Building Information Modeling, those goals only imagined since the mid-Seventies of the last century. The BIM process, bearer of several advantages for actors and designers who implement it in their workflow, may be employed even in various case studies related to some interventions on the existing architectural Cultural Heritage. The semantics typical of the classical architecture, so pervasive in the European urban landscape, as well as the Modern or Contemporary architecture features, coincide with the self-conscious structure made of "smart objects" proper of BIM, which proves to be an effective system to document component relationships. However, the translation of existing buildings geometric information, acquired using the common techniques of laser scanning and digital photogrammetry, into BIM objects, is still a critical process that this paper aims to investigate, describing possible methods and approaches.*

**Keywords:** BIM, laser scanning, AEC digital tools, Autodesk Revit, GreenSpider plug-in.

### Introduction

CAD tools focused on architectural design started to spread in the AEC professional practices beginning from the 80's of the last century, replacing traditional paper drawings with digital ones (Bermudez and King, 2000). Ever since, the computer drafting and modeling concept has gained more and more attention, due to the fact that IT tools evolved from sort of "digital multi-purpose drawing boards" to complete design frameworks based on enhanced parametric objects, combined together to originate whole buildings within virtual environments.

Every object is not only a geometric representation of real shapes, as in CAD systems, but it's a collector for data with specific meaning to the architect. They provide an abstract computer representation of the physical world that is convenient for designers: a wall as an object represents an actual wall in the physical world and a door as a digital object represents a real door.

This advanced graphic duality is essential in design validation and it is the foundation for *Building Information Modeling* (BIM), a coordinated, consistent and always up to date working process strongly supported by several software tools, continuously improved in order to reach higher quality, reliability, optimized scheduling, errors and costs reduction together with avoidance of any possible project misinterpretation (Garagnani, Cinti Luciani and Mingucci, 2011).

Therefore, BIM has not to be considered only 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, who have a common framework at their disposal (Eastman, Teicholz, Sacks and Liston, 2011).

This way, BIM becomes a collaborative strategy in architectural design, in which the term “*information*” implies a sense of *contents-sharing* and transparency among actors, in order to generate a teamworking culture devoted to efficiency and integration, not only focused on software mastering.

Even computer programs explicitly written for BIM evolved their interface from traditional GUI to a modern *object-oriented* one, highlighting their ease of use to guide designers’ attention on projects and not on tools.

Modern BIM engines, in fact, can easily create and manage parametric geometries, collapsing them in primitives that can be connected through hierarchical relationships one another: this is flawless when creating simple objects from software libraries, where shapes and constraints are already set, but it’s much more difficult when components are generated by existing morphologies, for example acquiring data using digital photogrammetry or laser scanning equipment.

In this case BIM abstractions have to be mostly remodeled by hand, since automatic feature recognition and extraction in available commercial AEC computer programs are still not effective, experimental and under development by several software houses.

A possible solution, experimented and documented in scientific literature, involves the *Historic Building Information Modeling* (HBIM) approach, in which parametric objects are built beginning from historic data and layered in plug-in libraries aimed to map the elements onto point clouds and image survey data (Dore and Murphy, 2012). However this methodology assumes buildings to document made of correctly codified components, already present in libraries, with limited capabilities to change them in order to represent possible existing different states.

This is the main reason *terrestrial laser scanning* (TLS), for example, gained interest since it is experimental no more and quality devices are becoming cheaper than in the past: this kind of high definition survey hardware can be steadily adopted by practices. Of course similar considerations can be extended to digital photogrammetry, since photography has long been recognized as a most important form of record, especially where historic buildings are concerned; nowadays dense point clouds extraction from pictures is speeded up greatly by computer vision software.

Several professionals and academic studies on point clouds translation into graphic primitives, even in real time, have been seminal for advanced development in building digital reconstruction field (Früh, Jain and Zakhor, 2005).

Numerous algorithms have been proposed for either interpolating or approximating an unorganized, noisy set of points on a surface, in order to obtain simpler parametric geometries: their common consideration is that primitive objects are, of course, lighter and much more editable in computer memory than their respective original master dataset.

This kind of “*existing buildings reverse engineering*” demands models that are ultimately intended for human manipulation and it implies the need for accurate inference of geometric and topological information, expressed in terms of component features and interconnections.

Nevertheless, a critical aspect in TLS applications, but generally in computer vision techniques too, is the correct segmentation of elements, since is still hard to automatically tell walls from windows or ceilings from floors, especially considering transparent surfaces.

However acquiring geometries remotely and turning them into smart objects abstractions, would amplify the model capability to store information, also considering various typologies of elements.

High precision survey on materials deterioration for example, followed by data recording into smart BIM components, allows frameworks setups where information can be filtered accordingly to operators needs with specific duties in restorations, preparing a powerful documentation system able to memorize data for future interventions.

This is particularly useful dealing with Cultural Heritage preservation in monumental sites (Fai, Graham, Duckworth, Wood and Attar, 2011), a field of studies in which the need for not ambiguous and durable database systems is extremely important (Gaiani, Benedetti and Apollonio, 2009). In this

case monument documentation is intended as a system aimed to collect data, storing topological information and content relationships outputting to several devices, from analytical software engines to paper sheets or mobile viewers such as PDAs or tablet PCs.

Autodesk Revit for example, software widely used in most of the practices all over the world, was one of the first BIM-related computer program to adopt point clouds import plug-ins in order to reach this archiving versatility since its release 2012 (Garagnani and Cinti Luciani, 2011); first imagined as an aid to building remodeling, Autodesk improved this module and current efforts are focused on point cloud features extraction of terrain surfaces and automatic floors and walls recognition beginning from selected point regions. Their technology preview is interesting even if some glitches and bugs have still to be addressed.

Once registered, point clouds can be merged to approximate planes, or single parametric elements can be generated by mesh interpolation, even considering thousands of vertexes: in both cases file transfer format from raw laser scanner data have to be carefully verified in order not to lose information due to excessive decimation or bad manifold translation.

Semantic splitting and real elements topologies are not transferred when importing point clouds in BIM modelers so metadata that permit object to be “*smart*” or “*intelligent*” (i.e. with a sort of self-consciousness of what kind of element they are and with whom they can interact) have to be specified later (De Luca, 2012).

This is the point where human operators can introduce their knowledge in component segmentation.

## Sant’Apollinare Nuovo in Ravenna: a case study on Cultural Heritage

In order to fine tune a methodology destined to acquire data from photogrammetry and TLS surveys to process afterwards in a BIM environment, some practical tests were conducted on Sant’Apollinare Nuovo in Ravenna, Italy, one of the most important examples of early Christian Byzantine art and architecture in western Europe; it was erected by Theodoric as his palace chapel during the first quarter of the 6th Century A.D., with an apse and atrium typical of ancient Basilicas and side walls covered with mosaics (Figure 1).

Using high definition laser scanner survey and digital photogrammetry for details hard to capture with TLS equipments, some point clouds were registered and processed to transform them in input for Autodesk Revit Architecture, vertical environment in which, instead of 3D CAD standard building primitives, geometries were modeled using higher-level BIM entities that can be modified working on a few parameters.

In Sant’Apollinare case study, points were registered using Leica C5 *time of flight* laser scanner, then integrated with some dense surfaces obtained through digital photogrammetry using Menci Z-Scan Software.

Data were eventually imported in Autodesk Revit Architecture 2012, after proper decimation in order to eliminate unnecessary information (1). The simplified whole dataset was transferred using .PLY file format, even if Revit standard point cloud import procedure opens .PLY files through an automatic conversion into .PCG format archives.

The original idea was to remodel parametrically the entire building mostly by hand, keeping laser survey and photogrammetric data as a sort of scaffolding for smart objects assembly. Even if some commercial plug-ins aimed to point clouds importing and editing in Revit exist, such as Leica CloudWorx or Imaginit Scan to BIM, they weren’t used to favor standard workflows. Autodesk’s automatic feature recognition plug-in, introduced in the first quarter of 2012, could not be tested since it is not yet commercialized.

The usual pipeline consists in point cloud importing (2), visualization in work area with linear units check, then generation of Revit families starting from visual data, if smart objects are required instead of a *frozen* set of points (Figure 2). In Revit environment, visualized point clouds cannot be used as snap points; geometry creation or modification tools can snap to implicit planar surfaces instead, which are dynamically detected in the point cloud. However, Revit only detects planes that are perpendicular to the current work plane (in plan, elevation, or 3D) and only in a small proximity of

the cursor. This is not so useful for users in need to approximate segmented geometries in order to translate them into smart objects.

This way, a simple plug-in was developed by the author with the ambition to create a versatile tool to import vertexes of interest only from the cloud, considering them as selectable snap points to reproduce accurate components with precise extensions, with the application of a whole different workflow. This plug-in, codenamed *GreenSpider* (3) after its capability to layout points in space as if they were nodes of an ideal cobweb, is a Microsoft Windows .NET 3.5 *Dynamic-link library* (DLL) developed in C# through RevitAPI 2012; this code is able to conveniently parse ASCII text files containing XYZ coordinates derived from real world data capture, translating them into native reference points in Revit's mass modeling environment (Figure 3).

Once set up through an installer that can be freely downloaded from the Internet, *GreenSpider* can be accessed directly in Revit *graphical user interface* (GUI) from an icon placed in the *external plug-ins* ribbon. Then the code searches for a file with .GSP extension, a plain text file format where XYZ numerical values representing vertexes are separated by semicolons, while commas are used for decimal marks. This plug-in operates Metric conversion for Revit Architecture so .GSP values are originally required in centimeters.

*GreenSpider* is still a prototype so it's possible to run only two commands identified by two different icons in Revit's GUI: *GSpoints* and *GScurves*. The first imports the vertex point cloud, while the second traces a spline interpolation among imported vertexes, in order to build surfaces with high accuracy.

This way the plug-in allows an easier modeling capability to Revit, which considers points as vertexes of simple parametric primitives pertaining to native families. Shapes generated can be imported in master models as smart masses, with semantic metadata embedded, allowing hyperlink presence to multimedia contents, self-conscious topology, lighter memory occupation and so on (Figure 4).

## Conclusions

Building Information Modeling is a novel strategy intended to optimize the building design process, avoiding among other things spatial conflicts, time wasting reworks and costs associated with them. Even if it's been developed for new buildings, BIM attitude to gather data about components, which can be properly related by virtue of their self-awareness and semantic, can be successfully applied to existing architectures as well.

This is a considerable aspect since the database of contents hosted in a digital model, structured following BIM criteria, is suitable to document heterogeneous Cultural Heritage sites. To be as faithful as possible, these contexts have to be surveyed using high definition technologies, destined to capture data about morphologies and preservation state of elements.

Point clouds, credited as a valid digital substitute aimed to represent reality with accuracy, can be used as output from active TLS or passive photogrammetric techniques.

Computer models generated this way are useful in particular for documentation purposes, for periodic checks on structures preservation and they allow studies on technological building systems over architecture history.

However, point clouds are not structured entities, since they are recorded without topology or semantic discretization. BIM on the contrary requires well defined relations among components, called "*smart*" by virtue of their own knowledge about their mutual placement.

Importing un-structured datasets into BIM software is still a tricky process but some progress can be made using dedicated plug-ins, such as *GreenSpider* for Revit, piece of software able to translate points into native reference snaps aimed to model elements with much more precision instead of a simple tracing out.

As presented in this paper, a dedicate BIM database for complex historic architectures can be generated in order to gather information and made it available for researchers, professionals or generic actors involved in Cultural Heritage preservation.

## Notes

1 - Scan files often reach values of hundreds of millions to billions of points hosted, with datasets including unsegmented elements. Hardware resources have to be powerful in order to allow points editing.

2 - For efficiency and improved performance, Revit uses only a limited subset of points for display and selection at any given time.

3 - GreenSpider is a free Revit 2012 plugin written by Simone Garagnani, under a Creative Commons Attribution-Non Commercial - Share Alike 3.0 Unported (CC BY-NC-SA 3.0) license. GreenSpider can be freely downloaded at <http://www.tcproject.net>.

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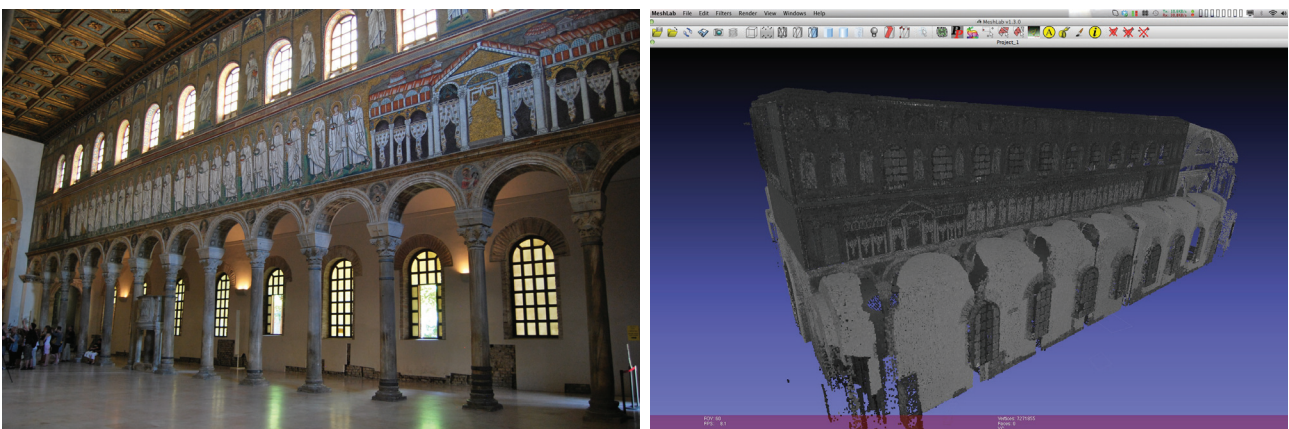


Figure 1. Sant'Apollinare Nuovo in Ravenna, Italy. The early Byzantine church presents a wide nave with side walls covered with mosaics (left). Some terrestrial laser scanner and digital photogrammetric surveys were performed in order to obtain a complete, registered point cloud of interiors (right).

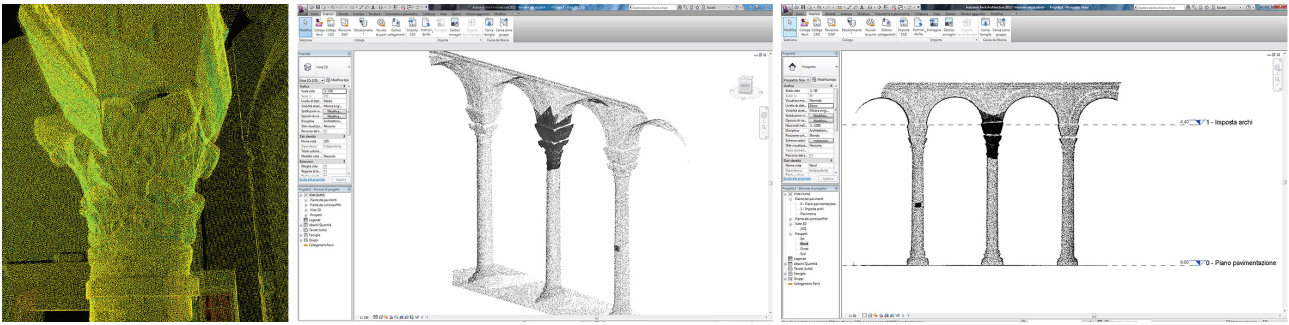


Figure 2. Conventional workflow with imported point clouds (left) in Autodesk Revit Architecture 2012: without any third party plug-in, points are intended as some sort of “frozen” un-structured geometry that cannot be used as snap to trace out parametric smart objects, even if correctly referenced to the floor (center and right).

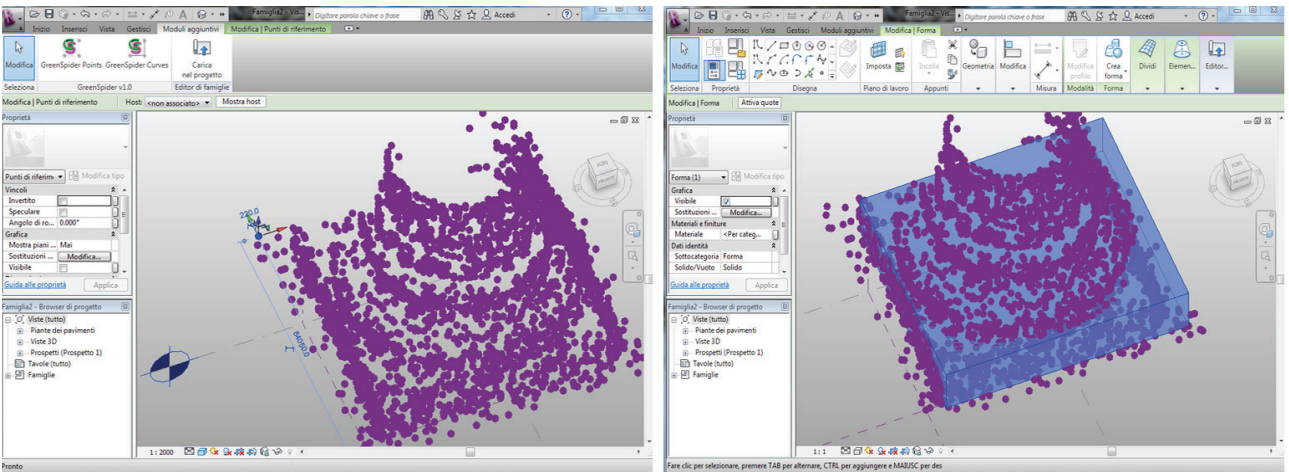


Figure 3. GreenSpider plug-in for Revit 2012, source code developed by S. Garagnani in order to import selected vertexes from un-structured point clouds as native reference points. This way “smart” BIM elements can be traced out with accuracy obtaining parametric objects which can be semantically segmented.

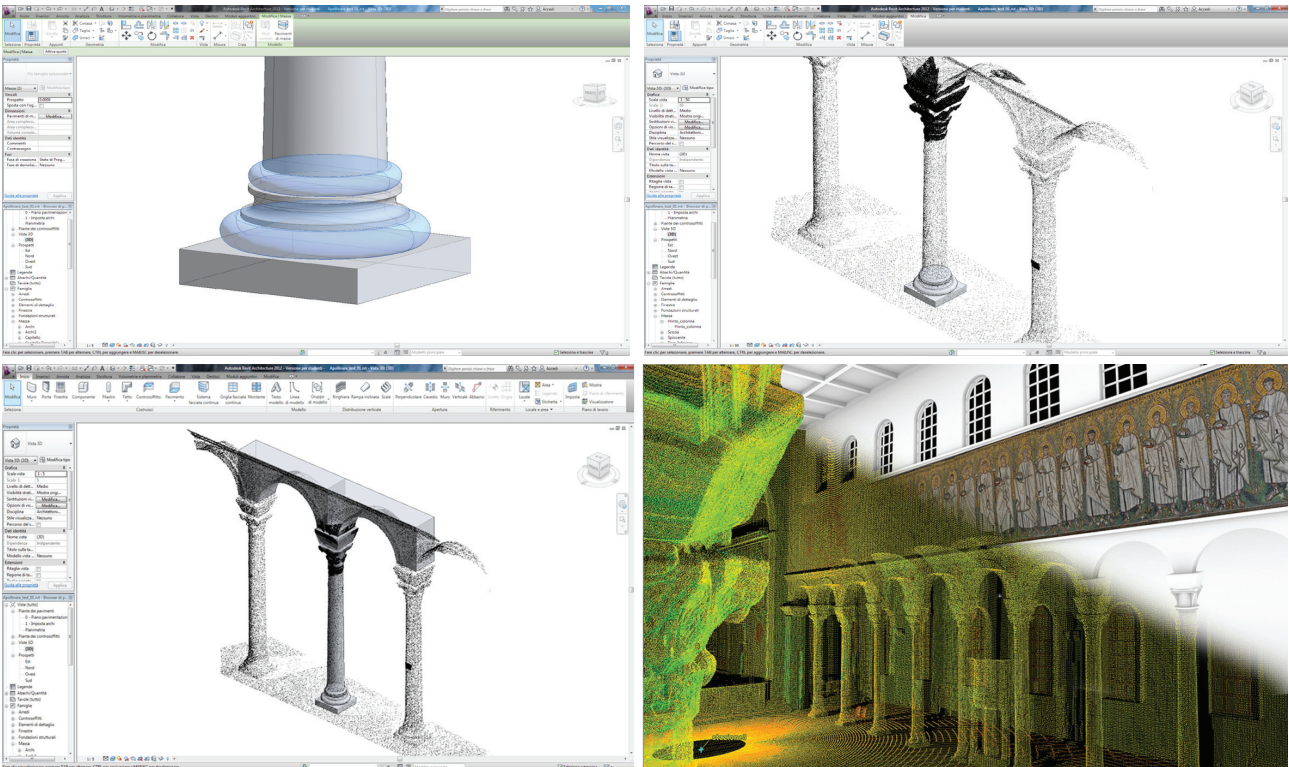


Figure 4. Once modeled as mass Revit families, single components can be imported into the master model, using original point clouds as a referencing scheme. Registered point clouds can be used this way to generate final complex database, aimed to Cultural Heritage documentation and representation.