# AUGMENTED REALITY AND REVERSE ENGINEERING AS INNOVATIVE APPROACHES FOR PLANNING AND MODELLING THE SUSTAINABLE RECONSTRUCTION OF BUILDINGS

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## ABSTRACT

The aim of the paper is to analyse the possibilities and advantages of using the information model created with support of innovative approaches and tools in the field of building reconstruction. Integration of innovative approaches, progressive methods and tools into the process of designing, modelling and planning the parameters of reconstruction projects have to simplify work and increase the quality, efficiency and sustainability of construction projects. The augmented reality and laser scanning as a tool of reverse engineering improves the collection of missing project documentation data and provides a basis for creating a building information model. The implementation of augmented reality and laser scanning in the building reconstruction projects could optimize the communication between project teams and clients, total cost of building reconstruction, time of the projects and plan the optimal structural and technological parameters of building reconstruction.

**Keywords:** reconstruction of buildings, information model, augmented reality, reverse engineering

## INTRODUCTION

The use of augmented reality in architectural projecting is relatively new and commonly unexplored option among the architectural and construction professionals. The augmented reality provides us an immense possibility to facilitate the project work. There a bunch of applications to be used in mobile technologies and various plug-ins for the 3D and 4D CAD software. There is a wide range of use for augmented reality in architectural project starting from visualisation of 3D models, revising the construction process and it also serves as a useful tool to intercommunicate among the construction professionals involved in the process of construction. Also, Building Information modeling has become the significant instrument for coordinating the data in the construction project. Its advantages can be applied also in the process of building renovation. Reconstruction is the specific project that requires intensive preparation. Consuming preparation is one of the barriers to implement Building Information Modeling in the reconstruction process. This situation could change by adopting new technologies such as laser scanning that will facilitate data collection. The original construction documentation is often incomplete or completely lost. Survey of the state of building is the basis for the final project. This is especially true for historic buildings where surveying takes up most of the time. Problems are especially in complicated details of facades and roofs. Documenting the state with laser technology significantly improves quality of work documentation. The documentation is then processed in a virtual environment. This environment facilitates the designer's vision of construction and it can be presented via 3D multimedia and 3D printers.

## DEFINITION AND MAIN CHARACTERISTICS OF AUGMENTED REALITY

The augmented reality allows us to blend the real and virtual world allowing us to obtain a more complete view of the world around us, making perceptible to humans a series of digital information in the most natural way possible to enhance the interaction between both worlds. The Augmented Reality (AR) as a technology appears in the middle of sixties (1968) in the past century by Ivan Sutherland´s creation of the first virtual reality end augmented reality head mounted display called "The sword of Damocles."

In the 1999 Hirokazu Kato creates an AR computer tracking library named ARToolKit released by University of Washington HIT Lab. Based on video tracking which permits to calculate the camera position in real world and its orientation and distance relative to the square black and white AR marker which allows to position correctly an virtual 3D model, 3D Image or 3D video. This open source project is a base of many contemporaneous AR software and mobile applications.

To definite the AR in the simple way we can use the Azuma´s definition of Augmented Reality [1] which affirms that AR combines the real and the virtual, it's interactive in real-time and that it must register in 3D.

For better understanding the difference between the Virtual Reality (VR) and the Augmented Reality (AR) we can use the Beaudouin-Lafon´s explanation of the world of virtual. As Beaudouin-Lafon states, the Virtual Reality enables us to experience the virtual world, interact with digital objects, but within a totally virtual environment, the AR goes a little further, and enable the virtual objects to be represented in real space, generating a connection of the real world with the virtual, (instead of inserting the user in a computer generated world, the AR covers the real world with the virtual world, or embedded/merges both worlds). [2]

## AUGMENTED REALITY AS A PART OF ARCHITECTURAL AND CONSTRUCTION PROCESS

During the developement process of an architectural project there are many possibilities to employ the AR tecnoligies. The more common use of AR is the visualising of the 3D models intended for the presentation to the client or for the development purpose within the project team. There are several plug-ins for the most common CAD programs which are used for the architectural visualisation, such as Autodesk 3D Max, Maya, SketchUp, Cinema 4D, Vectorworks, and Scia Engineer.

The software that is operating within all of these platforms is called AR-media plug-in. This software permits not only the marker based visualisation of the 3D model but also real- time lightning and switch mode between soft and hard shadow rendering. It also poses a very useful tool which performs a real-time sectioning along any axis and a multiple mode sectioning. It is compatible with short animation and also, what is very interesting at the point of view for the client presentation; it permits to show the 3D model of the building, floor by floor, in a real time manner, which simulates the real constructed model in that we can take off the roof of the house.

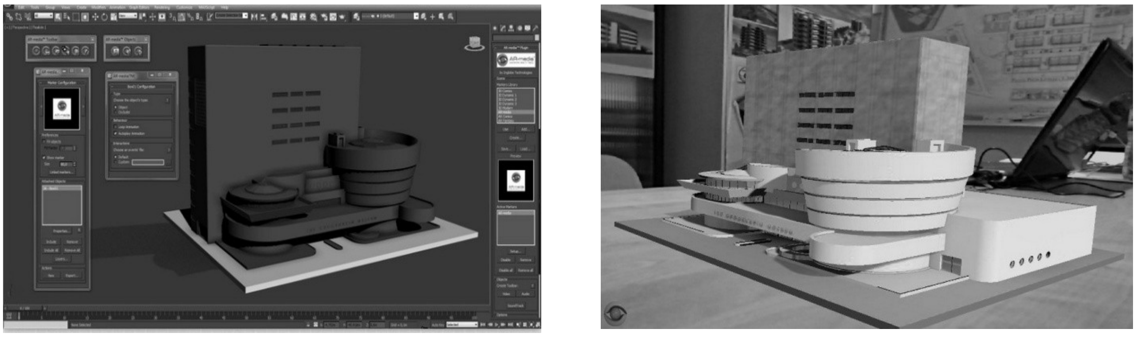

Figure 1 AR- media plug-in: User´s interface within Autodesk 3D max and visualization of 3D model in real-world environment [3]

To share these 3D models with other team members or clients AR-media offers a Player, which allows the user to visualise the geometries created with this plug-in. There is an iOS an Windows option but also exists the option for the Android platform, which allows the user to use this application outdoors and visualise the 3D virtual content in the real-world environmen

Figure 2  AR- media Player. Visualisation of 3D model in real-world environment [3]

The augmented reality technology could be also employed not only to visualise the future projects but also serves to a various uses like building maintenance or visualization of the missing parts of the ancient historical monuments. The plug-in called 3D Tracker which uses is object based tracking  is able to recognize even a complex objects independently of its scale like a building. For example it can be employed to visualise the real position of a building´s infrastructure, based on a project documentation, to allow a further maintenance of the buildings. Due to the angle and distance from the tracked object it superimposes the virtual layer with the desired information.

Another utilization of recognizing the complex object is a Rome Coliseum Application example. This reconstructs virtually the parts of this ancient construction which has been destroyed in the pass of a time. This application is for outdoor use and can be executed on mobile devices.

Figure 3 AR Tracker. Building manteinance example [4]

Figure 4 AR Tracker. Ancient building virtual reconstruction example [4]

## RECONSTRUCTION BUILDING SURVEY METHOD – LASER SCANNING AS REVERSE ENGINEERING APPROACH

First stage for reconstruction should be collecting data of the existing state. Original documentation often does not correspond to the actual situation. In any case, whether or not there is necessary to be documented the real state of construction. In the past this documentation was created by measurement. Measurements are extensive and require a team of people and a lot of time. Measurement of current state is redrawn to 2D on paper or digitally. The disadvantage of this work is working with minimum building data. More sophisticated tools can work in a 3D environment at the surface models. Lack of data in the process ties the hands at work. Using parametric modeling which would place the map of point cloud from scanner would open the way to the advanced modeling techniques based on building information model. 3D laser scanning is used in conjunction with other methods of recordation, including high-resolution photography, and visual inspection of the building’s materials. Full sets of 2D plan and elevation drawings are often required and the scan data itself is increasingly provided as part of the client deliverable. High-definition surveys are also used to precisely capture existing geometry for heritage buildings that are to be meticulously taken down and then re-built in another location. Scanning is a great tool for brick-for-brick, panel-for-panel matching of the original building with the re-built building. Scanning is used to help analyze structural damage or even cosmetic damage, such as older buildings that have begun to shift and sag over time. Where there has been a collapse or other serious damage, scanning is used to accurately assess the structural damage so as to enable accurate repairs. A corollary of this application is to use scanning to capture an accurate “before” geometric snapshot of a building prior to any construction being completed on the building. In this way, if a building is or is not damaged during construction, the contractor or building owner will have a record that can be used to quickly resolve disputes such as, “Hey, that exterior crack wasn’t there before!” or “I think you altered the shape of my building when you installed the underground garage!” Scanning provides inexpensive dispute resolution insurance. Monitoring deformation and building movement [5].

### *A.*
### ***Documentation of existing state***

Documentation of the actual state as it was mentioned in the introduction implements measurements are time consuming. A progressive scanning method allows generating original state of building very precise and time effective.  This method is of particular benefit in the statement of a bill. Square footage can be processed with great precision. From a given position the object to be digitized, the scanner projects a low-power, non-damaging laser light upon a section of the object’s surface. Each point of the surface touched by the laser light is captured by a CCD camera integrated into the scanner, and both the X, Y, Z coordinates and the laser light intensity of each of these points are recorded in the memory of the computer controlling the scanner. This operation is repeated thousands of times each second and generates a file containing a large amount of point data of the scanned surface. This file, displayed on the computer screen, shows the 3D shape of the scanned surface. Individual 3D digital images thus captured are then aligned together with appropriate software using overlapping sections of the images to create an accurate 3D digital model of the object. The software makes it possible to eliminate redundant points in overlapping sections in order to generate a homogenous density of 3D points throughout the model. Some scanners capture the color directly with laser scanning - in this case, RGB values (Red, Green, Blue) are recorded along with the X, Y, Z coordinates - or indirectly by mapping a color photograph taken while scanning the 3D digital image. According to the object or site to be scanned, the 3D scanning process is carried out by moving the object in front of the scanner or by moving the equipment around the object or inside and around the site [6]. Today, we can find a wide range of 3D scanning systems available on the market.

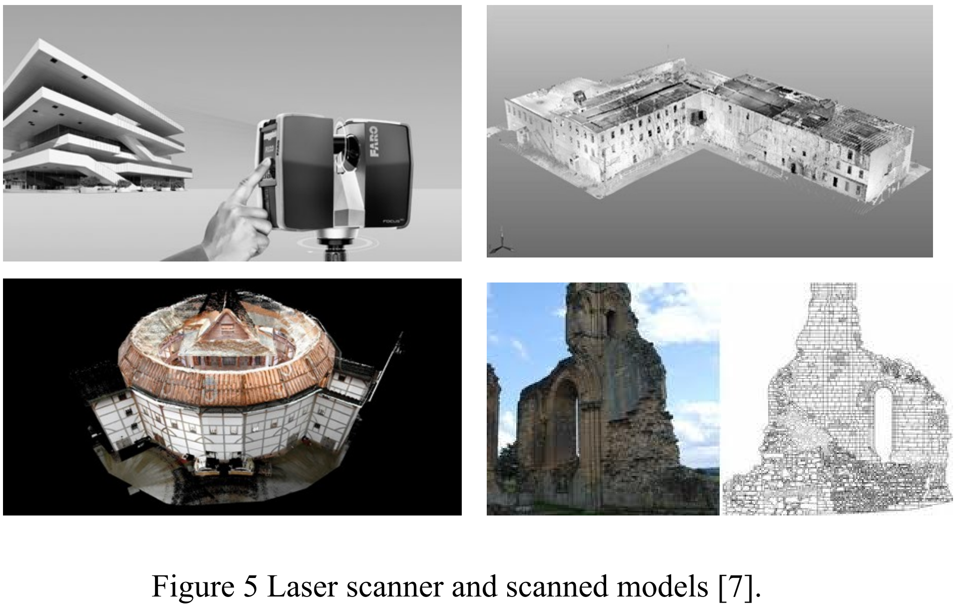

Figure 5 Laser scanner and scanned models [7].

While operating methods with a 3D scanner are typically quite similar, we will not use the same 3D scanning system to digitize a small statue, the interior or exterior of a building, or a human body. The choice of the right system is dictated by the needs and specifications of the project itself. Thus, a single system will not be suitable for all types of projects [6]. A 3-D laser scan produces a precise record of a physical space or object. Initially, the operator of the system takes a photo-mosaic image with a camera and then marks the area to be scanned. The laser scanner then rotates robotically, capturing data at a speed of up to 4,000 points per second. The result is a raw image that is loaded into 3-D visualization and modeling software, which produce accurate existing condition drawings. An example of a successful implementation of this technology comes from the historic tower that serves as the headquarters of the Eastman Kodak Company in Rochester, N.Y. Kodak decided to restore the building's facade, particularly the terra-cotta tile section on the upper four floors of the 19-story tower. The team of specialists charged with exterior repair and restoration decided to use the 3-D laser scanning technology. The entire exterior scan was completed in less than two weeks from 32 adjacent rooftop or ground-level positions. Approximately 84,000 square feet of 3-D facade data was collected and entered [8].

## FROM LASER SCANNING TO BUILDING INFORMATION MODEL

Building Information Modeling is used as a data repository for the project. BIM improves the quality of building reconstruction preparation. By using this technology it is possible to determine quantities in high precisions. Combine different materials and verify functionality through analysis. For all these processes will need to enter information on the current state. Laser scan method produces clouds of points in CAD as a result of the measurement. Building information model is essentially based on the CAD environment. It is therefore possible to use the laser scan method for survey the old state of building. Laser scanners can be used to capture dense 3D measurements of a facility's as-built condition. It is important to note that the results of the measurements will always be a cloud of points. It is therefore necessary to organize points to functional form which can be used or readable for BIM.

### *B. Data preparing and processing*

The actual scanning is the least complicated part of the process— the most challenging is the smooth export to BIM. Infinite views, from any vantage point, are available from the unified point cloud. Once the 3D point cloud data is consolidated and exported to a CAD or BIM platform, traditional A/E deliverables such as 2D plans, elevations, and sections can be readily extracted. While 3D models depict ideal conditions, 3D scans reflect the buildings as they actually are: seldom perfectly straight, level or plumb. 3D modeling is simplified using point cloud data for referencing, but the point cloud itself can serve this purpose, saving many hours of digital model building [7]. Given a point cloud of a facility, the modeling of a BIM involves three tasks: modeling the geometry of the components (“What is the shape of this wall?”), assigning an object category and material properties to a component (“This object is a brick wall.”), and establishing relationships between components (“Wall1 is connected to Wall2 at this location.”). These tasks do not necessarily take place sequentially, and depending on the workflow, they may be interleaved [7]. The goal of the geometric modeling task is to create simplified representations of building components by fitting geometric primitives to the point cloud data. Geometric primitives can be individual surfaces or volumetric shapes. For example, a simple wall can be modeled as a planar patch, or it can be a rectangular box (cuboid). Surfaces like moldings or decorative carvings may not be well modeled by a simple geometric primitive. In such cases, different modeling techniques can be used. For linear structures (e.g., moldings), a cross-section of the object can be modeled by fitting splines to the data and then sweeping the cross-section along a trajectory to form the object model [8]. More complex structures (e.g., decorative carvings) may be modeled non-parametrically, using triangle meshes, for example, or they can be modeled from a database of known object models [9]. Since BIMs are normally defined using solid shapes, surface-based representations need to be transformed into solid models [7].

BIM data import or points cloud export as a most challenging part of the process is done manually or ´´automatically´´. Literature [7] describes manual and automatic process. During the manual process, data transfer is divided to two different methods. The first approach is to fit geometric primitives to the 3D data directly. Geometric modeling software typically includes tools for fitting geometric primitives, such as planes, cylinders, spheres, and cones to the data, as well as special-purpose tools for modeling pipes. Automatic process is represented as a system that would take a point cloud of a facility as input and produce a fully annotated as-built BIM of the facility as output. This is a challenging problem for several reasons. Facilities can be complex environments, often with numerous unrelated objects, such as furniture and wall-hangings, which obscure the view of the components to be modeled. Depending on the information requirements of project participants as well as the context of a project, the problem of as-built BIM reconstruction can have several variants in terms of available inputs and expected outputs. On the input side, additional information about a facility, beyond the raw point cloud data, may be available. Such prior information can simplify the BIM reconstruction process because the prior model can be aligned with the collected data, and knowledge gleaned from that prior model can serve as guidance [7].

## CONCLUSION

Latest demands on cost and time efficient renovation and reconstruction of buildings constantly increases [10]. Therefore it is very important to deal with the implementation of advanced technology in this field. The use of augmented reality is the visualizing of the 3D models intended for the presentation of reconstruction works to the client or for the development, designing and decision purposes within the project team. Adaptation of Laser Scanning to BIM provides tools widely used in the automated process of reconstruction of buildings [11]. This technology will bring the quality of the process, speed and accuracy. The augmented reality and laser scanning as a tool of reverse engineering improves the collection and processing of missing project documentation data and provides a basis for creating a building information model of reconstruction project. The implementation of augmented reality and laser scanning in the building reconstruction projects could optimize the communication between project teams and clients [12], total cost of building reconstruction, time of the projects and plan the optimal structural and technological parameters of building reconstruction [10].

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