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Emerging BIM-3D-Laser Scanning Integration in Construction Practice

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Abstract. The up scaling of innovative information and communication technologies to feasible application within the construction industry is receiving increasing attention, research and funding from public and private agencies. Emerging Building Information Modelling (BIM) and 3D-laser scanners are amongst the leading technologies being recommended for use in construction. Although the potential of BIM in the capture and exchange of construction information has gained interests amongst researchers, the same cannot be said of the 3D-laser scanners. By appropriately integrating data from 3D-laser scanners with BIM can lead to greater benefits in managing construction information. However, the nascent nature of BIM and especially 3D-laser scanners means the nexus of these technologies is yet to be fully understood. This study investigates the use of 3D- laser scanners together with BIM in the optimisation of information exchange across the lifecycle of a construction project. The specific questions to be answered are what are: the practical applications of 3D-laser scanners? How can 3D-laser scanning be integrated with BIM to maximise information gathering and processing for the different applications? What are the benefits and challenges of adopting integrated 3D-laser scanners and BIM in practice? After addressing these research questions, this paper concluded by a way of summary and further discussed the direction of future research.

Keywords: Building information modelling (BIM), 3D laser scanning, Point clouds, 3D modelling, Automation.

1 Background

Recently, the construction industry has been engaged in increasing productivity, efficiency, output quality, infrastructures value and sustainability [1] by implementing emerging technologies, such as BIM and 3D laser scanners (3DLSs). However, improving the performance of the construction industry has faced many challenges vis-a-vis 3D models creation [2]; progress measurements and monitoring of works [3]; dimensional and surface quality assessment [4] and quality improvements in real-estate services [5]. The creation of 3D models is particularly challenging for all existing buildings, because building survey is a time-consuming activity, easily prone to errors. Generally, a building is composed of a wide array of components which can be difficult to identify and opportunely define in a model. The difficulty level for this task increases exponentially with increasing building size, especially if there are structural damages [6]. Structural damage can have various origins but after an earthquake, 3D modelling appears as a critical activity because, in general, time available for planning any action can be very limited. Challenges in both progress measurements during the execution of a building project and the dimensional and surface quality assessment are similar to the ones of 3D models creation. In fact, models updating requires a massive manual work in order to produce modifications to the digital model, even if it could be less dangerous because structures are built in a safer environment. Again, time can be a crucial factor because building activities can be executed quickly day by day. Dimensional and quality assessment of building materials is another challenging activity in an environment where automation is the final goal. In fact, materials need to be checked and accepted before entering on site. Today, it is common to perform this activity manually and, it can be repetitive, time-consuming and so prone to errors. Quality improvements in real-estate services need to be of detailed and high-quality 3D models and their creation can easily require significant efforts. A reliable and detailed digital twin could require the manual identification of any requested detail, in terms of geometrical and physical characteristics. 3D-laser scanners appear as the panacea for all these issues and improve BIM models creation, automatizing main time-consuming and mundane activities.

With regards to new buildings, BIM technology is already being used with a satisfactory results compared to existing buildings. However, building retrofitting is a valuable sector of the built environment. In fact, in some countries like Italy and Spain, existing buildings represent most of the real-estate asset. In Italy, 36.6% of real-estate (11.6 million homes) is more than 40 years old [7] and 80% of national real-estate needs of refurbishment [8]. These buildings lack the digital equivalent. In this case, professionals facing refurbishment projects must put in significant effort in performing the classical time-consuming activities to: retrieve data directly from the buildings, retrieve blueprints, generate models, validate them and only then they can start to design new solutions. In this workflow BIM technology is often used in last stage while previous ones are still conducted using traditional ways, with all related uncertainties and errors. Thus, 3-D laser scanner is quite usefull for collecting and managing data of existing building. In fact, 3-D laser scanners allow to automate almost the entire procedure, avoiding all time-consuming and mundane activities, extending the beneficial use of BIM technology also for existing buildings.

2 Overview of 3D laser scanners and BIM

A laser scanner is a technology based on the use of specific laser light and image sensors, opportunely assembled on a moving structure [9] generally positioned on a tripod support structure, that is directly posed on the ground. Laser scanners can be used for the identification levels and measurement of distances. Laser scanners can be used to measure distance between a landmark and an assigned point belonging to the surrounding environment, fundamentally evaluating the time elapsed between two pulses or evaluating the phase difference between the emitted and the received wave. By automatically and consequentially repeating this operation for a considerable number of different points, the laser scanner can generate a point cloud [10]. Hence, a point cloud is composed of a set of distance measurements representing a discrete analysis of the studied environment.

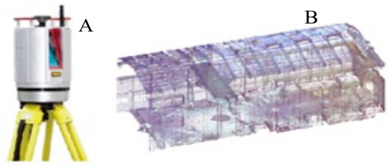

Fig. 1. A 3-D laser scanner on a Tripod (A) and a Point cloud obtained from a laser scanner (B) [11]

However, information obtained by means of a laser scanner, which is generally used for producing 3D models, orthophotos and in reverse engineering, needs to be processed in order to transform the point cloud into surfaces or volumes. In some cases, 3D-laser scanners have specific cameras in order to enrich the cloud points with information about colours. Even if the optical control of 3D-laser scanners can be considered mature enough [13], recorded data analysis is affected by an outstanding number of parameters, such as laser uncertainty, lens imperfection, illumination conditions [9] and objects' surface physical conditions [10]. The scientific community has proposed different methodologies for improving the reliability and usability of this technology from the automated conversion of scanned information to an information model [10], to different algorithms for registering point clouds [12],to the hardware improvement and calibration procedures [9, 12].

3D-laser scanners available on the market can be classified into fixed and mobile devices. Fixed 3D-laser scanners are positioned on a specific support structure, usually tripod, in front of the objects that will be scanned. Mobile instruments can scan the surrounding environment while moving. Hence, they can be integrated on cars, drones, and so on. In this case, scanners are much more sophisticated because of, at least, a stabilizing and a Global Positioning System (GPS) device. In fact, mobile devices need to define their position while scanning. 3D-laser scanners SLAM (simultaneous localization and mapping devices) [13] common in robotic sector, can be considered an evolution of classical mobile laser scanners. These devices can build a map of the surrounding environment and localize themselves on it, even if the GPS signal is absent.

3D laser scanner is a technology that facilitates the collection of physical data of real objects automatically, with various aims such as define and control products shape, objects digitalization, reverse engineering and mapping areas. During the last decade, it has experienced a significant development that has witnessed its use not only in manufacturing sector [14, 15] but in movies, virtual reality, archaeology, robotics [16], mining [17] and construction sector [4, 10, 18]. Concerning the construction industry, building surveying is an activity: time-consuming; potentially dangerous and not always possible, especially in case of survey of damaged structures; subject to errors. In this last case, it is important to cosider that if a building is surveyed with a low level of accuracy, the subsequent design phases could be heavily impacted.

BIM is a technology that has growing success for companies operating in the construction industry, even if it is not brand-new. The purpose of BIM is to improve performance in construction industry under a plethora of aspects [19], inter alia facilitating design operation and offering the possibility to integrate different design aspects, e.g. structural and Mechanical, Electrical and Plumbing (MEP) installations design. Even if BIM is not a brand-new technology, it is still facing significant challenges, especially concerning 3D models creation of existing structures and the facility management [20]. Once solved, the availability of a digital twin of any real structure will definitely revolutionise not only the built environment, but also security, digital economy [21] or rescue [6] as examples.

3 Application of 3D laser scanners in construction practice

As any new and advanced technology, related costs are high, and this has limited the 3D-laser scanner technology diffusion. However, possible applications of 3D-laser scanners in construction industry are numerous: automatic creation of 3D models [10]; progress measurement of construction works [18, 22]; dimensional and surface quality assessment of precast concrete elements [4]; improve quality in real-estate services [5]; archaeological and cultural heritage assets evaluation [23].

3.1 Creation of 3D models

3D models creation directly from laser scanner data represents one of the best advantages of 3D-laser scanners. In fact, current practices based on blueprints analysis, structures survey and then models creation are time-consuming and prone to errors. By means of a process known as scan-to-BIM [10], 3D-laser scanners allow to automate the process. In fact, professionals can simply place the device in different parts of the building and scan the areas. Alternatively, mobile 3D scanner can be used. The scanner produces point clouds that can be immediately used for clash detection, or 3D digital models creation. However, current practices are still based on manual procedures: 2D primitive elements, are positioned into the point cloud in order to fit with real elements. Then meta-data are attached to them [24]. Currently, the need for automating this procedure has already been recognised and the scientific community investigating and developing specific algorithms [10] to deal with meta-data attachment.

3.2 Progress measurements or monitoring of works

Usual procedures used for progress measurement of construction works is based on visual inspections, which can be massively influenced by personal perceptions. In a kind of modern quality control, buildings under construction are scanned in order to check their consistency with digital models [18]. In this case, the As-Built vs the As-Designed check, synthetically known as Scan-vs-BIM, can be performed with the best accuracy level. Nowadays, it can be successfully applied to MEP installations [18] where issues related to shapes and external finishes is a limitation in the use of 3D-laser scanner technologies.

3.3 Dimensional and surface quality assessment

3D-laser scanners can be used for quality controls, which play an important role especially when they are inherent to structural elements: any structural defect or failure could heavily impact the entire financial investment. Nowadays, precast concrete elements are more and more used in construction industry because of savings in terms of construction time and costs. However, their production cycle might generate goods of unsatisfactory characteristics and/or inadequate quality. Unfortunately, the common practice for dimensional and surface quality assessment of precast concrete elements is still based on visual inspections that are costly, time-consuming and subjective [4]. In this sense, the use of 3D-laser scanners represent a relevant innovation for the construction industry because: a BIM library of the produced precast concrete elements (the as-designed one) can be generated; according to the specific precast concrete element, laser scanner typology and parameters can be defined hence the structural element can be effectively scanned; captured data will be then cleaned by means of an opportune algorithm and inspection results will be stored in another BIM library (the as-built one) in order to effectively store information and allow comparisons [4].

3.4 Improve quality in real-estate services

3D-laser scanners and BIM technologies can be used for: capturing building interior and exterior characteristics in order to create 3D rich and accurate digital models that allow to perform virtual 3D walks; efficiently store buildings information that allows to improve real-estate management activities thus offering a better service for potential buyers [5]. In each case, data acquisition, processing and storing activities are hot topics and several different strategies can be applied. Data acquisition is automatically performed by the 3D-laser scanners depending, however, from a valuable number of parameters. Acquired data allows to generate 3D point clouds which should be first filtered, then they can be managed by means of specific software provided by the manufacturer of the 3D-laser scanners. However, nowadays there are several commercial 3D computer graphics and computer-aided design software able to open and modify 3D point clouds, e.g. Rhinoceros 3D from Robert McNeel & Associates. This allows to manually position the 2D elements within the point cloud in a way to generate the 3D digital model. Alternatively, data can be processed by means of specific segmentation algorithms that allow to trace boundaries so polygonal meshes can be created [11]. Furthermore, commercial software usually allows to save 3D point clouds as .stl format file or .dwg format file, which can be opened by a number of commercial software, including BIM software. Assuming that interoperability plays a central role in BIM technology [25], algorithms able to automatically translate the surface-based models into volumetric models and export them in Industry Foundation Classes (IFC) format file are under development [10].

3.5 Cultural heritage assets evaluation

Historical, artistic and cultural heritage can be effectively scanned in order to produce 3D models that reflect the reality. The high level of details as well as shapes and possible defects produced by the elements, elevate the difficult level to its maximum. Furthermore, in certain cases, cultural heritage survey must be repeated at regular intervals. The use BIM and 3D-laser scanners allows to perform evaluation in the fastest way, with the best level of accuracy and optimizing costs. Then data are organised and manually transferred to a digital model. Moreover, some techniques have been developed in order to capture colour information [23]. Consequently, these technologies allow to move cultural heritage assets evaluations on a different level, revolutionizing current practices and increasing productivity.

4 3D-Laser scanner-BIM integration

The process of integrating scanned data to a BIM digital model requires first the capturing of the data (see Fig. 2). The building has to be scanned and typically operations can vary according to the specific device used to scan and according to the typology of the building. In fact, referring to cultural heritage or to prestigious buildings, it can be necessary to add colour information by means of some high-resolution photographs [5]. The second step is composed of all activities needed for registering, cleaning and organising scanned data [26]. In fact, each point is registered attaching a specific set of geometrical information but not all points are related to the scanned building. This justifies the data cleaning activity. Furthermore, if the final user could be interested only to specific parts of the scanned information, the data organising activity is fundamental. Nowadays, there are specific software able to perform these activities. In some cases, especially when high detailed models are needed, it can be useful to repeat some scans in order to locally enrich the point cloud. In this case, data needs to be merged and recent software can also automate this activity. The third phase is composed of the digital model creation based on the registered point cloud. Some BIM software is able to directly import a point cloud so that the user positions the opportune building elements which can fit the point cloud. In this case, the user also assigns non geometrical information to the objects. Unfortunately, it is a time-consuming activity that will produce the biggest advantage only when automated. Alternatively, models can be created based on mesh or surfaces defined by using scanned points information [26]. Currently, researchers are trying to implement specific algorithms able to automatically transform complex point clouds into 3D models.

The proposed framework (see Fig. 2) is adequate for every application of 3D-laser scanners in construction practice. However, concerning the heritage assets evaluation as well as the real-estate services improvement and the classical 3D models creation, in case of scanning of complex buildings, high quality photographs and further detailed scans could be needed. A massive volume of information will be generated and next two phases become more complex and time-consuming. Instead, referring to progress measurements and quality assessment, some simplifications could be possible. Progress measurement of construction works, and their monitoring could be directly evaluated from the point cloud, therefore the 3D model creation phase might be avoided. Furthermore, the environment in which performing scans may interfere less with the scanner activity. In this case, detailed scans as well as high quality photographs might be avoided. This last advantage can be shared with the quality assessment activity. In fact, this activity carries the advantage of operating in the best controlled environment and laser scanners properties can be set at their best. Upon completion of the 3D model creation, it can be imported in BIM models as libraries.

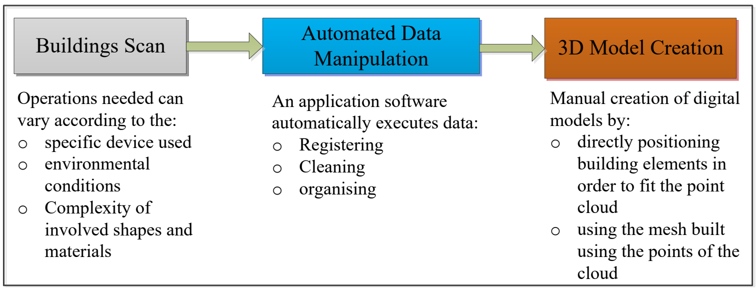

Fig. 2. Scan-to-BIM framework.

5 Benefits and Barriers to 3D-Laser scanner adoption

The most valuable aims of integrating BIM with 3D-laser scanners are: ensuring the efficiency of buildings, facilitate maintenance operations, reduce human workload and errors, as well as costs and inefficiencies. In fact, 3D-laser scanners allow to easily digitalize buildings and the surrounding environment, producing 3D semantically rich models. These considerations can be extended to both MEP installations and structural precast elements, opening to the automatized acceptance controls activity. Defects incidence can be reduced, allowing to save the 5% of total construction costs [4]. In case of refurbishments, the absence of data obliges professionals to perform time-consuming activities that can hugely impact performances and fees. Furthermore, real-estate services will have an increased accuracy, speed and quality.

Even if 3D laser scanners has the potential to revolutionise the approach to restructurings, the applied techniques are not considered mature yet for different reasons. Firstly, high devices cost, which can vary from US$ 40,000 to US$ 200,000 [4]. Alternatively, scanning activities can be externalised, but prices for cloud surveys are 40%-50% higher than in-house surveys [5]. Choosing the appropriate 3D-laser scanners is not easy also because of the relevant number of impacting factors, such as: types of scans – fixed or moving, outdoors or indoors, with or without GPS signal availability; types of objects to be detected – structures, installations, colours, finishes [4]; typical lighting conditions; level of precision required; relative position between objects to be scanned and the scanning device [14]. Furthermore, making informed choices about which device to use is a challenge because of the wide spectrum of applicability of laser scanners in the market. The most relevant weakness for this technology is represented by the data processing: devices produce a huge amount of data that requires a high computing power for opportunely processing, filtering and manually transforming them into a 3D digital model. Unfortunately, algorithms for completely automate such operations are still under development.

6 Conclusions

This paper analyses the use of 3D-laser scanners within the built environment, describing its potential beneficial effects, especially when integrated with BIM technology. Current practices, especially for existing buildings, are still massively depending on trivial manual activities, such as buildings survey, that can heavily impact projects performance and related costs. The 3D models generation activity is still a manual operation that has been only partially automated by means of 3D-laser scanners. However, it will be completely automated as soon as specific algorithms for the treatment of data collected by 3D-laser scanners will be developed. In this last case, professionals can only focus on design activities, improving performance of the construction industry. The need for detailed 3D models is recognised as one of the main trends in scientific research [27]. In the context of the integrated BIM environment, the automation in 3D models creation and updating plays a central role. Future research is pointing towards new technical solutions able to reduce the number of impacting factors in 3D-laser scanners performance as well as new algorithms able to improve the process of automated transformation of point clouds to 3D models [10] with meta-data attached [5]. Furthermore, reliable metrics for laser-scanning applications, defined in terms of accuracy required, distance to target and point cloud density [26] are needed in order to both standardize scanning activities and define minimum acceptable quality.

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