3D Capture Techniques for BIM Enabled LCM

Fodil Fadli[1](✉), Hichem Barki[1], Ahmed Shaat[2], Lamine Mahdjoubi[3],
Pawel Boguslawski[3], and Vadim Zverovich[3]

[1] Department Of Architecture and Urban Planning, College of Engineering,
Qatar University, Doha, Qatar
{f.fadli,hbarki}@qu.edu.qa
[2] MZ & Partners Architectural and Engineering Consultancy, Doha, Qatar
ashaath2002@yahoo.com
[3] Department of Architecture and the Built Environment,
University of the West of England, Bristol, UK
{lamine.mahdjoubi,pawel.boguslawski,vadim.zverovich}@uwe.ac.uk

Abstract. As a special kind of Product Life cyle Management (PLM), Building Life cycle Management (BLM) is a centric activity for facility owners and managers. This fact motivates the adoption of Building Information Modeling (BIM) approaches as a way to achieve smart BLM strategies for cost reduction, facility knowledge management, and project synchronization among the different stakeholders. Unfortunately, the current BIM state of the art is tailored towards the management of new projects, while ongoing and completed AEC projects could hugely benefit from BIM integration for better BLM strategies. In this regards, it is absolutely necessary to acquire knowledge about the dynamic facility aspects (crowd movement, as-is updates, etc.). Up-to-date, 3D capture appears to be the only reliable way to cope with such situation. In this paper, we analyze 3D capture techniques, ranging from photogrammetry to 3D scanning, with an emphasis on helping 3D capture practitioners to make critical decisions about the choice of adequate acquisition technologies for a particular application. We discuss 3D capture techniques by exposing their pros and cons, according to several relevant criteria, and synthesize our analysis by developing a set of recommendations to enhance the life expectancy of buildings via the integration of BIM into Life Cycle Management (LCM) of the built environment and its buildings.

1 Why 3D Capture Is Essential to BIM?

3D capture techniques aim to generate virtual models through the usage of different kinds of sensors in an environment of interest. Thanks to the recent technological progress of computing devices and the rapid drop of their prices, 3D capture gained more popularity and became more accessible for professionals and even amateurs. As a consequence, it is now easy to quickly generate large amounts of very complex virtual models, ranging from unstructured point clouds to meshes and surfaces, encoding the geometry, topology, texture, and other physical properties of the surrounding world.

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3D capture finds applications in many domains, including BIM, robot motion planning, life cycle analysis [11], and emergency preparedness [7,12]. It is essential as it constitutes the first step towards the development of suitable BLM processes employing BIM models that greatly help practitioners by offering better visualization and interaction means. BIM is a recent approach that aims to complement or supersede traditional CAD design. The current state of the art reveals that it is much easier to achieve BIM for new projects than for already completed or in progress projects, complicating by the way the undertaking of life cycle-related tasks on existing projects, e.g., maintenance, renovations, etc. This is a big concern when one considers that many countries have realized the importance of BIM and are initiating BIM reforms and pushing towards its quick adoption. While initial CAD/GIS plans, if they exist for a particular scene, represent a valuable source of information; acquiring knowledge about dynamic scene aspects (human behaviour, construction and as-built differences) is a necessary and relatively difficult task, making 3D capture unavoidable in our BLM context, because it is the only way to deal with dynamic scenes information.

In this paper, we introduce, review, and analyze the usage of 3D capture techniques, ranging from photogrammetry to 3D scanning. Contrary to prior review papers which tend to summarize the literature or avoid discussing some relevant capture aspects, our comprehensive analysis is oriented towards 3D capture practitioners who need to make critical decisions, by examining the relevant aspects of each technology, the different pros and cons, and the potential application domains. We conclude this work by providing a set of recommendations for field practitioners, in order to enhance the use of such techniques in BIM integrated life cycle management. We shall note that even if this work introduces 3D capture techniques in general, the provided review focuses only on the most prominent ones: photogrammetry and laser scanning.

2 3D Scene Capture Techniques

The current literature shows that 3D capture retained much attention in the past decades. Even capture techniques cannot be strictly categorized, one may broadly distinguish 3D scanning/modeling approaches and image-based techniques.

Manual building surveying (manual geometry measurements and drafting boards usage) represents the most basic and oldest capture technique. As a consequence of computing devices emergence and the development of CAD tools, CAD modeling became popular and allowed the generation of 3D models. The aforementioned techniques are characterized by long modeling times, the inability to encode fine architectural details, and the requirement for highly skilled operators.

Based on the employed sensor underlying acquisition principles, one may classify 3D scanning techniques into different categories [20], such as passive/active, reflective/transmissive, destructive/non-destructive, optical/non-optical, etc. Active probing techniques capture the shape of 3D physical objects using Coordinate Measuring Machines (CMM) composed of mechanical arms that probe

Fig. 1. 3D scanning devices. Left: A contact-based MicroScribe device (photo taken from [3]). Right: The Riegl VZ-400 terrestrial laser scanner.

objects' surfaces along user-defined profiles (cf. Fig. 1 left) [3]. Although successfully used for reverse engineering, such a time-consuming and manually operated technique does not provide consistent control on the sampling accuracy, does not allow recording visual properties of objects, and doesn't operate on soft or large-size objects (destructive approach).

Non-contact 3D scanning techniques, whether optical (Lidar) or non-optical (Radar, Sonar, or Computer Tomography (CT)) employ different sensing principles and may also be classified into transmissive and reflective ones, depending on the nature of the interaction of the emitted wave with the target objects. These techniques do not intrinsically interfere with the scanned object and thus reduce the impact of the capture on fragile objects. Lidar or laser scanning is the most relevant in our context and consists in emitting laser beams, of frequencies typically between 500–1500 nm [6], and analyzing their reflections, in order to deduce the distance between the device (cf. Fig. 1 right) and the scanned objects. One of the main reasons of the wide adoption of laser scanning is laser's tight focus allowing to capture large scenes, compared to other optical techniques.

As an image-based capture technique, photogrammetry has a long history [18] but it is only recently that it has been used to model 3D scenes, thanks to the recent popularization of high quality cameras (cf. Fig. 1 right). The principle consists in deducing the 3D structure of a scene by examining a set of overlapping images, generated by positioning targets with known coordinates on the scene objects to be captured, and then taking several image captures from different positions and angles. By using such a priori information about the position/orientation of the camera and the target points coordinates, the captured images can be combined by using some principles of projective geometry, in order to construct a 3D scene model [10]. Photogrammetry excels in extracting scene colour and texture information under reasonable conditions.

3 Analysis and Usage of Capture Technologies

In the sequel and based on several criteria of interest, we will compare photogrammetry and laser scanning, which are the most prominent capture techniques among the two aforementioned broad categories. Variations of such techniques qre discussed whenever relevant.

Resolution, Precision, and Range. The quality of a capture device is usually assessed through a set of objective measures defined as range, resolution, precision, and accuracy parameters. Compared to photogrammetry, whose accuracy is unpredictable because of many parameters (e.g., the 2D image to 3D model conversion errors), the accuracy of laser scanning may be easily estimated in advance. Even if some previous work claims that recent photogrammetric devices are able to achieve similar or even higher resolution/accuracy than laser scanners, there is an agreement that laser scanning performs better in general and can go below the millimetre accuracy. For complex geometry scenes and objects, photogrammetric techniques are still unable to reproduce accurate details [20]. Furthermore, the fact that laser beams have tight focus implies that they are more precise in capturing scenes at higher ranges, and even at very short ranges at the level of molecules [9].

Environmental conditions represent an important factor that determines the usability of capture techniques, as some of the latter are guaranteed to perform correctly only under some environmental conditions. Because of its emissive nature, laser scanning is less affected by ambient light fluctuations and the resulting acquisition data is relatively invariant with respect to climate conditions, except that it is unable to operate on very shiny materials like water surfaces. In contrast, photogrammetry is highly influenced by weather/lighting conditions and the outcome deteriorates for large dark scenes. This concern represents one of the main cons of photogrammetric techniques.

Data and Operation Complexity. As laser scanning is the most advanced data capture, it is predictable that it is the most efficient in data capture, while millions of points can be captured per second and this rate is even increasing with the progress of laser technology. In fact, laser scanners provide an automated way of scanning large 3D areas in 360 horizontal direction, allowing for more capture density. In contrast, photogrammetry relies on several 2D image captures followed by a heavy post-processing for 3D point cloud generation, making it less efficient and constrained by the single image capture resolution. Laser scanning operates in near real-time while photogrammetry is employed in an offline fashion because of the aforementioned reasons. In the literature, laser scanning has been reported to be slower than photogrammetry for high resolution captures. However, this is an unfair conclusion as photogrammetry is unable to reproduce the higher resolution captures of laser scanning and even if it does, it becomes terribly slow.

A natural consequence of the high capture speed of laser scanners is the large size of the captured data. According to the laser capture resolution, the more laser beams are emitted, the more points are collected. For complex and large scenes, typical point clouds may easily contain billions of points coming from hundreds of individual scans. Even if large point clouds provide very detailed information about a scene, such huge data amounts make the processing and knowledge extraction tasks more involved and time consuming. On the other hand, photogrammetric results are smaller, but the continuous progress of imaging devices and image processing algorithms gave rise to applications involving tens of thousands of images and thus yielding to very large point clouds.

The most critical issue of photogrammetric approaches concerns the processing or combination of the individual image captures into a unique model. Due to the manual placement of targets for image registration and the manual choice of camera positions/rotations, such a process becomes very time consuming and tedious. The most time consuming sub-step in a photogrammetric process is the combination of the individual 2D images into a unique 3D point cloud. For laser scanning techniques, 2D-to-3D conversion is eliminated as the capture is already three-dimensional and the registration of the individual 3D point clouds is relatively easier. For more details about 3D capture complexity and processing cost precise measures, the reader is referred to [2,16].

Safety and Autonomy. Photogrammetric techniques are safer than laser techniques as the former require the use of conventional still cameras, while the latter are harmful for the operator's eyes. The recent trend going towards the usage of LED light as a replacement of laser is an alternative that addresses the safety concern of laser scanning, while presenting the advantage that LED light is as accurate as laser for close range captures only. Regarding the capture autonomy and hence mobility, photogrammetry outperforms laser scanning as the latter makes usage of power-consuming built-in amplifiers. It is worth noting that recently, some hardware manufacturers successfully introduced handheld and flexible laser scanners for small size objects capture, and that attempts have been made to use them for large scenes capture.

Equipment and Operation Cost. Evaluating the capture budget is a crucial factor from the a financial point of view. Photogrammetric techniques are the most accessible ones as they employ still cameras whose prices are rapidly decreasing and whose performance and specifications are continuously increasing. In contrast, despite their commercialization since three decades, laser scanners prices are still high. According to [20], laser scanners prices range from tens of thousands of dollars to hundreds of thousands of dollars, depending on the sophistication of the scanner, the included accessories/software, and the specifications. In consequence, laser scanning is still restricted to companies or educational institutions with consequent budgets. Recently, scanner rental services have emerged [1] as an alternative for institutions with lower budges. Another factor influencing the cost of a capture process consists in the lifetime of the capture device. While photogrammetric devices may be used for decades, laser scanners have a much smaller lifetime (thousands of hours) because they are quickly deteriorated by the operational temperature of the built-in amplifier [6]. When it comes to the operational cost of a capture process which is correlated to the learning curve of that process, since still cameras can be found on almost any private office, it is natural that they are the easiest to use, compared to the non-public-friendly laser scanners which require specific trainings and thus an additional operational cost.

Applications. Whenever some geometric or physical information about a scene is required or needs to be reconstructed, data capture enters into action. Photogrammetry and 3D scanning have been interchangeably and successfully used in many applications. On the one hand, Terrestrial Laser Scanning (TLS) has been applied for interior building modeling, navigation, and exploration [23], while Airborne Laser Scanning (ALS) has been used for 3D city/terrain modelling and landslide volume computation in geology, in order to capture the geometry of cities and terrains [21]. In transportation projects, it has been used for acquiring design and construction data [16]. Cultural heritage and historical buildings digitization is probably the most explored domain where laser capture has been used for heritage documentation and preservation [23]. On the other hand, photogrammetry touched similar application domains like for example in bridge engineering [17], but the application domain that deserved most of the researchers attention was cultural heritage preservation, where it has been used for the digitization and reconstruction of photorealistic 3D models for many historical sites [5,10], thanks to the ability of photogrammetry to better capture visual aspects of scenes.

4 Life Cycle Management (LCM) Connection to Sustainability Assessment (SA) in the Built Environment (BE)

In order to understand and adapt LCM usage in the BE and hence interoperability to BIM, sustainability and its assessment must be well understood and scrutinized. In fact LCM goes in accordance with SA to determine its integration into any BIM model. In this respect, we elaborate on the most adequate definition of sustainability and its rigorous assessment.

There are as many definitions of sustainability and sustainable development as there are individuals and interest groups trying to define the term. All the definitions however, share a common concern for: (i) living within the limits (ii) understanding the interconnections between economy, society, and environment, and (iii) equitable distribution of resources and opportunities [13].

In 1981, Malcolm Wells suggested a matrix, which appears to be the first attempt to use indicators to help achieve sustainability [22]. Although, Wells' matrix was invaluable, it was still far from comprehensive. It did not either elaborate real complexity or recognize value shifts and differences in the sustainable design process. In 1990, Kroner has further developed the matrix with categories and sub-categories, while Salem enlarged it by adding a priority tab [8]. It was further refined during the last decade but remained limited to environmental factors mainly [13]. Assessments of sustainability can help inform the societal discussion and influence the environmental governance towards the main objectives of sustainability. The effectiveness of an assessment system in this regards requires that it matches up well against a number of requirements, in such a way that it can be seen to be: (i) hopeful, (ii) holistic, (iii) protective, (iv) Harmonious, (v) Participatory, and (vi) habit forming [19].

LCM-SA Interoperability into BIM Models. The recent decades have witnessed a maturing of concern and interest in building performance that is increasingly evidenced in building design. Sustainable or green design is not simply about attaining higher environmental performance standards or investing in new values; it is also about rethinking "design intelligence" and how it is placed in buildings. The distinction between the notions "Green", "Intelligent", "smart" and "Sustainable" is critical in what underlies valid sustainable buildings. Sustainability assessment is a procedure used to evaluate whether environmental, economic and societal changes arising from man's activities and use of resources are decreasing or increasing our ability to maintain long-run sustainability.

During the last two decades, the science of "assessing sustainability in the built environment" has flourished and the number of assessment tools exploded dramatically to reach over 100 tools worldwide [14]. Local assessment systems have developed in different countries and regions; responding to perceptions of what is needed in their local conditions. These assessment systems and tools share much in common but also evidence differences of scope, approach, reporting and mitigation measures.

This study opened the door to new horizons in BIM integration of LCM/SA and the use of capture techniques, in fact this would allow the tools stated previously to include life cycle assessment and costing, energy systems design and performance evaluation, productivity analysis, indoor environmental quality assessment, operations and maintenance optimization, whole building design and operations tools [15], and enable their apps into BIM oriented platforms. Commonly-used tools worldwide are performance and/or predicted performance based systems. Each features a suite of tools developed for different buildings and projects such as residential, commercial, industrial, retail and educational and health buildings. Therefore this study will develop further recommendations to enable the use by field practitioners.

5 Recommendations to Enhance Qualities of the Built Environment

The conducted comparative study reveals that laser scanning technology represents the future of 3D capture. It is the most promising technique as it is the most accurate one. Photogrammetric techniques provide less garbage than laser techniques do, but photogrammetric data requires costly post-processing in addition to being limited by the image accuracy and the precision of the registration process.

As predicted in [18], it is more interesting to combine different capture technologies, as each one comes with its own set of pros and cons. It is natural to think that combining laser scanning and photogrammetry improves the accuracy of photogrammetry and reduces or ideally eliminates the manual steps required for generating 3D models. This observation is consolidated by the recent trends of the combined usage of capture techniques. For instance, a progress reporting application has been proposed in [11], where both photogrammetry and laser scanning have been combined to improve the accuracy and speed of collecting data from a construction site. In cultural heritage digitization, laser scanning and photogrammetry have been conjointly used in many works [4,5,24]. In robot motion planning, laser and vision sensors were combined for the development of a robot navigation system in indoor environment [25].

As a synthesis, an ideal and universal 3D capture technique doesn't exist. Our discussion shows that when the need arises for data capture in a particular context, a good practice would be to start by carefully identifying the application requirements, and then transposing these needs to each technique, in order to find the most adequate capture technique for that context. As an advice, one might consider using other techniques, in conjunction or complementation of the primarily chosen one, in order to improve the capture process. In cultural heritage, it appears that combining laser scanning (more precision) and photogrammetry (better visualization) gives the best results, while in the emergency preparedness context, laser scanning combined with other techniques (e.g., RFID) represents a good candidate.

6 Conclusion

In this work, we have conducted a comparative study of the most prominent 3D capture techniques as the capture process is unavoidable for developing a smart BLM impementation through BIM. We have introduced 3D capture techniques and compared them by exposing their weaknesses and strengths, according to many relevant criteria for field practitioners like equipment/operation costs, mobility, accuracy, precision and range, data complexities, etc. As 3D scene capture is involved in a plenty of application domains, our study targets a wide audience of professionals. It provides a set of recommendations and advice that help data capture actors for the correct and critical choice of adequate technologies that best suit the targeted application. Our study shows that an ideal capture technology may not exist for a particular application domain, but the usage of more than one technology is highly recommended for getting better results.

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References

1. Laser scanning Europe. Rent a laser scanner at little cost. http://www.laserscanning-europe.com/en/rent-laser-scanner/rent-laser-scanner-little-cost
2. Leica Geosystems. http://www.leica-geosystems.com
3. MicroScribe Portable Scanners. http://www.3d-microscribe.com/

4. Agnello, F., Brutto, M.L.: Integrated surveying techniques in cultural heritage documentation. In: ISPRS Archives, vol. 36, 5/W47 (2007)
5. Al-kheder, S., Al-shawabkeh, Y., Haala, N.: Developing a documentation system for desert palaces in Jordan using 3D laser scanning and digital photogrammetry. J. Archaeol. Sci. **36**(2), 537–546 (2009)
6. Baltsavias, E.P.: A comparison between photogrammetry and laser scanning. ISPRS J. Photogrammetry Remote Sens. **54**(2–3), 83–94 (1999)
7. Barki, H., Fadli, F., Boguslawski, P., Mahdjoubi, L., Shaat, A.: BIM models generation from 2D CAD drawings and 3D scans: an analysis of challenges and opportunities for AEC practitioners. In: Proceddings of The International Conference on Building Information Modelling (BIM) in Design, Constructions and Operations (2015)
8. Bell, S., Morse, S.: Sustainability Indicators: Measuring the Immeasurable?. Earthscan, London (2008)
9. Cracknell, A.P.: Introduction to Remote Sensing, 2nd edn. CRC Press, Boca Raton (1991)
10. Debevec, P.E., Taylor, C.J., Malik, J.: Modeling and rendering architecture from photographs. In: Proceedings of the 23rd Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH 1996, pp. 11–20 (1996)
11. El-Omari, S., Moselhi, O.: Integrating 3D laser scanning and photogrammetry for progress measurement of construction work. Autom. Constr. **18**(1), 1–9 (2008)
12. Fadli, F., Barki, H., Boguslawski, P., Mahdjoubi, L.: 3D scene capture: a comprehensive review of techniques and tools for efficient Life Cycle Analysis (LCA) and Emergency Preparedness (EP) applications. In: Proceddings of the International Conference on Building Information Modelling (BIM) in Design, Constructions and Operations (2015)
13. Fadli, F., Sibley, M.: Measuring sustainability levels of tourist resorts: STAM and the use of radar diagrams. In: The International Conference of the Center for the Study of Architecturein the Arab Region (CSAAR), pp. 1315–1331 (2007)
14. Fadli, F., Sobhey, M., Asadi, R., Elsarrag, E.: Environmental impact assessment of new district developments. In: WIT Transactions on The Built Environment, pp. 517–528 (2014)
15. Fowler, K., Rauch, E.: Sustainable Building Rating Systems Summary. Technical report Pacific Northwest National Laboratory Report 15858 (2006)
16. Jaselskis, E.J., Gao, Z., Walters, R.C.: Improving transportation projects using laser scanning. J. Constr. Engin. Manag. **131**(3), 377–384 (2005)
17. Jiang, R., Jáuregui, D.V., White, K.R.: Close-range photogrammetry applications in bridge measurement: Literature review. Measurement **41**(8), 823–834 (2008)
18. Masson, B.T.: Paul Debevec and the Art of Photogrammetry. pp. 2–4 (2000). www.vfxpro.com
19. Pintér, L., Hardi, P., Martinuzzi, A., Hall, J.: Bellagio stamp: principles for sustainability assessment and measurement. Ecol. Ind. **17**, 20–28 (2012)
20. Scopigno, R.: Tutorial T1 : 3D data acquisition. In: EUROGRAPHCS 2002 Tutorials (2002)
21. Tse, R.O.C., Gold, C., Kidner, D.: 3D city modelling from LIDAR data. In: van Oosterom, P., Zlatanova, S., Penninga, F., Fendel, E.M. (eds.) Advances in 3D Geoinformation Systems, pp. 161–175. Springer, Heidelberg (2008)
22. Wells, M.: Gentle Architecture. McGraw-Hill, New York (1981)

23. Xiao, Y., Zhan, Q., Pang, Q.: 3D data acquisition by terrestrial laser scanning for protection of historical buildings. In: 2007 International Conference on Wireless Communications, Networking and Mobile Computing, pp. 5966–5969 (2007)
24. Yastikli, N.: Documentation of cultural heritage using digital photogrammetry and laser scanning. J. Cult. Herit. **8**(4), 423–427 (2007)
25. Zender, H., Martínez Mozos, O., Jensfelt, P., Kruijff, G.J., Burgard, W.: Conceptual spatial representations for indoor mobile robots. Robot. Auton. Syst. **56**(6), 493–502 (2008)