Supporting Deconstruction Waste Management through 3D Imaging: A Case Study

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Abstract –

Conventional demolition approaches of razing a building at the end of its life-cycle generate a large amount of mingled debris, which is difficult to reuse and recycle. Compared to demolition, deconstruction involves disassembling a building systematically and it is a more environmentally friendly alternative. Recent research studies have focused on the transition from demolition to deconstruction to minimize the amount of generated waste and maximize the amount of recycling and reusing material. However, due to tight schedule requirements, extra labor cost, and the lack of drawings and design information, it is difficult for an owner to estimate the cost and duration of deconstruction ahead of time. 3D imaging technologies, such as laser scanning and image-based 3D reconstruction, provide an opportunity to obtain data about as-is conditions at a job site and hence can potentially help in identifying quantities of materials that will be recycled. Existing 3D imaging workflows have two primary limitations: visibility and appearance ambiguity. First, 3D imaging can only capture visible objects before a deconstruction process starts. Also, data captured before deconstruction or at different times during deconstruction can only include a subset of all building components. Second, building components with similar appearances can be made from different materials, resulting in misclassification and errors in quantity estimation. Only a few case studies have discussed how visibility and appearance ambiguity can affect the usage of 3D imaging in deconstruction waste management. In this paper, the authors aim to illustrate the application of 3D imaging during a small-scale deconstruction project in Pittsburgh. Specifically, the authors documented the waste generated during deconstruction manually and by using two different 3D imaging technologies: laser scanning and image-based registration. We then quantified the number of invisible objects and objects with ambiguous appearances at different stages of deconstruction. Through the comparison between the quantity takeoffs from 3D imagery and the ground truth, the paper aims at providing insights on the following questions: 1) How accurate are the quantity estimation and documentation of two 3D imaging technologies (laser scanning and imagery) compared to the actual waste generated? 2) Does 3D imaging capture all components of interest during deconstruction?

Keywords –

3D Imaging; Demolition; Deconstruction; Waste Management; Laser Scanning; Image

1 Introduction

The paper starts with an introduction of challenges encountered in deconstruction projects and review how previous research aimed to address these limitations.

1.1 Background

The demolition projects in the US generated over 547 million tons of demolition debris in 2015, which had tripled compared to the 170 million tons of debris in 2005 [1]. Over 30% of demolition debris had become landfill without being adequately recycled [2]. Demolition often generates mingled waste, which might contain hazardous materials, such as asbestos, lead, PCBs and medical waste [3]. With the concerns mentioned above, several researchers have proposed utilization of deconstruction instead of demolition to systematically disassemble a building into reusable components [4–7]. As governments all over the world publish stricter waste management and landfill regulations and guidelines, such as [8], deconstruction is becoming an important alternative to conventional demolition approaches.

Many barriers need to be overcome for a successful transition from demolition to deconstruction. For example, deconstruction projects often require a longer period and extra labor cost compared to demolition ones and such extra time and cost deter owners from adopting deconstruction approaches [9]. Deconstruction planning also requires a more accurate quantity takeoff than demolition. First, the feasibility of a deconstruction project heavily depends on the value of salvaged material. Therefore, owners need an accurate quantity takeoff to support an economic assessment for a deconstruction project [10]. Second, deconstruction allows for preservation of a reusable component to maximize its value, such as keeping a reusable door rather than a 30-pound wood [11]. In a demolition project, waste quantity is usually estimated by using waste index inferred from historical data [12] and quantities from related deconstruction databases [13,14] of materials, which cannot satisfy the two requirements mentioned above.

Deconstruction projects also require prior knowledge of an existing building to facilitate planning and selection of disassembling procedures [10]. For example, a deconstruction project manager needs prior information of a building to estimate how long a project will take, how many workers are needed during deconstruction, and how much material can be recycled. However, as-built documents are often not available for buildings to be deconstructed. For example, 169 out of the 433 buildings demolished in Portland in 2016 had no as-built drawings information while the rest of buildings had drawings that were obsolete and hence were not reliable for deconstruction planning [15].

Another challenge when shifting from demolition to deconstruction is the need for detailed documentation of removed components. In a demolition project, the amount of recycled material is often measured by landfill diversion rate, which measures how much waste has been diverted from landfills and can be conveniently calculated using landfill receipts [16]. In comparison, documentation during deconstruction requires to record categories, quantities, and specifications of each component to support future recycling and potential tax reporting [5].

Several researchers have proposed many approaches, such as Building Information Model (BIM)-based deconstruction planning, reality capturing, and design for deconstruction, to address the limitations above [6,10,17]. The section below overviews these related research works and discusses their strengths and limitations.

1.2 Previous research

Previous research on obtaining information to support deconstruction waste management can be broadly categorized into two groups: 1) retrieving information from as-designed documents and 2) retrieving information from as-captured data. For instance, many researchers have been using Building Information Model (BIM) to facilitate the planning and waste management during demolition and deconstruction [5,6,17,18]. With an up-to-date BIM, it is convenient to generate an accurate quantity takeoff and a detailed deconstruction plan [19]. However, BIM is usually not available for most buildings to be deconstructed as mentioned in Section 1.1, which generates extra labor and time cost for manually creating a BIM for a deconstruction project.

Reality capturing through 3D imaging, such as laser scanning and RGB-D images, have become an active research topic in the Architectural, Engineering, and Construction (AEC) industries to capture the as-is status of a building [20]. For instance, Scan-to-BIM approaches that convert point clouds captured by a laser scanner to an integrated BIM are widely used for progress monitoring, as-designed and as-is comparison, and facility management [21–23]. Structure-from-Motion methods that reconstruct a 3D model from images are also well studied in the past ten years [24,25].

Previous case studies on using 3D imaging in deconstruction projects have focused on reconstructing a BIM from point clouds captured before deconstruction begins and generating quantity takeoffs from the reconstructed model [26,27]. However, many concerns exist about the possibility of using existing reality capturing approaches in deconstruction projects. The first concern is related to occlusion. For instance, Liu et al. reported that a data collection event with three laser scans for each room could only capture about 40% of the total components [28]. Most facility components are invisible due to occlusion before deconstruction begins, which will affect the completeness and accuracy of quantity estimation. While using progressively-captured data during deconstruction can possibly mitigate the occlusion problem, it raises new concern about the balance between data collection frequency and component coverage rate. Another issue is around identifying which 3D imaging technology would be more suitable for supporting deconstruction projects, especially due to the need for efficiency. This paper aims to provide insights on these issues through a case study of a deconstruction project.

2 A case study of using 3D imaging in a deconstruction project

Section 2 will first provide an overview of motivating problems associated with the case study, and then briefly introduce the project settings.

2.1 Problem statement

As mentioned in Section 1.2, existing reality capture approaches are faced with many challenges when used for deconstruction projects. This paper introduces the application of two types of 3D imaging - laser scan and imagery – in a small deconstruction project and examines the following questions in detail:

- Completeness: What portion of a building can be captured through 3D imaging at different stages of a deconstruction project and how will it affect the quantity estimation?

- Quantity Estimation Accuracy: Can 3D imaging technologies provide accurate geometric information to support quantity estimation?
- What is the cost of using a 3D imaging in a deconstruction project, including labor hours, data collection, data processing, and data storage?

2.2 Project information

The case study was conducted on a two-story house job site with an area of 500 ft^2, consisting of a living room, a kitchen, a restroom, a bedroom, and two mechanical rooms. Figure 1 shows the exterior look of the building to be deconstructed.

Figure 1. The front view (left) and back view (right) of the building to be deconstructed

The goal of the deconstruction project is to reuse most structural and facility components in a new construction project, including but not limited to interior oak, roof panels, appliances, doors, windows, solar thermal systems, decking and lumbers. There are 125 groups of components to be recycled in total. Table 1 shows an example list of components.

Table 1. Example list of components to be recycled

Category	Components
Structure	Cypress plywood
	Cedar exterior cladding
	Laminated Veneer Lumber
	Structurally Insulated Panels
Doors and Windows	Fixed window
	Awning window
	Metal door frame
	Door wood
Appliances	Light fixtures
	Hand sink
	Solar photovoltaic panels
HVAC	Air diffuser
	Flex duct
	Insulated piping

The deconstruction of the building was mostly conducted manually with the help of a crane for lifting only. Since the building was designed for research purpose, it has a full set of design drawings and a 3D model, which provided useful information for pre-deconstruction planning. In the actual deconstruction process, the deconstruction team identified all components to be recycled from drawings and the 3D model first, created a detailed deconstruction plan, and then performed the actual disassembly. Figure 2 shows the interior disassembly plan for structural components. There are corresponding deconstruction plans for mechanical rooms, appliances, and exterior structural components respectively. A crew with about 20 students was involved in deconstruction activities. During deconstruction, once a component is removed from the building, the deconstruction team documents the component and uses the record as ground truth to evaluate the 3D imaging approaches discussed later.

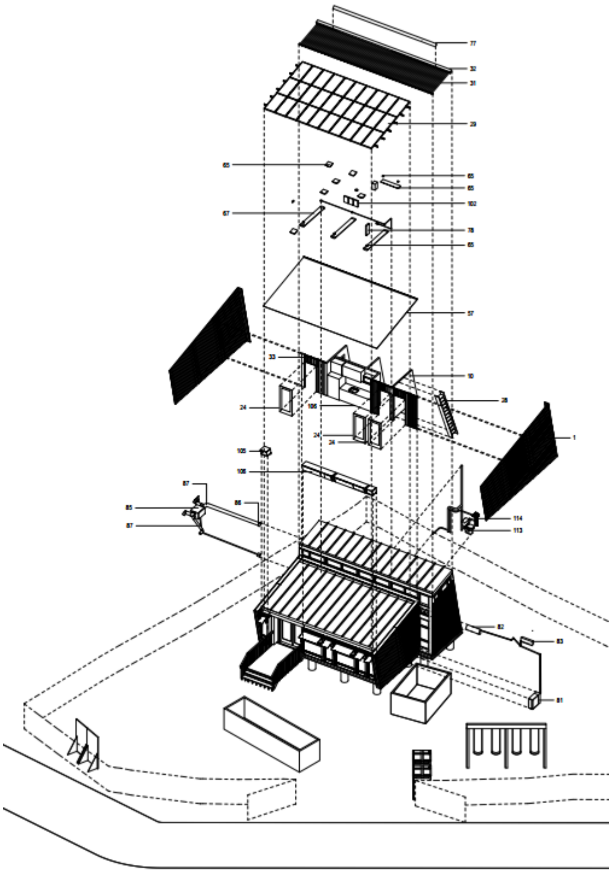

Figure 2. Interior disassembly plan for structural components (Figure generated from the 48-719 Architecture Design Studio: AECM UDBS course material taught at CMU during Fall 2018)

2.3 Application of 3D imaging technologies in the deconstruction project

Two 3D imaging technologies were used in this project to collect data for the purpose of quantity estimation and documentation. One is terrestrial laser scanning which captures point clouds at different locations on site and the other one is unstructured images captured by cameras at fixed locations and hand-held cameras together. Below, we will introduce the details of how each technology was used in the deconstruction project.

2.3.1 Laser scanning

In this project, we used a Faro Focus3D S120 laser scanner to capture point clouds of the building. The laser scanner can capture 5 million points per scan with a view angle ranging from 0 to 360° horizontally and 30 to 330° vertically. In addition, the laser scanner also captures a panorama image to facilitate visualization and point cloud registration.

Figure 3. Point clouds captured at different times during the project: (a) before deconstruction, (b) after removing furniture and exterior walls, (c) after removing door and window frames, (d) after lifting the roof

Since laser scanning requires dedicated time for data collection to avoid possible occlusions from moving workers and equipment, we conducted 4 data collection events during the period of deconstruction, each consisting of 6-12 scans covering both interior and exterior of the building. The first scan event was conducted before deconstruction, the second was conducted right after removal of exterior panels, the third was after removal of door and window frames, and the fourth was after lifting of the roof. Figure 3 shows an example data captured from the laser scanner.

2.3.2 Imagery

Images captured by RGB-D cameras, DSLR cameras, and smartphones are also used for supporting deconstruction documentation. Before deconstruction began, we used an Intel Realsense D435 RGB-D camera to capture a set of images around the building. During deconstruction, two DSLR cameras were set up in the front of the building to record time-lapse image sequences. There were also 4-6 cameras moving around the job site to capture working progress and components being removed. At the end of the deconstruction project, there were more than 5,000 images available. Figure 4 shows example images captured during deconstruction.

Figure 4. Example images captured during deconstruction (Top: exterior; Bottom: interior)

2.4 From progressively-captured 3D imaging to quantity takeoff

The goal of using 3D imaging in a deconstruction project is to obtain a quantity takeoff consisting of important entries for cost estimation and activity planning, such as component categories, quantities, dimensions, materials, and recyclability. In this case study, we will focus on extracting categories and quantities from 3D imageries as a primary result. We used following methods to generate a component list and compared it with the manually-calculated ground truth. For laser scans, we manually identified and annotated objects in registered point clouds and measured their dimensions. Figure 5 shows an example of window frame annotations in the captured point cloud.

Figure 5. Component annotation from laser scans (red: fixed window, blue: awning window, green: mix-type window)

For images, since there are much more images (~5,000) compared to laser scans (6-12 scans per data collection), it is laborious to annotate objects on images to obtain the number of components. Therefore, for the purpose of evaluation only, we used the ground truth component information extracted from drawings to help identify objects presented on images. A component presented in the digital model is marked as found if at least one image captures the object on site. Similarly, a component presented in a digital model is marked as missing if there is no image captures the object. Figure 6 shows a concatenation of images covering all components of the mechanical room.

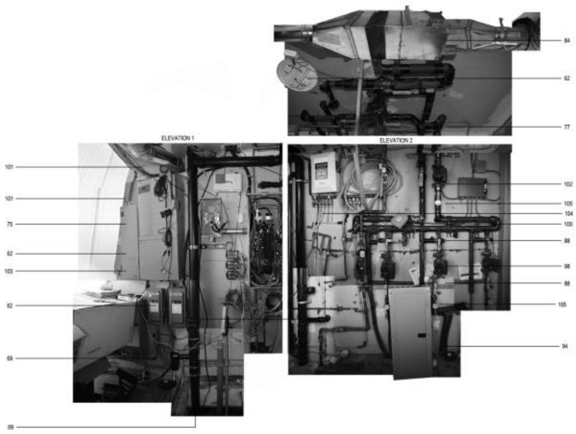

Figure 6. Components identified on images of the mechanical room (Numbers indicate the index in quantity estimation)

Table 2 below shows an example list of quantity takeoff in this case study. In the complete table, we also documented whether a component is recycled, labor hours for removing a component, and whether a component is seen on laser scans and images respectively. The quantity takeoff will be used for evaluation in the next section.

Table 2. Example list of a quantity takeoff

Component	Dimension	Quantity	MasterFormat
Hardwood boards	4’-4’’-2’’	9	061300
Plywood	4’-1’-3/4’’	3	061626
Door track	10’ - 10’’	4	083513
Glass door	8’-3’	1	081710
Structurally insulated panels	12’-9’	6	036866
Cabinets	2’-2’-1’	2	060000
Wash sink	-	1	-

3 Evaluations

In this section, we first define the metrics employed for evaluating the application of various 3D imaging approaches into a deconstruction project. Next, the results are analyzed to demonstrate the benefits and limitations of each 3D imaging technology.

3.1 Metrics

As mentioned in Section 2.1, this case study aims to address multiple concerns of using a 3D imaging approach in deconstruction projects, including completeness, capability of dimension measurement, labor time, and amount of data generated. Below we will talk about the metric used for the evaluation of each perspective.

- Completeness: The completeness of quantity estimation is defined as shown below where the number of identified components is calculated by counting the components that are captured during data collection and the number of total components is determined based on on-site documentation logs. We use the completeness to measure the accuracy of quantity estimation.

$$\text{Completeness} = \frac{\#\ of\ identified\ components}{\#\ of\ total\ components}$$

- The capability of dimension measurement: This metric indicates how well a 3D imaging approach supports dimension measurement, which is critical for quantity estimation. For example, if a user conducts a measurement on the captured data, obtaining a real-size measurement and an up-to-scale measurement that requires correction make a significant difference in quantity estimation.
- Time: We measured the time used for data collection, data processing, and component annotation to evaluate the efficiency of a 3D

imaging method.

- Amount of data generated: This metric measures the space needed to store the captured data.

In the primary experiments below, we ignore two important metrics for the moment: identifiability and dimension error. Identifiability indicates whether a 3D imaging method can distinguish objects with similar appearances. Since in this case study all components are annotated manually, we will leave the evaluation of identifiability after automating the quantity estimation process using 3D imaging. Also, for the metric dimension error which shows how much a measurement on length, area, or volume deviates from its ground truth, we will leave the evaluation for further experiments whose measurements are not performed manually.

3.2 Results and analysis

In this section, we will present the evaluation of two 3D imaging technologies using the metrics mentioned above. In our evaluation, we didn't include all the components listed in the as-designed documents. Small and unimportant components, such as woodscrews and assorted wires, are ignored when evaluating 3D imaging technologies. After selection, we have 1,041 components from 123 categories.

Table 3. Evaluation of using 3D imaging for quantity estimation in the deconstruction project

Metric	Laser Scanning		Imagery	Manual
Completeness	1	54%		
	2	19%	100%	100%
	3	11%		
	4	2%		
	Total	86%		
Dimension	Real-size		Up to a scale	Real-size
Data collection	16 hours		4.5 hours	48 hours
Annotation	20 hours		-	0 hour
Storage	13 GB		2.2TB	22kb

Table 3 shows the evaluation results for each 3D imaging technologies in comparison with documenting quantities manually. There are several interesting points worth discussing:

3.2.1 Completeness

The results indicate that with four laser scanning events, we can capture about 86% of the total components that need to be recycled. Specifically, the first data collection event consisting of 12 scans can only capture 54% of the components of interest, indicating that directly using scan-to-BIM approaches to estimate quantities is not very accurate.

Through inspection of the missing objects, we found that the incompleteness of data captured by laser scanning comes from two sources: 1) occlusions, 2) the temporal gap between two laser scans.

Occlusion refers to the problem that some components are invisible until other components are removed. The comparison between the completeness of the progressively-captured data and the one of data captured before deconstruction indicates that capturing data progressively during deconstruction can mitigate the occlusion problem. Figure 7 Metal studs behind the kitchen region are invisible in Scan 1 (left) but become visible in Scan 2 (right)shows how progressively captured data can address occlusions presented in a scene.

Figure 7. Metal studs behind the kitchen region are invisible in Scan 1 (left) but become visible in Scan 2 (right)

If an invisible object in a previous scan is removed before the next round of data collection, it will be missing in the quantity estimation. In our case study, there were 30 solar panels installed on the roof which cannot be captured by a terrestrial laser scanner in the first scan. After lifting the roof, these solar panels were removed between the third and the fourth scan, resulting in one of the primary errors in our quantity estimation.

In comparison, images captured by handheld cameras and time-lapse cameras can cover all objects of interest. Though in this case study we captured more imagery data than usual, the result shows that with enough crowd-sourced image data, it is possible to generate a complete quantity takeoff without missing components.

3.2.2 Dimension measurement

Point clouds intrinsically support measurements and can achieve a low dimension error of ~2-5 mm as reported in previous research [25]. Image-based approaches cannot provide the functionality of measurement unless all images are well calibrated, which limits its application in quantity estimation.

3.2.3 Time efficiency

Table 3 also shows the time used for data collection and annotation to obtain a quantity estimation. For data collection, we only counted the dedicated labor hours in our calculation. Therefore, crowd-sourced images captured during deconstruction activities require the least time to collect. However, when it comes to annotating objects to generate a quantity estimation, it is quite difficult for human beings to annotate over 5,000 images, which originates the need for either reconstructing a 3D model from images or recognizing components automatically. For point clouds, annotating objects manually also took a significant number of hours. Therefore, automation in identifying components of interest will benefit both laser scanning-based approaches and image-based approaches.

4 Conclusions

This paper presents a case study of using two different 3D imaging technologies to support quantity estimation and documentation in deconstruction projects. Through the evaluation of completeness, the capability of dimension measurement, and time efficiency, we highlighted the importance of capturing data progressively during deconstruction and automating the process of annotating components from 3D imaging data. In addition, despite that we have a deconstruction schedule, planning when and where to perform data collection is still challenging during deconstruction. It is necessary to develop an approach to plan progressively data collection events during deconstruction. Also, though imagery data covers all recyclable objects during deconstruction, the amount of data is enormous. Therefore, the next step of our study will be to develop an automated approach to process progressively-captured data from 3D imaging to support deconstruction planning and documentation.

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References

[1] Agency EP. *Sustainable Management of Construction and Demolition Materials*.; 2015. https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials#America.

[2] Consulting H. *Construction and Demolition Waste Status Report - Management of Construction and Demolition Waste in Australia*.; 2011. http://www.environment.gov.au/protection/waste-resource-recovery/publications/construction-and-demolition-waste-status-report.

[3] Valle D, Worth F. Construction Waste Management Database | Whole Building Design Guide. *Build Des*. 2008:5-6. https://www.wbdg.org/resources/construction-waste-management. Accessed October 19, 2018.

[4] Dantata N, Touran A, Wang J. An analysis of cost and duration for deconstruction and demolition of residential buildings in Massachusetts. *Resour Conserv Recycl*. 2005;44(1):1-15. doi:10.1016/j.resconrec.2004.09.001

[5] Akbarnezhad A, Ong KCG, Chandra LR. Economic and environmental assessment of deconstruction strategies using building information modeling. *Autom Constr*. 2014;37:131-144. doi:10.1016/j.autcon.2013.10.017

[6] Akinade OO, Oyedele LO, Bilal M, et al. Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS). *Resour Conserv Recycl*. 2015;105:167-176. doi:10.1016/j.resconrec.2015.10.018

[7] Kibert CJ, Chini AR, Languell J. *Deconstruction as an Essential Component of Sustainable Construction*.; 2001. https://www.irbnet.de/daten/iconda/CIB3122.pdf. Accessed January 27, 2019.

[8] *CONSTRUCTION AND DEMOLITION WASTE GUIDE-RECYCLING AND RE-USE ACROSS THE SUPPLY CHAIN*.; 2012. https://www.environment.gov.au/system/files/resources/b0ac5ce4-4253-4d2b-b001-0becf84b52b8/files/case-studies.pdf. Accessed March 8, 2019.

[9] Kibert CJ. *Sustainable Construction : Green Building Design and Delivery*. John Wiley & Sons; 2016.

[10] Rios FC, Chong WK, Grau D. Design for Disassembly and Deconstruction - Challenges and Opportunities. *Procedia Eng*. 2015;118:1296-1304. doi:10.1016/J.PROENG.2015.08.485

[11] Iacovidou E, Purnell P. Mining the physical infrastructure: Opportunities, barriers and interventions in promoting structural components reuse. *Sci Total Environ*. 2016;557-558:791-807. doi:10.1016/j.scitotenv.2016.03.098

[12] Llatas C. A model for quantifying construction waste in projects according to the European waste list. *Waste Manag*. 2011;31(6):1261-1276. doi:10.1016/j.wasman.2011.01.023

[13] Solís-Guzmán J, Marrero M, Montes-Delgado MV, Ramírez-de-Arellano A. A Spanish model for quantification and management of construction waste. *Waste Manag*. 2009;29(9):2542-2548. doi:10.1016/j.wasman.2009.05.009
[14] Yuan H, Shen L. Trend of the research on construction and demolition waste management. *Waste Manag*. 2011;31(4):670-679. doi:10.1016/j.wasman.2010.10.030
[15] Sustainability B of P and. *Oregon Deconstruction Program Report*.; 2017. www.exploredecon.com. Accessed January 27, 2019.
[16] Tchobanoglous G, Theisen H, Vigil SA, Alaniz VM. *Integrated Solid Waste Management: Engineering Principles and Management Issues*. Vol 949. McGraw-Hill New York; 1993.
[17] Cheng JCP, Ma LYH. A BIM-based system for demolition and renovation waste estimation and planning. *Waste Manag*. 2013;33(6):1539-1551. doi:10.1016/j.wasman.2013.01.001
[18] Eadie R, Browne M, Odeyinka H, McKeown C, McNiff S. BIM implementation throughout the UK construction project lifecycle: An analysis. *Autom Constr*. 2013;36:145-151. doi:10.1016/j.autcon.2013.09.001
[19] Volk R, Stengel J, Schultmann F. Building Information Modeling (BIM) for existing buildings - Literature review and future needs. *Autom Constr*. 2014;38:109-127. doi:10.1016/j.autcon.2013.10.023
[20] Wei Y, Kasireddy V, Akinci B. 3D imaging in construction and infrastructure management: Technological assessment and future research directions. In: *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Vol 10863 LNCS. Springer, Cham; 2018:37-60. doi:10.1007/978-3-319-91635-4_3
[21] Xiong X, Adan A, Akinci B, Huber D. Automatic creation of semantically rich 3D building models from laser scanner data. *Autom Constr*. 2013;31:325-337. doi:10.1016/j.autcon.2012.10.006
[22] Anil EB, Tang P, Akinci B, Huber D. Deviation analysis method for the assessment of the quality of the as-is Building Information Models generated from point cloud data. *Autom Constr*. 2013;35:507-516. doi:10.1016/j.autcon.2013.06.003
[23] Bosché F, Ahmed M, Turkan Y, Haas CT, Haas R. The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components. *Autom Constr*. 2015;49:201-213. doi:10.1016/J.AUTCON.2014.05.014
[24] Chaiyasarn K, Kim T-K, Viola F, Cipolla R, Soga K. Distortion-Free Image Mosaicing for Tunnel Inspection Based on Robust Cylindrical Surface Estimation through Structure from Motion. *J Comput Civ Eng*. 2016;30(3):04015045. doi:10.1061/(ASCE)CP.1943-5487.0000516
[25] Golparvar-Fard M, Bohn J, Teizer J, Savarese S, Peña-Mora F. Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques. *Autom Constr*. 2011;20(8):1143-1155. doi:10.1016/j.autcon.2011.04.016
[26] Ge XJ, Livesey P, Wang J, Huang S, He X, Zhang C. Deconstruction waste management through 3d reconstruction and bim: a case study. *Vis Eng*. 2017;5(1):13. doi:10.1186/s40327-017-0050-5
[27] Marino E, Spini F, Paoluzzi A, et al. Modeling Semantics for Building Deconstruction. doi:10.5220/0006227902740281
[28] Liu X, Eybpoosh M, Akinci B. Developing As-Built Building Information Model Using Construction Process History Captured by a Laser Scanner and a Camera. In: *Construction Research Congress 2012*. Reston, VA: American Society of Civil Engineers; 2012:1232-1241. doi:10.1061/9780784412329.124