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Implementation of Laser Scanning and Photogrammetry in the US Commercial Building Sector

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Studies investigating the construction project stakeholders experience with implementing laser scanning and photogrammetry as Reality Capture Technologies (RCT) in the US commercial building sector are limited. Therefore, this study explored the status of construction project stakeholders experience with the use of RCT. The research aimed to answer questions regarding stakeholder's personal experience with RCT and their companies' use of RCT on commercial projects, RCT use on the specific commercial building project types, and use of RCT on both new construction and renovation projects in the commercial sector. A survey was distributed to owners/developers, designers, contractors, and Construction Managers (CMs)/owner representatives in the US. Survey findings indicated that the majority of the respondents had heard of RCT, used RCT personally, and worked for the companies that used RCT on their projects. Core and shell buildings, healthcare, and education projects were the major commercial project types on which participants reported using RCT. Additionally, participants reported implementing RCT on both new construction and renovation projects. The research contributes to the body of knowledge by providing the current status of RCT use on commercial building projects by US construction project stakeholders.

Key Words: Laser scanning, Photogrammetry, Reality Capture, Commercial Buildings, Construction project stakeholders

Introduction and Purpose

The construction industry has traditionally been slow in adopting new technologies and, as a result, has been suffering from low productivity (McCoy & Yeganeh, 2021). However, there has been a significant surge of using Building Information Modeling (BIM) by the AEC industry (Boton & Forgues, 2018; McGraw-Hill Construction, 2014; Smith, 2014). In addition, research about creating as-built BIMs (i.e., BIM models generated in the construction phase) and as-is BIMs (i.e., BIM models generated when the project is in the operation and maintenance phase) has been increasing in the last decade. Data acquisition is considered the first and one of the most challenging steps of creating both as-is BIMs of existing buildings and as-built BIMs of new construction projects.

The emergence of advanced data capturing technologies, also known as Reality Capture Technologies (RCT), indicates the importance of developing efficient ways for collecting accurate geometric data on both new construction and renovation projects (Lu & Lee, 2017; Volk et al., 2014). Reality Capture is a process that uses hardware such as laser scanners, cameras mounted on Unmanned Aerial Vehicles (UAVs) or high definition 360-degree photography to collect spatially accurate surface points of an existing object, building, or site and generate a three-dimensional (3D) representation of real-world conditions in the form of textured, high-resolution, geometrically precise 3D point cloud data or meshes (Autodesk, 2021; Skanska, 2021; Almukhtar et al., 2021). In addition, project site webcams, ground penetrating radar, robotic total stations, and GPS rover are also considered reality capture hardware (Dodge Data & Analytics, 2021). In this study, RCT denotes laser scanning, photogrammetry, and the integration of these two technologies.

Despite the numerous research studies on laser scanning, photogrammetry, and UAVs in the construction industry, there is limited research exploring AEC professionals' perspectives about RCT use. Therefore, the goal of the study was to investigate the perceptions of the US construction project stakeholders about using RCT in the commercial building sector. Specifically, this research investigated perceptions of owners/developers, designers, contractors, construction managers (CMs) and owner representatives.

Literature Review

In recent years, technological advancement has provided the opportunity to collect accurate and comprehensive data representing real-world conditions (Almukhtar et al., 2021). Traditional surveying techniques, such as measuring tapes, optical theodolites, and calipers, were time-consuming manual processes that resulted in incomplete and inaccurate documentation of existing field conditions (Klein et al., 2011). RCT have been developed to overcome the limitations of traditional surveying methods and enhance construction productivity. Research on advanced data capturing techniques has been rapidly growing in the last two decades (Wang & Kim, 2019). Recent technological advancements have provided new opportunities for RCT implementation on construction projects. For example, the point cloud data generated by reality capture can be used for 3D model creation, construction progress tracking, construction Quality Assurance and Quality Control (QA/QC), construction safety management, restoration of historical heritage, building performance analysis, and renovation purposes (U.S. General Services Administration (GSA), 2009; Wang & Kim, 2019). With recent advancements, reality capture using photogrammetry and remote sensing technologies such as laser scanning has become a superior approach that provides accurate, fast, and reliable information about construction sites, work, and equipment (Wang & Kim, 2019; Wang et al., 2020).

With the expansion of BIM use, the need for accurate and up-to-date information about the project has increased (Lu & Lee, 2017). The use of RCT on a project can help AEC professionals in decision-making by providing a full understanding of the project. Using laser scanners or photogrammetry, AEC professionals can collect accurate 3D-datasets of a building, structure, or environment and compare what exists in reality with 3D design models. Using RCT throughout different phases of a project enables construction tasks to conform to the drawings and specifications and helps the project team avoid deviations and identify problems early to avoid additional costs downstream. RCT can be utilized on new construction projects as well as renovation, addition, and interior fit-out projects. However, literature indicates that less than 9% of the research on RCT focuses on renovation projects (Almukhtar et al., 2021; Wang & Kim, 2019).

Inaccurate assumptions about the existing conditions of a building resulting from a lack of as-built documents can lead to unintended errors and even accidents (Lu & Lee, 2017). And, design teams may benefit from complete as-built documents as a starting point to develop their design in renovation, addition, and interior fit-out projects. Having accurate geometric data of an existing environment reduces uncertainties during the design phase, assists designers to obtain accurate dimensions where there may be a lack of as-built plans, enables the visualization of the design model in the existing context, reduces the number of visits to the job site, and enables effective collaboration among the stakeholders throughout a project (Autodesk, 2021; Leica Geosystems AG, 2017, Rubenstone, 2020). Data visualization helps owners in decision-making, and increasing the owners' awareness regarding the benefits of using RCT throughout the project lifecycle could increase the demand for RCT services on construction projects (Deutsch, 2015; Gerges et al., 2017).

Modern RCTs devices are less expensive, lighter weight, easier to operate, and are able to collect data at a higher level of accuracy than in the recent past. The point cloud data can be registered in real-time in the field using a handheld mobile device. In addition, new RCT software solutions have provided a smoother Scan-to-BIM workflow (Autodesk, 2021). Although the reduced barriers to the use of RCT in the last decade have led to wider adoption of these technologies in the AEC industry, at the time of conducting this study, no research was found investigating the status of RCT implementation by different construction project stakeholders. Therefore, given the potential advantages of RCT implementation and limited research on different construction project stakeholders' experience with using RCT, this research investigates the prevalence of RCT use on commercial construction projects in the US through the exploration of the following research questions (RQ):

RQ 1: Have US construction project stakeholders heard of RCT?
RQ 2: Do US construction project stakeholders have personal experience with RCT?
RQ 3: Do US construction project stakeholders' companies have experience with RCT?
RQ 4: On what commercial project types do US construction project stakeholders use RCT?
RQ 5: Do US construction project stakeholders use RCT on new construction projects and renovation projects?

Methodology

In order to address the research questions, the authors developed a quantitative, cross-sectional survey that was distributed among various stakeholders in the commercial construction industry. The research questions aimed to investigate the perceptions of different construction industry project stakeholders about RCT use. Descriptive statistics were conducted to analyze the survey results. The statistical analysis in this study was conducted using IBM SPSS statistical software. Specifically, frequency distribution and cross-tabulations were used to address the RQs.

Survey and Distribution

The survey comprised two sections: 1) Demographics and questions regarding respondents' awareness and general knowledge of RCT, and 2) Questions related to stakeholder experience with RCT use on construction projects. The online survey defined RCT for participants as the process of collecting surface data points to produce a digital 3D depiction of an existing object, building, structure or site using static, mobile or aerial laser scanning (LiDAR) and/or photogrammetry equipment (Autodesk, 2021). The survey responses were collected for four weeks. The potential participants were identified in two different ways. First, the survey link was distributed to the US-based membership of the Construction Management Association of America (CMAA) and a selection of members of the International Facility Management Association (IFMA) working in the US. Second, a survey link was shared with the authors' LinkedIn connections that work in the US AEC industry.

Results and Discussion

Sample and Data Screening

The survey was distributed widely and among numerous segments of the construction industry. However, given the commercial focus of the current manuscript, the sample was delimited to respondents who indicated that their primary construction industry sector was 'commercial' (n = 187). Of the 187 participants that worked primarily in the commercial building sector, 11 did not respond to the question about their role on a typical construction project, yielding 172 responses for analysis. The participants were coded into four groups based on their role on a typical construction project, including 1) owner/developer, 2) designer (including architects and engineers), 3) contractor (including general contractors and subcontractors), and 4) Construction Managers (CM) and owner representatives. Since the variables were independent, pairwise deletion was employed in this study, resulting in a different number of responses (n) for each analysis. Table 1 shows the demographic data of the cleaned and screened sample. Forty percent (68) of the 172 respondents were contractors, while 17% (30) were designers. The same number of respondents were owners/developers (37, 21.5%), and CMs and owner representatives (37, 21.5%). The average industry experience was over 20 years for all groupings except contractors, who reported an average of 15 years of industry experience.

Table 1. Description of commercial building sector participants by their role (n=172)

Stakeholder	*n*	*%*	*Average industry experience (years)*
Owner/Developer	37	21.5	23.9
Designer	30	17.4	21.3
Contractor	68	39.5	15.4
CM and Owner Representative	37	21.5	25.9

Addressing the Research Questions (RQs)

Research Question 1 explored if the stakeholders had heard of RCT. A majority of the 160 participants who responded to this survey item, (128, 80%) indicated they had heard of RCT (see Figure 1). Approximately 83% of the contractors, 81% of the designers, 77% of the CMs & owner representatives, and 76% of the owners/developers who responded to the survey had heard of RCT. The survey findings indicated that most construction project stakeholders, regardless of their role, reported hearing about RCT.

Research Question 2 investigated if construction project stakeholders had personal experience using RCT. The results revealed that 68 (53%) of the 128 respondents indicated personal experience using RCT on their projects (see Figure 2). Almost 70% of contractors and approximately half of owners/developers (52%) had personal experience with RCT compared to one-third of designers (33%) and 37% of CMs and Owner Representatives. It should be noted that of all the 68 respondents who had experience with RCT, over half (56%) were contractors, while 19% were owners/developers, 15% were CMs and owner representatives, and 10% were designers. The literature confirmed that adopting RCT on a project requires using both physical equipment (i.e., laser scanners, cameras, etc.) for capturing geometric data and software applications for data processing. The results indicating that a larger portion of contractors, who are more involved in the day-to-day field activities, had personal experience with RCT than other stakeholders is congruent with recent literature.

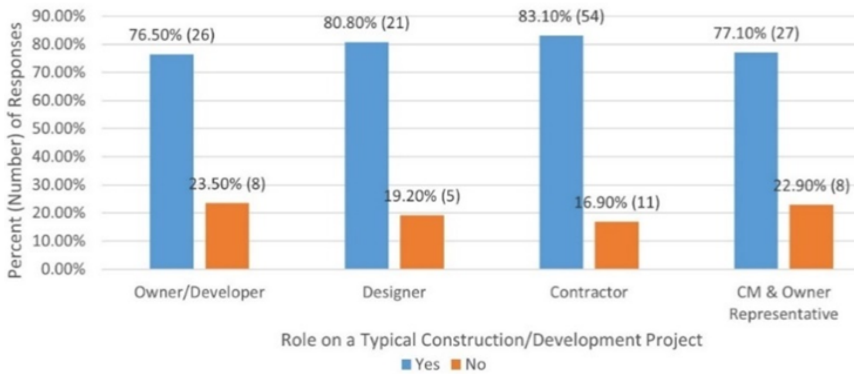

Figure 1. Stakeholders' Familiarity with RCT (n=160)

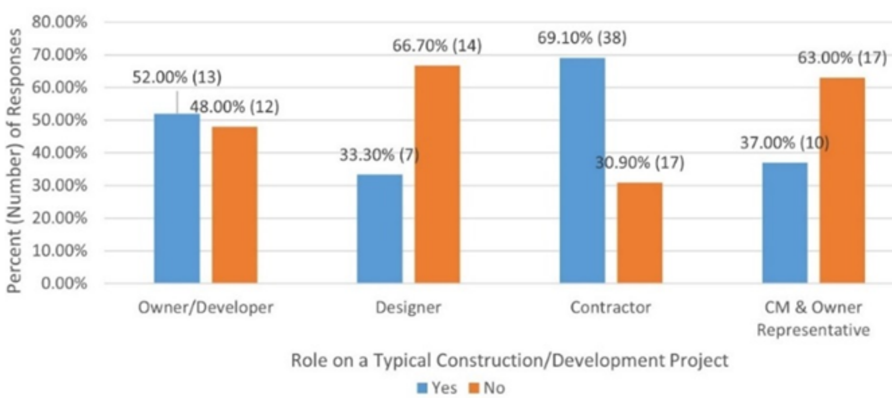

Figure 2. Stakeholders' Personal Experience with RCT (n=128)

Research Question 3 explored the experience of participant's companies with RCT. Of 128 participants who responded to this question, more than half (79, 62%) reported that their company had experience with using RCT on their projects, approximately one-fourth (29, 23%) indicated their company had no experience with RCT, and approximately 16% were not sure about their company's experience with RCT. As shown in Figure 3, a majority of the contractors (43, 78%), more than one third (8, 38%) of the designers, about half of the owners/developers (13, 52%) and more than half of the CM and owner representatives (15, 56%) stated that their company had experience with RCT. This is an important finding since it suggests that using RCT is more common among contracting firms than among other stakeholders. These findings correspond to the results of the recent studies, in which contractors surpassed designers in implementing BIM on their projects (McGraw Hill, 2014).

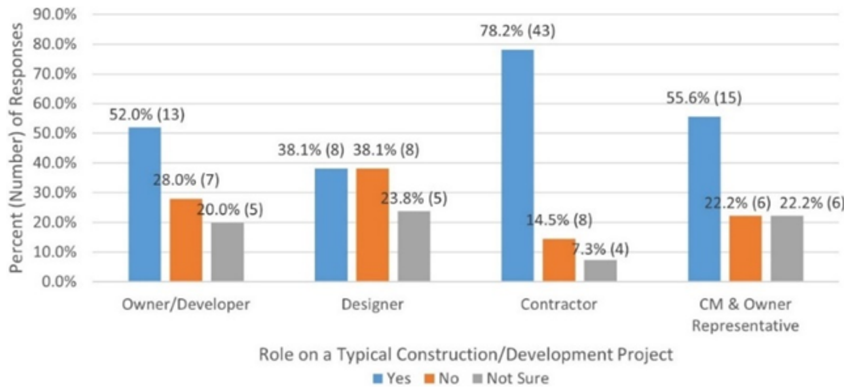

Figure 3. Stakeholders' Company's Experience with RCT (n=128)

Research Question 4 investigated participants' experience with using RCT on specific commercial project types, including core and shell buildings, multi-family residential, retail, mixed-use, education, healthcare, interior/tenant fit-out, and other types of projects. The participants were asked to select the commercial project types in which they used RCT. It should be noted that participants were asked to "select all that apply" when answering this question. Figure 4 shows the use of RCT on different commercial project types regardless of a participant's role on a typical construction/ development project. Almost half (78, 49%) of the 158 participants who responded to the question stated they used RCT on core and shell projects. Approximately 45% of 151 respondents reported they used RCT on healthcare projects. Interestingly, less than one-fourth of 146 respondents (33, 23%) reported using RCT on multi-family residential projects. This is an important finding that may suggest that construction project stakeholders tended to use RCT more on complex projects (e.g., healthcare projects and core and shell buildings) than simple projects (e.g., multi-family residential and retail). This finding corresponds to the results of previous studies about emerging construction technologies in which construction project stakeholders were more willing to use technologies on complex structures (Dodge Data & Analytics, 2015; McGraw Hill Construction, 2014).

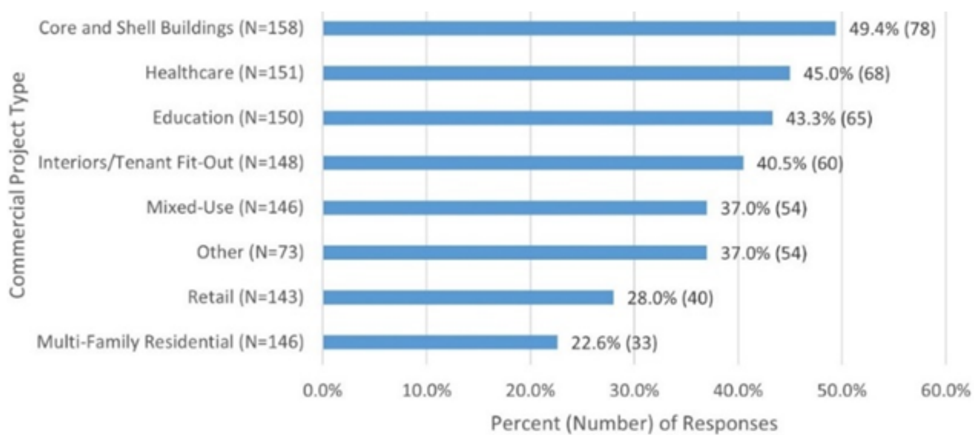

Figure 4. RCT Use on Specific Commercial Project Types: All Respondents

Research Question 5 explored the use of RCT on new construction projects and renovation projects by stakeholder. A majority (51, 65%) of 78 respondents who had experience with using RCT reported using the technology on new construction projects (see Figure 5). Approximately three-fourths (31, 76%) of the contractors, 57% of CM and owner representatives, 56% of designers, and half of the owners/developers indicated that they had experience with RCT on new construction projects. It should be noted that, except for contractors, the number of participants responding to this question was relatively low. For addition, renovation, and/or interior fit-out projects, 49 (68%) of 72 respondents indicated using RCT on addition, renovation, and/or interior fit-out projects (see Figure 6). Almost three-fourths (74%) of the contractors, 64% CM and owner representatives, 64% of owners/developers, and approximately half of the designers (56%) reported that they used RCT on addition, renovation, and/or interior fit-out projects.

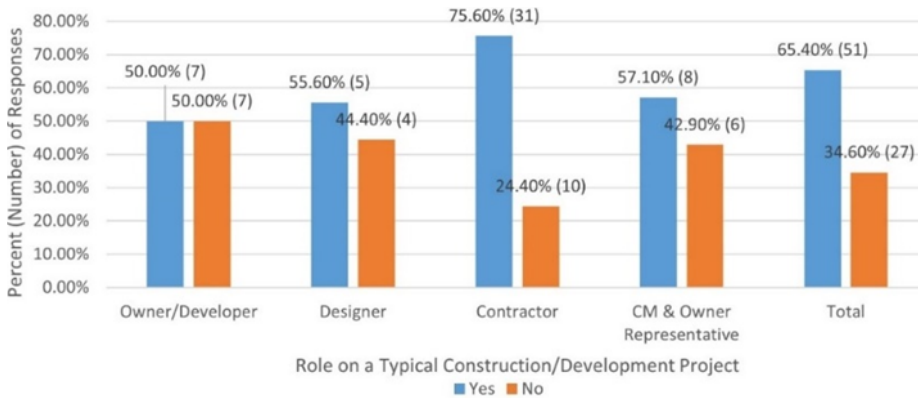

Figure 5. Stakeholders' Experience with RCT Use on New Construction Projects (n=78)

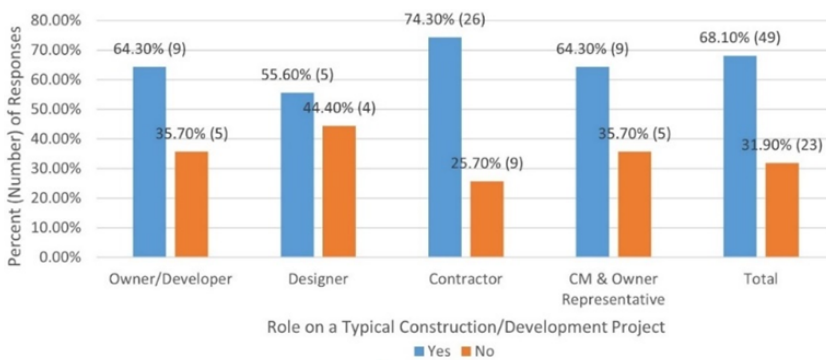

Figure 6. Stakeholders' Experience with RCT Use on Addition, Renovation, and/or Interior Fit-Out Projects (n=72)

Discussion and Conclusions

This study represents an initial attempt to better understand the current status and extent of RCT use among US construction stakeholders in the commercial building sector. This study adds to the body of knowledge by shedding light on the perceptions and experiences of US construction project stakeholders with RCT. Incomplete survey responses were culled, and the complete responses were classified based on the respondent's primary market sector. The collected responses from the designers, contractors, owners/developers, and CMs/owner representatives who reported commercial buildings as their primary market sector were further analyzed in this paper.

The study finding indicated that the majority of all four groups of stakeholders had heard of RCT. The results revealed that over half of the respondents had used RCT personally, or their company had implemented RCT on their projects. This finding reinforces the hypothesis of the general acceptance of RCT use within the commercial building sector. Additionally, and as expected, a larger number of contractors reported having experience with RCT as compared to other stakeholders. Research findings showed that core and shell buildings, healthcare, and education projects are the major commercial project types on which participants used RCT. On the other hand, fewer respondents stated that they had experience with using RCT on multi-family residential and retail projects. This was an important finding indicating that survey participants tended to use RCT more on complex projects.

Finally, the research findings revealed that those stakeholders with RCT experience implemented RCT on both new construction projects and renovation projects, suggesting that using RCT may benefit all projects, regardless of project type. The literature review revealed few studies exploring or reporting the use of RCT on renovation projects. However, respondents reported similar frequencies of using RCT on both new construction projects and renovation projects. These findings may suggest that once a company implements RCT, they may utilize the technology on all their projects, regardless of the project type.

Limitations and Future Research

The following limitations should be considered when interpreting the results of this study. The collected data from different construction professionals were sub-aggregated before conducting the statistical analysis. Responses from architects and engineers were aggregated into the designer group, and responses from the general contractors and subcontractors were combined in the contractor stakeholder group. Also, those participants who chose “other” as their role, but their text entry indicated they were CMs or owner representatives, were aggregated in the fourth group of stakeholders (i.e., CM and owner representatives). Additionally, the results of this study may not be generalizable to the whole US construction industry due to the relatively small sample compared to the population. Thus, findings herein should be interpreted given these limitations, and readers should be cautious regarding generalization of the results beyond the study sample.

Literature review revealed the need for further exploratory studies on RCT use during the project lifecycle. Determining the benefits and obstacles of using RCT during different phases of the project could be the next step. Future studies are needed to investigate RCT use within different construction sectors, including heavy civil, facilities management, and single-family residential. Additionally, exploring the use of RCT in existing buildings would be a potential area for future studies due to the increasing trend to incorporate circular economy and sustainability across the project lifecycle.

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