Transforming Construction with Reality Capture Technologies:
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REALITY DATA CAPTURE FOR RECLAIMED CONSTRUCTION MATERIALS

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Abstract: In recent years, opportunities are emerging to recover and reuse salvaged materials from building demolition and deep renovation projects to solve new design and procurement problems. However, the procurement process is often financially tasking due to the lack of well-detailed representations of reclaimed materials being readily available. Therefore, the exploitation of the advancement in 3D data capturing systems can aid the process and has already been applied widely for circular design strategies in building projects such as building adaptation, material refurbishment and regenerative design. Thus, this paper particularly explores the practicality of 3D scanning for reusable reclaimed elements at two secondary distribution sources in the Canadian environment.

The paper outlines 3D material data capture processes at the two reclaimed material sources, using four different types of scanners to scan reclaimed elements like (1) structural steel, (2) windows & doors, (3) wood, (4) flooring, and (5) kitchenettes. Furthermore, the case study analyses the simplicity of the scanning process and the quality of the produced scans using commercialized scanners like; the faro laser, the freestyle, the dotproduct3D, and the iPad scanner. Based on the characteristics analyzed in this study, the two reclaim sources required different scanning systems due to the length and size of some of the building components and the layout of elements at each location. The findings in this study indicate the need to further assess scanning equipment for varying degrees of use across the industry to enhance equipment attunement, and advancements should support the movement towards a circular economy in the built environment.

Keywords: 3D Scanning; Lidar; Reverse logistics; Reclaimed materials; Material reuse; Scan accuracy; Scanning efficiency, Scan layout; Scan Workflow; Scan processing.

1. INTRODUCTION

The trend toward sustainability in the built environment industry is evolving; the circular process of deconstruction and material reclaim are trending upwards rather than the linear process of demolishing and landfilling. However, with the built environment industry being amongst the highest waste-producing sectors, with an equally high rate of natural resource consumption, the industry still faces challenges managing the materials obtained from deconstruction projects (Yeheyis et al. 2013). The challenges with reclaimed material management are tackled by incorporating digitization techniques in circular frameworks to aid the process of achieving circularity; an essential application is in the adoption of technologies for reverse logistics in building construction.

Reverse logistics in construction involves reclaiming materials for reuse or recycling purposes. Material reuse is considered a better ecological option than recycling due to the non-remanufacturing aspect of using the material (ICE 2008). However, it has significant economic and technical limitations affecting the adoption of the process. There are four types of reclaimed salvaged materials; the onsite reused component, the salvage from other sites, the reconditioned materials and recycled-content building products (Gorgolewski and Morettin 2008). Furthermore, material reuse can be carried out through building adaptation or building with used materials. Building adaptation has evolved significantly and is prominent in the industry, as it is often carried out during major renovations or restoration projects. Whereas building with reclaimed materials is often limited to unique projects focusing on eco-logistics or small renovation projects.

The process of sourcing and reusing reclaimed material as part of a new building is often hindered by the availability of accurate supporting data. Therefore, this study presents an experimental evaluation of 3D scanning techniques for reclaimed building material components. The study analyses the use of 3D scanning systems of various levels for the capture of different material types. The faro laser scanner, the freestyle scanner, the dotproduct3D, and the iPad scanner were used in this study to scan the following materials (1) reclaimed structural steel, (2) reclaimed windows and doors, (3) reclaimed wood, (4) reclaimed flooring, and (5) reclaimed kitchenette. The study further assesses data processing involved in using the different 3D scanners to scan reclaimed material elements and reports on the efficacy of using each method to collect and process the scans. The creation of a 3D representation for reclaimed materials could be the first approach toward accurately extracting data for used salvage materials.

Thus, the objectives of this paper are as follows.

- To scan reclaimed elements using different scanners and document the process.
- Process all the scans obtained using their respective platforms and document the process.
- To review the process of collecting and processing scans and analyze the potential of adopting the scanning method for reclaimed material management.

2. LITERATURE REVIEW

The limitations with reusing reclaimed materials were classified as social, technical and economic barriers, weighted at 15%, 23% and 39%, respectively(Rakhshan et al. 2020). The main factors influencing the economics of material reuse are the cost of labour-intensive activities like demolition, material sorting and design with reclaimed materials. Concurrently, the leading social barrier is the perception of difficulty incorporating salvaged materials in the new building projects. Meanwhile, the technical barrier is the feasibility of working with reclaimed elements that have limited information and a high level of complexity to enable fusion with a new or different construction style (Rakhshan et al. 2020). The study carried out by Rogers and Tibben-Lembke (2001), which analyzed the stimulating factors for reverse logistics in construction, also highlighted the need to apply technologies for the process of material recovery to enhance the economic efficiency of reusing the recovered building materials. Furthermore, it is indicating the current state of the reverse logistics system in the built environment industry is seriously lacking in technological refinement.

Materials obtained from deconstructed buildings often have varying sizes and shapes with unique attributes, making it difficult to characterize and accurately estimate their value(Rose and Stegemann 2018). In addition, the management of the materials post-extraction is highly manual, limiting the reclaim process efficiency and resulting in reclaimed elements being significantly more expensive than new materials. Given the highly mixed inventory of materials, the implementation of 3D scanning would enable enhanced representation of the reclaimed materials to allow the organization, tracking, and estimating the value of reclaimed materials.

The development of 3D models for buildings was aided by the emergence of BIM (Building Information Modelling), which complemented the development of the 3-dimensional capture of objects represented within a 3D space (Rocha and Mateus 2021). However, the demand for 3D representation of pre-existing buildings with limited dimensional information or absent documentation also influenced the evolution of data capturing systems (Rocha & Mateus, 2021). Therefore, there are three types of 3D scanning: structured light (infrared), photogrammetry and lidar. The 3D scanning systems adopted in this study implement different technologies, some of which are hybrid. The Light Detection and Ranging technology (LIDAR type scanner) are often more expensive but more accurate with distances depending on the system's sophistication (Esnaashary Esfahani et al. 2019). 3D scanning technology has been used in previous studies for building adaptation projects, heritage conservation projects, building restoration, building documentation and project management (El-Omari and Moselhi 2011),(Mullumby and Bahl 2021), and (Cepurnaite, Ustinovicius, and Vaisnoras 2017). Thus, this study explores the use of scanners ranging from $1500 -$70,000 in price.

3. METHODOLOGY

This section discusses the methods used in acquiring and processing scans for the study; It will contain four sections. The first section will discuss the scanner types and models, the second section will discuss the scan component layout, the third section will discuss the scan processing methods, and the fourth section will discuss the scanning workflow.

3.1 3D Scanner types

The four types of scanners presented in Figure 1 below were used in this study to capture reclaimed materials of varying sizes under different lighting conditions.

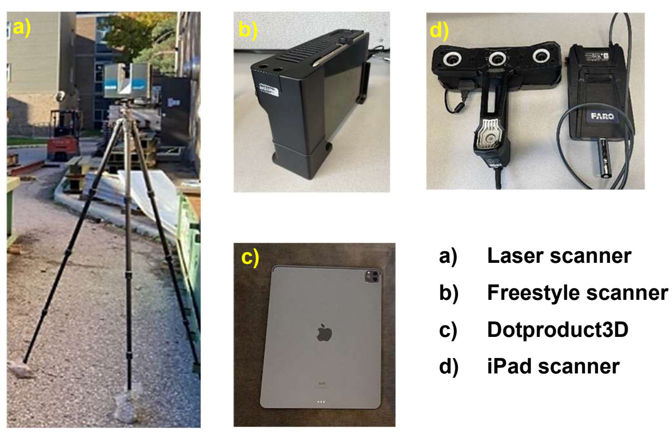


Figure 1: Shows the types of scanners used in the case study.

The faro scanners and the dot product scanner specifications were obtained from their retailer's technical specification sheet. While the specification for the iPad scanner was obtained from the study carried out by (Luetzenburg, Kroon, and Bjørk 2021). The basic specifications of the scanners used in this study are as follows:

The faro laser scanner used in this study is the "Faro Focus M70"; the laser scanner consists of three parts, the battery, the mountable scanner, and the tripod. It has up to 165-megapixel colour and a ranging error of ±3mm. In addition, the scanner functions under direct sunlight weighs 4.2kg and has a battery life of 4.5 hours.

The faro freestyle scanner used in this study is the "Freestyle 2" model; it uses a laser triangulation system. The scanner comprises three parts: the camera, the mobile PC, and the handheld device. The scanning distance is up to 10m, and high-quality coloured images of up to 0.5mm accuracy can be attained using the scanner; the long-range accuracy is 0.5 mm at 1 m distance. In addition, the processing unit weighs 1.3kg, while the scanner weighs 1.5 kg (a total of 2.8 kg in weight). The system is also operational under direct sunlight.

The Dotproduct3D used in this study is the "DPI-8S" model; it uses an android operating system;(Ekins 1993); the system uses near-infrared structured light and an RGB 3D depth imaging system. The battery life lasts for 2-3 hours, with a mass of 1.11kg, and it is not operational under direct sunlight. In addition, the scanner can capture up to 3.3m depth with a range accuracy of 0.8mm at 1m depth.

The iPad used in this study is the "11-inch (3rd Generation) iPad" model. The iPad scanner has a scan depth of up to 5m and accuracy ranging from 1 to 10cm depending on object size. Object sizes below 10cm have poor resolution when scanned using the iPad. The iPad scanner functions averagely well under direct sunlight. Although, it performs better in a sheltered environment for accurate capture. Lastly, the iPad weighs 466g.

3.2 Scan material arrangement

Figure 2 below shows each type of material setup for scanning. This study has three types of material setup inspired by the typical arrangement of materials at the reclaim material stores; the arrangements are either singular, grouped or stacked. Therefore, the study assessed three scan arrangements: singular scans, group scans and bulk scans. The bulk scans represent the scanning of items of the same characteristics stacked (typically arranged in bulk). The singular scans represent individual item scans. Finally, the group scan represents multiple individual items captured in one scan. Figure 2 below shows the different types of material setup for capturing.

Group scan layout **Bulk scan layout** **Single Scan layout**

Figure 2: Shows the component arrangements for scanning in the case study

3.3 Scan Processing

The scan process for the laser and freestyle scanners differs from the others; The iPad scanner and dot product scanners can use the same platform used to process, edit, and measure the captured scans. Therefore, it does not require the transfer of data to another system for further processing. Although the freestyle scanner processes the raw scans using the attached smartphone device, the scans cannot be edited on the device; instead, they must be exported for editing. In comparison, the raw scan must be exported for processing and editing when using the laser scanner. However, once all the files have been processed to an E57 or XYZ file, they can be used across multiple platforms for editing, segmentation, etc.

3.4 Scan Workflow

The scanning workflow presented in this study is depicted in accordance with the experimental process in this study. The scanner type predetermines the setup process for each capturing equipment. However, the setting for each scanner varies with few details and gives the ability to adjust the settings according to the respective level of detail or colour required for capture. Furthermore, the capture process for the handheld devices requires the user to hold the scanner in a position to capture the entire surface; the handheld devices were used to slowly canvas the area to limit noise in the resulting scans during the capturing process. While the faro laser scanner, which is mounted on a tripod, automatically captures the entire area of a scan once the required size has been predetermined. Table 1 below presents the scan processes for each type of scanner.

Table 1: Show the steps taken while using each scanner for scanning in the field.

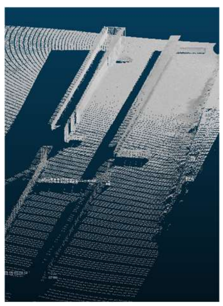
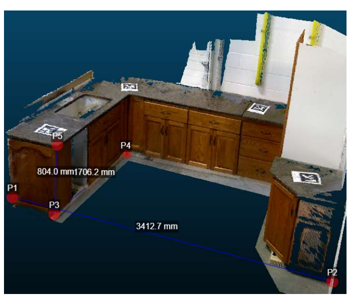
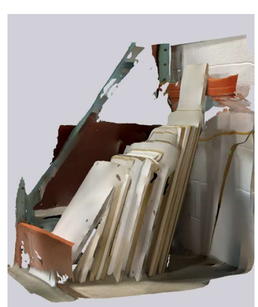
	Faro laser	Dotproduct3D	iPad	Faro freestyle
Setup	The tripod is balanced and levelled, then the scanner is mounted on the tripod, and the level is adjusted using the levelling bubble.	The tablet is mounted on the handheld device and connected to the device using a small USB cable	The iPad scanner does not require other hardware.	The processing unit is connected to the camera system with a cable, and then a smartphone is mounted on the handheld camera. Once the processing unit is turned on, the smartphone is connected to the camera using a small USB cord
Settings	Once the scanner is turned on, the area to scan is set within the range of 0 to 360 degrees. The scanner is set to register colour or not, and the registered points' density is adjusted using options in the settings. In addition, the positions to place the scanner are predetermined if multiple elements are being captured.	The setting within the system is adjusted to define the depth of the scan and the density of capture.	The advanced lidar scanner is selected within the 3D app, and the settings are adjusted to the desired depth of scan and density.	Once the scanner is tethered to the phone via the USB, the device is detected, and the settings are adjusted accordingly for colour, range, and others. The processing unit remains connected to the system throughout capture, so the processing unit is strapped on, and scanning begins.
Capture	Once the setting has been adjusted, the start button is selected. The capture does not require human interference, so it stops once the pre-set area to scan has been captured. The process is repeated multiple times to capture the entire area of the intended scan.	Once the scanner has been connected using the USB, the scanner must warm up before the first scan, after the warmup. The area of the item or items is canvased with the scanner without losing tracking.	Once the settings have been adjusted, the start button is selected. And the area of the item or items is canvased with the scanner without losing tracking.	The capture starts once the settings have been adjusted, and the handheld device is held in place to canvas the item or items without loosing tracking.

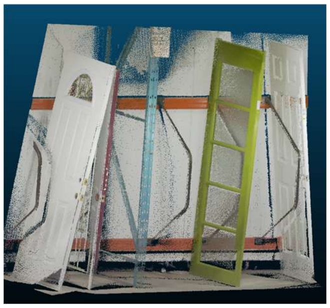
4. CASE STUDY

The case study in this paper examines the ease of implementing 3D systems at two different reclaim material retail stores in the region of Kitchener/Waterloo. The reclaim stores typically receive salvaged materials from the public or deconstruction companies within the region; they receive a mix of furnishing, cabinetry, kitchenettes, wardrobes, doors, windows, flooring, toilet fixtures, light fixtures, reclaimed porch poles, staircases, mixed wood, lumber logs and masonry. Furthermore, the reclaimed steel elements used in this study were elements used for testing by the University of Waterloo; the elements were scanned before being taken for reuse for a private bridge project at Owen Sounds in Ontario.

From the scanners presented in Figure 1 above, the faro laser scanner was used to capture six steel elements laid out in an open area; the maximum length of steel captured was 9.6m, and a total of seven scans were collected for all the elements. In addition, the freestyle, dot product and iPad scanners were all used to carry out scans at the reclaim material store. The freestyle scanner was used to capture a total of 20 scans; the dot product scanner was used to capture a total of 40 scans, while the iPad scanner was used to capture 15 scans. The scans included furnishing, windows, doors, banister poles, wood, and kitchenettes. Samples of the collected scan are presented in Table 2 below.

Table 2: Show detail of scans captured using all four scanners.

	Group scan	Bulk scan	Single scan
Faro laser scanner			
Dotproduct 3D scanner			
iPad scanner			

Faro freestyle scanner			

4.1 Discussion

4.1.1 Scan quality assessment

The adoption of technology in a business is typically influenced by the ease of integration involving factors like perceived difficulty, time constraints and complexity (Alford and Page 2015). In addition, the benefit of adopting advanced technology is a recognized opportunity amongst business owners for marketing and management purposes (Alford and Page 2015). Therefore, qualities that contribute to the efficiency of capturing, processing, and extracting scans are assessed along with the quality of the scan collected using the different types of scanners. The purposefulness of considering the efficiency of the systems is because of the impact on adoption. The two stores involved in this study function typically like a business; the stores must ensure they are meeting their needs financially and functioning efficiently. The stores function as reverse logistic businesses that plan, control, and maintain the efficient cost material flow to recapture and create value. The ability to simply enter reusable elements into a database with limited complexity and required information, along with the ability to find reused materials with an accurate searching database, would significantly improve the ease of working with reclaimed elements. Therefore, the following qualities are considered for each scanner type to assess applicability for use: scan detail, measurement accuracy, equipment portability, scanner range, processing efficiency, editing efficiency, segregation capability, efficient measuring, and cost of the equipment.

Scan detail- The scan detail refers to the resolution of the scan captured; it considers how smooth the scan is and how detailed the depiction of the object is using the scanner.

Measurement accuracy – The measurement accuracy refers to how accurate the scans were in representing the size of the captured component. It is a primary factor that will affect the estimation of value for a reclaimed element using a standardized system like cost per square meter

Equipment portability- The portability of the equipment influences the ease of continuous capturing of materials. The bulkier the equipment, the harder it is to carry around for all-day use, so the equipment portability is a key factor when considering the length of use of a scanner.

Scanner range- The range of scan, which represents the depth of scan, is a factor to consider when scanning multiple elements; it eases the process of collecting scans in bulk and accommodates a larger scan area at once; however, the processing times for scans increase with the increase in captured area.

Processing efficiency- Processing efficiency refers to the ease of post-processing the scans; an efficient system would be needed in a fast-paced environment with a fast-processing speed to limit the time consumed. And a user-friendly interface will ease the editing, measuring, and sharing process.

Editing efficiency- The editing process has to be easy to learn and execute to enable the ease of training and execution. The editing feature is important since it enables the cropping or trimming of scans.

Segregation capability- Manual segregation refers to the ability to separate the processed scans using the editing tools, which can be required in cases where multiple elements are scanned together.

Efficient measurement- The measuring efficiency refers to the ease of extracting measurements from the scans, which influences the ability to efficiently determine the size of the elements. Since the extraction of dimensions would be a key factor for the scanner's use, the simplicity of getting basic measurements is important.

Cost of equipment- The affordability of the scanner is a highly influential factor when considering the impact on the business; the cost-efficiency of the system would determine whether a scanner would be purchased for the proposed use. Rogers and Tibben-Lembke (2001) stated that financial resource is a key barrier to reverse logistics; therefore, the implementation of advanced technology in the business process would need to be financially viable with positive perceived benefit of use.

Finally, based on the procedure and steps taken in scanning and processing a total of 82 reclaimed elements in the region of Waterloo/Kitchener, the assessment of the qualities stated above was carried out by comparing all the scanners to themselves based on their usage. The qualities were ranked either Low, Medium, High, or Very High. All the scans were carried out by a single individual using the four scanners over a period of four months, collecting scans on a weekly basis. Thus, Table 3 presented below displays the ranking in qualities taken into consideration for the purpose of use at the reclaimed material stores.

Table 3: Shows the ranking of the scanners according to the reviewed qualities.

Qualities	Faro laser scanner	Dotproduct3D scanner	iPad scanner	Faro freestyle scanner
Scan detail	High	Medium	Low	High
measurement accuracy	High	Medium	Low	High
Equipment portability	Low	High	High	Medium
Scanner range	Very High	Medium	Low	High
Processing efficiency	Low	High	High	Medium
Editing efficiency	Low	High	High	Medium
Segregation capability	High	Medium	Low	High
Efficient measuring	Medium	High	High	Medium
Cost of equipment ($)	$\approx 70{,}000$	≈ 2500	≈ 1500	$\approx 25{,}000$

4.1.2 Needs assessment (data and process)

The radar chart in figure 3 below depicts five critical elements from Table 3 above to assess the characteristics discussed in the previous section in more detail.

Firstly, the scan detail, which refers to the quality of the scan, highly influences the accuracy of measurements taken and the ability to segregate elements. Hence, as observed, the laser scanner had the highest level of accuracy, followed by the freestyle scanner, the dot product and then the iPad scanner. On the other hand, the iPad scanner had the lowest level of accuracy overall, while the laser scanner and the freestyle scanner present high levels of accuracy for well-detailed designs. However, in the case of reclaimed material stores, the use of medium-level accurate depiction could suffice; with up to a few centimetres level of accuracy as estimated for the iPad, it can be used to estimate prices based on the area and size of products.

Furthermore, a single detailed scan acquired using any of the scanners would present a good estimate. However, the scan quality influences the ability to segregate grouped or bulk scans; The iPad has the lowest quality of scan for bulk items with a low level of detail that can not be efficiently segregated to determine basic measurements. As stated earlier, details lower than 10cm are not easily captured using the iPad scanner, but all the other scanners performed better when capturing smaller edges with a higher level of detail to enable segregation, especially useful when capturing items in bulk.

Secondly, the equipment portability is an essential factor depending on the scanner's purpose. For an environment that requires a portable 3D system, the iPad or dot product scanner are both under 1.2 kg in weight; in comparison to the laser and freestyle scanners that are over 2.5 kg in weight. However, the ease of workflow also needs to be evaluated when selecting a scanner. The scans taken using the dot product and the iPad scanner can be immediately processed and edited after scanning, while the freestyle scanner requires additional steps in exporting files to a different platform for editing and sharing. In contrast, the laser scanner requires a transfer to a different platform for processing and editing, making the process longer.

The primary purpose of implementing a 3D scan system for reclaimed material stores is to enhance the process of capturing dimensions and enhance value estimation. The level of accuracy needed when depicting kitchenette fitting varies from the level of detail required for a new building design. All the scanners captured the 3D images to a good level of detail. Therefore, the calibre of the scanner should be selected in accordance with the need. In the case of the two reclaim stores, the freestyle scanner was much more efficient for the first store due to the length and size of some of the larger building components, while the dot product scanner was much more effective for use in the other store with the much smaller and less dense environment.

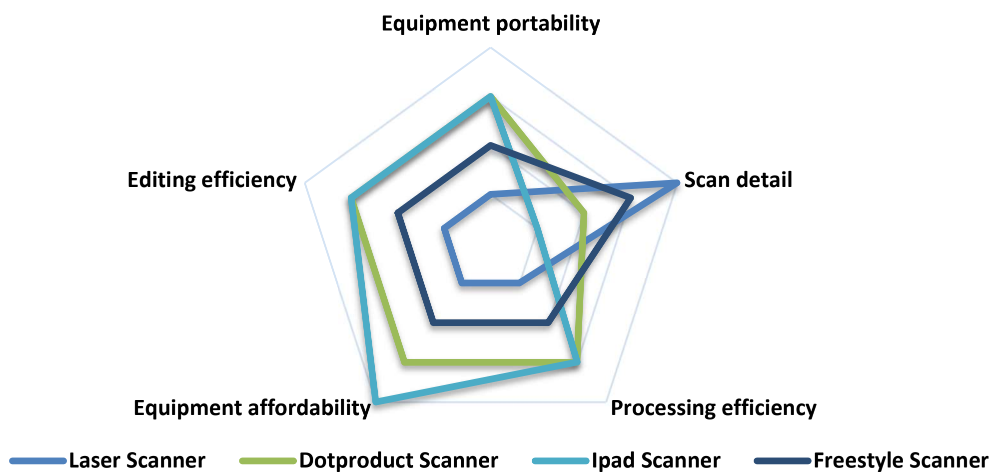


Figure 3: Shows the radar chart for key characteristics rated between very high and low.

5. CONCLUSION AND FUTURE WORK

There is a lag in exploiting modern-day technological advancement for reverse logistics within the construction industry, despite the exploitation of specialized systems for construction processes such as design, construction, and management. As a result, the reverse logistics system remains heavily dependent on labour-intensive processes and methods. With the increasing cost of new materials in the market and the cost of landfill disposal, the implementation of 3D data capture in reverse logistic streams would improve management and impact the prices of reclaimed material. In addition, it would further enhance localized trade, encouraging industrial symbiosis with the aid of technology, limiting sourcing for new materials, and enabling integration of old and new resources, reducing the overall cost of construction materials for a project.

Furthermore, this study contributes to advancing knowledge on technological requirements to enhance reuse in the circular economy; it expands the range of applications of 3D scanning technology to material reuse sourcing. Future extensions to this study could involve assessing the efficacy of the scanning process for buildings before deconstruction to enable the early entry of soon-to-be-available materials to the market prior to deconstruction. This further strengthens the aspect of industrial symbiosis within the community, helps tackle storage-related issues, and limits material degradation in storage.

In conclusion, this study has depicted the process of using four different types of scanners for materials of varying sizes and analyzed the effectiveness and level of quality produced using each scanner type. In addition, the scanner's prices range from as little as 1500 to 70,000; this presents insights for different scales of business looking to use affordable or highly enhanced scanners for the management of products. The two businesses involved in the case study showed significant interest due to the potential of attracting online clients with the capture of 3-dimensional images and have taken an interest in implementing 3D scanning in their business process.

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