An Investigation of Google Tango® Tablet for Low Cost 3D Scanning

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Abstract –

Google Tango® is an augmented reality based Android tablet that contains customized hardware, an array of sensors, and software designed to track the full 3D motion of the device while simultaneously creating a map of the environment. The embedded sensors allow the device to make over a quarter million 3D measurements every second, updating its position and orientation in real-time, and combining that data into a single 3D model of the space around it. This arrangement allows users to create experiences such as indoor navigation, 3D mapping, augmented reality, physical space measurement, and environment recognition in a virtual world. The aim of this research study is to investigate the scope and accuracy of Google Tango® tablet for generating 3D point cloud based scans that could be used for schematic designing, space management, and for renovations and retrofitting planning. In addition, other functionalities of Tango® tablet that could be useful to designers, constructors, and facility managers (FM) are investigated. A mixed-methods approach was adopted for this study. Four testing scenarios were designed to collect the necessary quantitative data. In addition, interviews with BIM/laser scanning professionals were conducted to get their insight. The data analysis indicated that the accuracy of 3D scans in most cases is within ±5% of actual measurements which is fairly reasonable for schematic planning. Hence this technology could provide significant cost and time savings for the design, construction and FM industries. The paper first discusses the main concept and applications of Tango® tablet. After that, its possible applications for design, construction, and facility management are illustrated. This is followed by a brief discussion on the methodology and data collection methods. Based on the presented results, major findings and conclusions are outlined and recommendations for researchers and practitioners are presented.

Keywords –

Project Tango®; Simultaneous Localization and Mapping (SLAM) devices; 3D scanning; Point cloud; Augmented reality

1 Introduction

Tango® is an augmented reality computing platform, developed and authored by Google [1]. It uses computer vision to enable mobile devices, such as tablets and smartphones, to detect their position relative to the world around them without using GPS or other external signals. This arrangement allows developers and users to create experiences that include 3D mapping, indoor navigation, augmented reality, physical space measurement, and environment recognition in a virtual world [2]. Google has produced two devices to demonstrate the Tango® technology: the discontinued Peanut® phone and a 7-inch tablet. More than 3,000 of these devices had been sold chiefly to researchers and software developers interested in building applications for the Tango® platform [2]. This research study tested the 7-inch Tango® tablet which is shown in Figure 1.

Figure 1 The Google® Tango Tablet [1]

The Tango® platform is developed based on the concepts of motion tracking, depth perception, and area learning [3]. Tango® devices contain customized hardware sensors and software designed to track the full 3D motion of the device, while simultaneously creating a map of the environment. The sensors allow the device to make over a quarter million 3D measurements every second, updating its position and orientation in real-time, and combining that data into a single 3D model of the space around the user [3]. The main specifications of Tango® tablet are shown in Table 1.

Table 1. Specifications of Google® Tango Tablet [2]

Screen	7.02" 1920x1200 HD IPS display (323 ppi) Scratch-resistant Corning glass
Dimensions	119.77 x 196.33 x 15.36mm
Weight	0.82 lbs (370g)
Cameras	4 MP 2mm RGB-IR pixel sensor, 1 MP front facing, fixed focus
OS	Android 4.4 KitKat or higher
Wireless	4G LTE Dual-band Wi-Fi (2.4GHz/5GHz) WiFi a/b/g/n NFC chip
Audio Output	Dual stereo speakers 3.5mm audio connector
Memory	128 GB Storage; 4 GB RAM
Ports	Micro HDMI; USB 3.0; Micro SD card; Nano SIM slot
Processor	NVIDIA® Tegra K1 w/ 192 CUDA cores
Sensors	Motion tracking camera; 3D depth sensing; Accelerometer; Ambient Light; Barometer; Compass; GPS; Gyroscope

The applications of Tango® tablet are much broader than design, construction and facility management, as it could be used in other sectors such as retail, automotive, fashion, and service industries [3]. Tango® tablet does not offer laser-quality scanning but it allows users to perform rapid 3D acquisition of the surrounding space. It could create maps or floor layouts of large facilities. Once a building project is occupied, users can populate the building with more interior details. A Tango-enabled device could eventually access other analytics, such as temperature, vibration or noise, to create a rich map of the facility [4].

2 Background and Rationale

Over the last twenty years or so, laser-scanning technologies have seen a significant shift in applications across multiple disciplines [5]. Currently, there are a large number of commercial 3D scanners available for many different markets and applications covering art, automotive industry, archaeology, product design, architecture, fashion design, body measurement, civil engineering, metrology, forensics, and national security [6]. There are benefits and limitations of each type of scanner in terms of resolution, scan area, mobility, data capturing speed, tolerances and cost [7].

Clark and Liu conducted a field testing for drywall installation using laser scanning and BIM. They determined that field scanning requirements for simple rooms such as offices are minimal requiring only one medium resolution scan with an image capture for reference - a 20 minute time investment for each office space. The accuracy of scans proved that the integration of laser scanning and BIM technologies can be used in a specific area without having to make any (traditional) field measurements. The study additionally concluded that on most construction projects, the window for conducting scans is relatively short and suggested the need for a faster scanning process [5].

Becerik-Gerber et al. performed research on data acquisition errors during laser scanning caused by target setup, acquisition, and reorientation. They explored how different target types and target layouts affect the registration accuracy [8]. Their research suggested that laser scanning is not a straight forward process and a great care is needed to achieve reliable results. 3D laser scanning requires stillness in the scene that is captured. Thus, ongoing production activities can prove troublesome. If the geometries in the scene are numerous and complex, more data captures are required to get comprehensive spatial data of the entire scene [9]. Hence laser scanning requires both time and effort which in turn increases its overall cost.

The Google Tango® tablet provides a new avenue for conducting fast and low-cost scanning. Combining Infrared (IR) depth sensors and cameras paired with Simultaneous Localization And Mapping (SLAM) technology allows for scanning on the jobsite quickly with minimal training and preparation time by any construction personnel or trade worker. The purpose of this research study is to test the feasibility of Google Tango® tablet and its applications for use in the design, construction and facility management practice. This research specifically focused on preparation time, scanning time, and accuracy of the scans.

3 Google Tango® Applications (Apps) for Design, Construction, and Facility Management

Following is a brief description of Google Tango® applications for design, construction, and facility management industries. Readers interested in more details are advised to read the detailed study by Froehlich [10] or visit Tango® website [2].

3.1 Tango® Constructor

The most important Tango® app is “Constructor” which allows users to scan and view 3D models (or meshes) of the surrounding space. The users may export 3D scan files to various BIM software or other VR/AR tools (e.g. Unity®) [11].

Figure 2 Google Tango® Constructor Application [11]

3.2 Tango® MeasureIt

“MeasureIt” is a simple application that allows users to take measurements of the surrounding space with a Tango® device. Users can simply point the device at what they would like to measure and use the cursor to place points. The measurements are displayed in an Augmented Reality view [12].

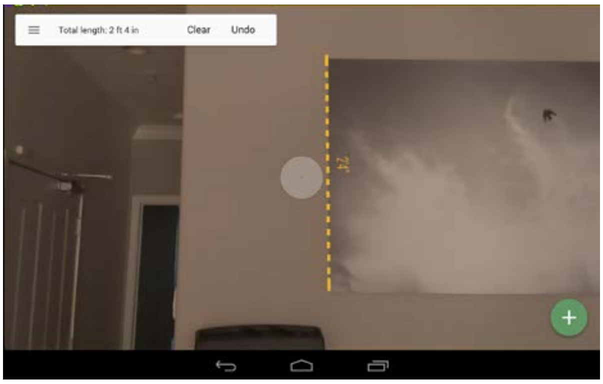

Figure 3 Google Tango® MeasureIt Application [12]

3.3 MagicPlan

MagicPlan creates floor plans. It measures existing rooms and surrounding spcaes, and draws floor plans just by taking pictures. Users have to simply add objects, annotations, and attributes to create the complete plan of a property. These plans can be saved in PDF, JPG, PNG, SVG, DXF, and CSV formats [2].

Figure 4 MagicPlan Screenshot [2]

3.4 Matterport Scenes

This app allows users to capture real-life scenes such as small spaces or objects in digital 3D. They can view, measure and share, from anywhere. In addition, they can measure any point-to-point dimension or use 3D trim to crop objects of interest. These objects can be shared via a Cloud-based library [2].

3.5 Wayfair™ View

WayfairView uses Augmented Reality (AR) technology to place real (furniture and related) products from Wayfair’s (www.wayfair.com) extensive catalogue into any room on a 1:1 scale. WayfairView allows users to check the scale of products, see how items match their current décor, rearrange furniture in the space, and save or share photos [13].

Figure 5 Wayfair View Application [13]

3.6 Lowe’s Tango® App

For the past two years, building products retailer Lowe's has been developing visualization applications using augmented and virtual reality tools, and Tango® made this technology accessible for everyday customers, right in their hands. Lowe’s considered it a big step which can allows customers to better visualize and select products for their homes [2].

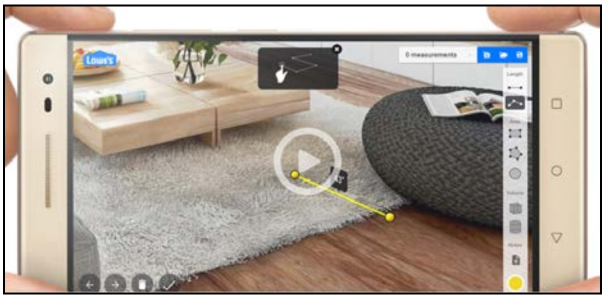

Figure 6 A screenshot of Lowe's Vision Tango App [2]

In addition to these six apps which were extensively tested in this research, there are several other available apps (most of them are currently in their beta versions) which are worth testing but were considered outside the scope of this study.

4 Research Aim, Objectives, and Scope

The aim of this research study is to investigate the scope and accuracy of Google Tango® tablet for generating low-cost point cloud based 3D scans that could be used for conceptual designing, space management, and for renovations and retrofitting planning. The research objectives includes the following:

1. Investigation of the state-of-the-art handheld Simultaneous Localization And Mapping (SLAM) enabled devices for onsite scanning and BIM model development;
2. Demonstration of their applications in design, construction, and facility management; and
3. Development of relevant examples for classroom and industry demonstrations.

This research was conducted using Google Tango® tablet which at the time of this research was the only SLAM enabled device available in the market.

5 Methodology and Data Collection

5.1 Methodology

A mixed-methods approach was adopted for data collection due to its strength for including both quantitative and qualitative data streams [14]. The major steps in this study were as follows:

1. The preliminary data was collected via extensive literature search. Related case studies published in various technical journals, magazines and conference proceedings were collected, reviewed and summarized.
2. Initial testing of the tablet was carried out though scanning as-built conditions. Three as-built area scans, a small conference room, a mechanical room, and a graduate students office in the Miller Gorrie Center on the campus of Auburn University, were generated. The produced scans were then compared to the as-built drawings. Time to prepare, conduct, and process the scans was assessed for each scenario.
3. Next, 3D scans of a mailroom located in the Whiting-Turner Contracting Company office, were created using terrestrial laser scanning and Tango® tablet and compared. The accuracy of both scans was verified using an already developed BIM model of the facility.
4. The results were presented to a focus group of 4 experts with experience in BIM, laser scanning, and advanced visualization technologies. Their feedback was collected using a series of questions and open discussion.
5. At the end, both quantitative and qualitative data were compared to draw necessary conclusions and recommendations.

5.2 Data Collection

5.2.1 Quantitative Data

The following procedure was adopted for scanning and/or creating point cloud using the Tango® tablet:

Due to the SLAM technology in the Tango® tablet and its ability to compute and recognize its location independently, without the aid of GPS require minimal preparation time (typically 3-5 minutes). Additionally, there was no need for markers to be placed as required by laser scanners. Unlike a fixed scanner, (e.g. laser scanners) the Tango® tablet utilizes built-in motion tracking which allows the user to sweep the area from different angles scanning untethered within a space.

The Tango® Constructor app was used to conduct the scans. Upon starting the tablet it calibrates itself requiring the user to extend the tablet out in front of him/her in a steady position for a few seconds. Once the tablet is calibrated, the user has full range to scan spaces within 0.5 to 4 meters (1.5 to 13 feet) away from the tablets sensors. Currently the tablet is designed to work best indoors at moderate distances [3]. The application supports functions allowing the user to pause, resume, or reset a scan in progress. This allows scanning to stop or pause and resume scanning of the same area. Additional options allow for the scan to be saved in the native file type for the application, as well as an .OBJ file type.

The results of a scan produce a 3D mesh which can be saved in the .OBJ file format and transferred to a computer for further processing. The file was then imported into Autodesk® Memento software and exported as an Autodesk® Recap Point Cloud file. The converted scan was then imported into Autodesk® Revit as a point cloud file thereby providing the same functionality as a laser scan produced point cloud.

5.2.2 Qualitative Data

The quantitative data analysis results were presented to a focus group of 4 experts who have 8 years or more experience in the field of BIM, laser scanning, and other advanced visualization technologies. The discussion started with the following questions: (1) Is Google Tango® a viable alternate to laser scanning? (2) What are its best applications in design, construction, and facility management? (3) What are its biggest benefits and limitations? and (4) What is the future of Tango® and other similar (SLAM) devices in the AEC industry? The experts provided their opinions on these four questions and then open-discussion was held to reach a final consensus. The major findings of the focus group are reported in section 6.5.

6 Results

6.1 Scenario 1: Conference Room Scan

The size of the chosen conference room was approximately 13ft x 18ft with a conference table and chairs centrally located in the room. To test the accuracy of the produced 3D models from the scan, two starting points, point A and point B were determined in the conference room, as shown in Figure 7.

The scanning path followed the perimeter of the room, clockwise from each starting point. A total of ten scans were conducted, five scans with a start at point A, and five scans with a start at point B. A live view of the 3D Mesh could be seen on the tablet screen as it scans the area. The view shows the mesh model simultaneously being constructed and refining itself as the tablet sweeps the area. The user has the following options for viewing scan on the screen: *first person*, *third person* or *top view*. First person view was chosen as it displays scanning in real-time as the user moves the tablet over areas to be scanned. Each scan was completed within the time range of 5-8 minutes. The scanning times and results are dictated by the user and their movements through the space.

The duration of a scan using the Tango® tablet is constrained by both hardware and software limitations. Hardware limitations include the battery life (appox. 80 minutes) and overheating of the device after 30 minutes of use which considerably affects the accuracy of the sensors. Main software limitation is the position loss of the Tango® tablet (drifting) during a scan due to motion tracking failures that results in noisy 3D models [3, 10].

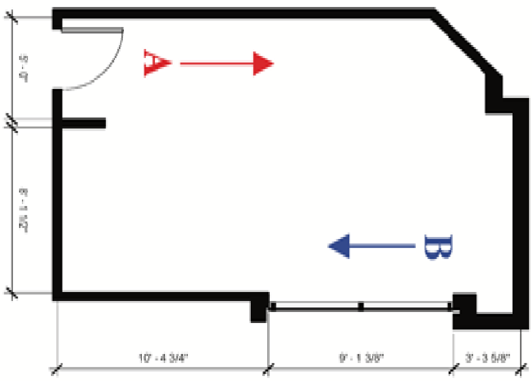

Figure 7 Starting Points of Scan

Figure 8 illustrates the results of a scan initiated at starting point A, scanning clockwise around the room.

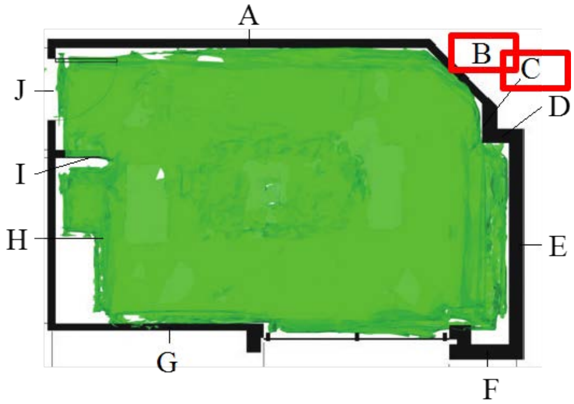

Figure 8 Tango® Scan of Small Conference Room

Table 2 shows a comparison of the results with the as-built model measurements.

Table 2 Small conference room scan analyses of As-built measurements and Tango® scanned measurements

Wall	As-Built Model		Tablet Scan Average		Variance
	m	ft	m	ft	%
A	5.54	18.16	5.65	18.53	2.01
B	1.19	3.90	0.96	3.14	19.44
C	0.63	2.07	0.53	1.75	15.38
D	0.39	1.29	0.39	1.28	0.94
E	2.65	8.71	2.66	8.74	0.34
F	0.93	3.04	0.90	2.95	2.92
G	2.59	8.50	2.64	8.65	1.77
H	2.47	8.11	2.48	8.14	0.27
I	0.66	2.17	0.69	2.27	4.99
J	1.52	5.00	1.55	5.07	1.49

As can be noted that the percentage variance for most measurements is within ±5 percent except for walls B and C. Both walls were unevenly illuminated by the natural light coming from the front window and that may be the cause of this large error. This assumption was further supported by the data collected in scenario 2. It is important to note that the scanning accuracy of the overall model deteriorated with time and its movement along the path [10]. This was due to drifting of the tablet and its ability to maintain its known location in the space. The portions affected by the drift maintained a greater level accuracy based of its new coordinate location within the space.

6.2 Scenario 2: Mechanical Room Scan

Next the mechanical room within the Gorrie Center was chosen for scanning. The room is filled with mechanical equipment, piping, and ducts. The small space would be a challenge for laser scanning, and multiple views were required to develop a 3D scan of the space. Figure 9 shows a point cloud of the Mechanical Room produced from the tablet. The scan of the Mechanical Room gave the tablet more surfaces and objects to reference itself to as compared to scenario 1. Overall there was only minor drifting which occurred along the bottom wall as shown in Figure 9. The location where the drifting happened was poorly lit as well as having only flat surfaces, both of which are the likely cause of the drifting. The entire scan of the room was completed in 19 minutes. The complexity and tight spaces of the room required additional attention in order to get a usable model. The existing Revit model did not include the modelling of the pumps, pipes, ducts and equipment. The point cloud produced from the tablet scan shows the location of those items. Table 3 shows a comparison of measurements using As-built model and Tango scans. It is important to note that the variances for all walls are within ±5% except Walls D, E, and G due to either uneven illumination or poor lighting conditions.

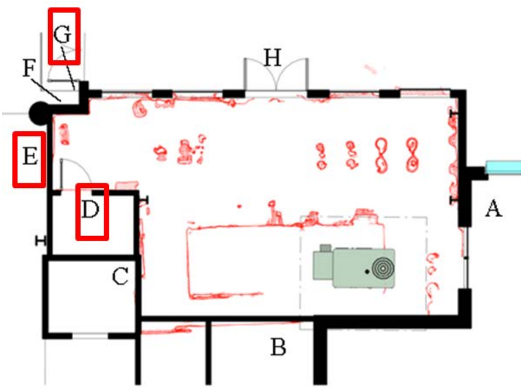

Figure 9 Mechanical Room Plan and Superimposed Scan

Table 3 Mechanical room scan analyses of As-built measurements and Tablet scanned measurements

Wall	As-Built Model		Tablet Scan Average		Variance
	m	ft	m	ft	%
A	6.28	20.60	6.49	21.29	3.3
B	9.22	30.25	9.65	31.66	4.7
C	3.62	11.88	3.81	12.50	5.2
D	2.50	8.20	2.11	6.92	15.6
E	2.22	7.28	3.15	10.33	41.9
F	1.04	3.41	1.07	3.51	2.9
G	0.46	1.51	0.41	1.35	10.9
H	10.68	35.04	10.90	35.76	2.1

6.3 Scenario 3: Graduate Students Office

In this scenario, the accuracy of the Google Tango's MeasureIt® app was tested by taking measurements of the Graduate Students Office located in the Gorrie center. Table 4 shows the variance percentage between the results of a laser scan and Tango measurements. The results of this scenario showed greater improvement in accuracy in comparison to the 3D space scanning performed in scenario 1 and 2. Overall time to prepare, conduct, and process the data was almost one-third as compared to scenarios 1 and 2.

Table 4 Graduate students' office scan analyses of As-built measurements and Tablet scanned measurements through MeasureIt App

Wall	Laser Scan based Measurement		Tango based Measurement		Variance
	(Meters)	(Feet)	(Meters)	(Feet)	(Percent)
A	1.63	5.34	1.60	5.24	1.86%
B	3.26	10.71	3.24	10.64	0.61%
C	0.59	1.93	0.60	1.95	-1.19%
D	3.78	12.41	3.76	12.33	0.61%
E	12.11	39.73	11.97	39.26	1.18%

It is important to note that the measurements of the spaces produced varying results based on where the points were selected within the physical space. Measurements were taken both at the bottom and at the top of walls. This arrangement reduced discrepancies within the data sets utilizing the straight edge of the floor and ceiling to get a perfect straight line. Additionally, measuring a space within a fixed point of view is proved to be more accurate than those requiring walking or moving through the space with the tablet.

6.4 Scenario 4: Mailroom Scan

In the final scenario, the Tango® tablet was used to scan the mailroom of the Whiting-Turner Contracting Company office located in Tampa, Florida. The intent of this testing was twofold: (1) to compare measurements taken by laser and Tango® scans; and (2) to visually assess the level of detail for both scans and to their determine their viability for schematic planning.

Figures 10-12 (all images courtesy of the Whiting-Turner Contracting Company) compares the level of details using an actual photo, a laser scan, and a Tango® scan of the same area.

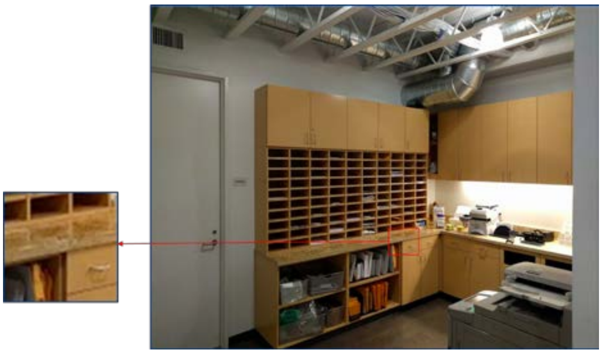

Figure 10 Mailroom photo taken by iPhone 5S

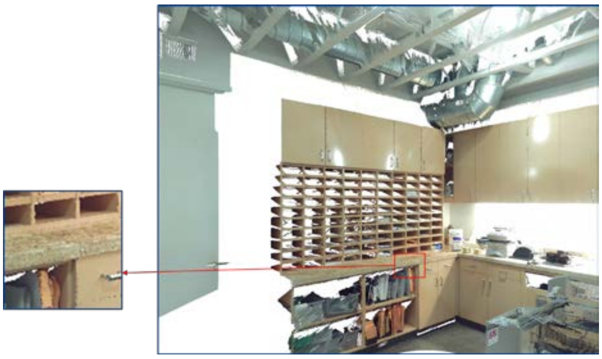

Figure 11 Mailroom image through a Laser scan

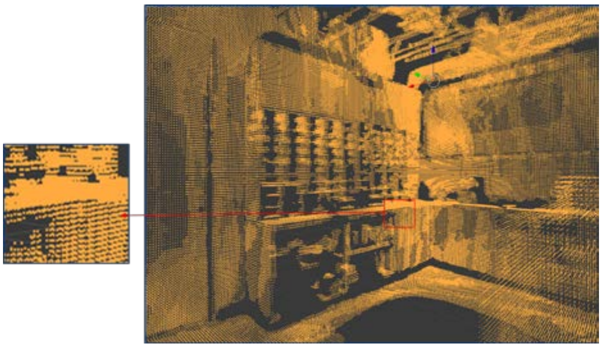

Figure 12 Mailroom image through a Tango® scan

Although not shown here but all measurements of laser and Tango® scans were very close to each other and within a variance of ±5 percent. In this case, all scans were created under artificial lighting and every effort was made to minimize the illumination effect that was the major error source in scenarios 1 and 2. By comparing Figures 10-12, one can determine that the level of detail of Tango® is the poorest but it can still recognize objects fairly well and can be reasonably used for schematic planning.

6.5 Main Findings of the Focus Group

The focus group members agreed on the following conclusions:

- Google Tango® is an innovative piece of technology that has a lot of potential in the design, construction an FM industries. At this point, it is neither very accurate not very reliable to be considered as an alternate of laser scanning however it can be reasonably used in the initial planning process as a substitute of laser scanning especially for maintenance and retrofitting projects.
- It can be used for schematic design comparisons, jobsite layout, measuring the height of overhead obstructions for safety planning, and/or planning for confined spaces.
- Its biggest advantage is its cost which is around $500 and can be easily afforded by most design and construction firms. Since the tablet is at its infancy stage and most of the apps are in their beta versions hence it is difficult to fully rely on the results they produce.
- The tablet offers several promising applications for design, construction and facility management. It is hoped that the software developers will further develop and refine their apps.
- The focus group members were in agreement that a time period of at least 3-5 years would be needed before one can see its commercial use in the design, construction, and FM industries.

7 Conclusions and Recommendations

The Google Tango® tablet is an innovative piece of technology allowing the user to quickly scan and/or measure surrounding spaces. While the technology is still in its infancy it shows a promising future for use in the design, construction, and FM industries. The cost paired with the Android OS provide a versatile tool to aid any user regardless of the industry. With many retailers developing applications for consumer shopping and home use, SLAM and AR are not going away.

While scans generated through Tango® tablet are not of the same quality or high accuracy as of terrestrial laser scans, they can serve as a beneficial aid during design and construction. Time and skill required to complete scans on site are minimal and can prove to be a beneficial tool. Additionally, there are significant costs and time savings in comparison to the cost of traditional laser scanners.

This research determined that there is a wide range of factors that influence the integrity of a produced point cloud. For any area in order to be scanned must have surfaces capable of being registered by the tablet sensors. Translucent or glass material cannot be read by the tablet, as well as shiny or surfaces with a gloss finish. The tablet sensors are not able to get an accurate depth reading due to the scattering of the transmitted laser and IR signals. Uniform lighting is very important to fully scan an area without noise or distortion. Too much light, or not enough light caused drifts in the tablet's location within the space as well as holes in the produced model or point cloud. Direct sunlight on surfaces, specifically cause holes, as they are not able to be scanned, similar to glass or windows. As this research was conducted indoors, lighting was found to be detrimental to the overall quality of a scan. The users' method of scanning a space, in regards to how they hold the tablet, their speed through the space, and ability to thoroughly scan around the space from multiple perspectives can affect the scan quality. Further research to determine the best practices for scanning using the Tango® tablet would be beneficial. Additionally, through this research it can be determined that the quantity and close proximity of surfaces to one another can produce a more accurate model. The more surfaces the tablet is able to identify and register, the more accurate it can identify its own location within an area to be scanned.

The use of the Google Tango® allows users to relay information of which it is spatial aware of, thereby improving the coordination and communication of trades on site. Deploying a downloadable application of the Model allows for simple exchange of information. Not only can the Google Tango® tablet serve for trade coordination but it can serve as a digital manual for building handover. Providing an owner with SLAM device with the spatially aware information within a BIM model can serve as a beneficial information tool.

This research tested the applications of area scanning for design, construction and FM industries and determined that Tango® tablet has the great potential for fast area scanning. While scanning of large spaces is not nearly as accurate as scanning smaller ones, they both offer advantages. Future research will build upon this study, continuing research with the Tango® Tablet, as well as the Microsoft® HoloLens. The HoloLens® is a mixed reality headset which utilizes SLAM technology to overlay information within a space. The headset allows users a hands-free experience and like the Tango® tablet, it scans the space as the user moves around. Finally, the SLAM is an innovative technology that has yet to be fully realized but offers great potential to innovate the design, construction and FM industries.

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