INDOOR NAVIGATION TECHNOLOGY EXPLORATION AND APPLICATION IN UNIVERSITY BUILDINGS

by

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ABSTRACT

As commercial and industrial buildings are so complex, navigating inside of those buildings, findings rooms, and exits has become difficult, especially for the those who are new to the building. To overcome these difficulties, this research project is related to indoor navigation or wayfinding. Different technologies such as Wi-Fi positioning, Bluetooth, low energy beacon, ultrasonic, infrared, semantic maps, building information modeling, and augmented reality has been applied for indoor navigation due to the unavailability of global positioning system, which is extensively used in outdoor navigation. The purpose of this research is then to explore the literature of indoor navigation technologies, uses of as-built 3D scan use in indoor navigation, and to develop a prototype application by using as-built 3D scans to assist users who are new to the building and want to locate facilities. For example, finding the restroom or nearest exit-way in case of emergency.

In this research, the prototype application is based on a 3D scan of the Roy F. Mitte (RFM) building. The research presents the results of the perception of students who visit the RFM building to evaluate if indoor navigation technology could assist them in navigating based on their facility needs. This research uses a mixed method to explore, analyze the data, and discuss the findings. This research also examines the potential of 3D scans and digital twins for use in emergency evacuation procedures inside of buildings. To fulfil the objectives of this research, the author used a Faro Laser scanner and scanned an as-built indoor hallway of the RFM building. Due to limitations, the author used the fourth floor of RFM building for the prototype development. The author collected 3D point clouds and converted them to mesh and generated an area target using Vuforia engine. Finally, the author exported the mesh model and area target to the Unity application to develop a prototype indoor navigation application using Vuforia engine and Unity.

The research will be used to fulfill a portion of the Construction Management M.S. thesis requirement.

Keywords: *3D Scan, Digital Twin, Emergency, Indoor Navigation*.

I. INTRODUCTION

Background of the Study

We have access to much information about outdoor locations due to the development and widespread use of GPS technology. We know, in real time, what the fastest routes are to get to a certain place. While GPS and cell tower-based outdoor positioning methods have been extensively studied and standardized, indoor navigation is a new field of study that has spawned many novel designs and algorithms. The market for indoor navigation encompasses a wide variety of application domains, including, but not limited to logistics, health care monitoring, location-based services (LBS), emergency services, tourism, and people management. (Renaudin et al., 2007). Indoor mapping for grocery stores and other indoor spaces makes it simpler to plan for potential crises, expedites the response time of emergency personnel, and increases the number of people who are likely to survive an incident (Mappedin, 2020). This is because indoor mapping provides information, which is one of the most important tools for risk management. Indoor mapping is also essential in large buildings, such as those found in universities, so that new students can easily find their way to their classes and to safety in an emergency. To ensure public safety, the first step is to prepare and develop plans for an emergency. Literature shows that there are several research on technologies and approaches that have been in practice to support indoor navigation in buildings such as Wi-Fi, Bluetooth Low Energy (BLE), ultrasonic, and infrared. In a similar vein, there has been recent publications of study into the development of 3D models capable of representing the layout of a whole building (including all rooms, hallways, doors, and windows) for the purposes of disaster analysis, evacuation planning, and wayfinding (Kwan & Lee, 2005; Isikdag, Underwood, & Aouad, 2008; Lee & Zlatanova, 2008; Lee, 2009).

As a highly precise and time-saving technique, 3D laser scanning is a wonderful way to get information about a building. Construction progress tracking, quality control of building components, construction site safety, safety management, disaster recovery, energy modeling and management, and modeling for existing buildings have all benefited from the integration of 3D laser scanning and BIM technology (Liu et al., 2021). As an additional point of interest, the term "Digital Twin" (DT) has recently gained popularity in the field of indoor mapping. The field of DT studies has not settled on a single definition, but rather has come to accept several concepts. The three-dimensional model, which is discussed in Wu et al. (2021), is the one that can be applied to the most different situations. It is made up of a communication network that links the two components together, as well as a virtual representation of the real-world environment and the actual objects that make up that environment.

Problem Statement

Literature shows there are many indoor navigation technologies such as Wi-Fi, Bluetooth Low Energy (BLE), ultrasonic, infrared, BIM, IFC, semantic and 2D map based, magnetic maps, omnidirectional images and semantic web based. However, author of this research finds the gap in literature that, although advanced technology has been in practice for indoor navigation, no research has been published collaborating the scanned as-built 3D buildings, computer vision, and augmented reality with smart phone. Further, most of literature with technology has been used in hospitals to locate the patient’s room number. There is a lack of research that focuses on the application in university buildings, which are unique in design and difficult to navigate, especially if the user is new to the structural layout.

This research focuses on the possibility of collaboration of these technologies for indoor navigation in university buildings during an emergency. This research selects the Roy F. Mitte (RFM) building of Texas State University campus to collect the data and analyze. Students from various departments attend classes and labs in this building. New students are often confused with the building's layout, which may become stressful if they have to exit the building in case of an emergency. Similarly, finding restrooms may be difficult if the users are unaware of the layout of the building. In a situation like this, having an indoor navigation system available could be of assistance.

Research Objectives

The main objective of this research is to explore the literature related to technology applied in indoor navigation and whether an as-built 3D scanned model and one of indoor navigation technology can assist people to find their path inside an university building in case of an emergency. To achieve this aim, the following objectives were established:

1. Perform systematic literature review of indoor navigation in a building and the technology applied for it.
2. Identify the significance of indoor navigation during emergencies in the RFM building.
3. Expand the knowledge of 3D scanning and digital twins among students.

4. Carry out a comprehensive three-dimensional scan of the fourth floor of RFM building using the FARO Scanner to align with prototype application (smart phone supported) to help students find exits during an emergency.

II. LITERATURE REVIEW

The complexity of indoor environments has reached new heights (Brown et al., 2013, Liu, 2017). Humans need rapid exits from buildings in the event of danger, whether from natural causes or terrorist attacks. A school building is a large and complicated structure that can be difficult for new students to learn their way around to their classes, labs, and the nearest emergency exits. Those problems can be fixed by integrating indoor navigation technologies with the application of 3D scanned real environment, augmented reality based on Vuforia Engine.

Indoor Navigation

How to "get from point A to point B" is a question that can be answered by the art and science of navigation, which involves pinpointing a moving vehicle's current location and directing it to a predetermined destination (National Geography, 2020). Golledge (1995) investigates how people choose navigation routes and provides a model that incorporates cognitive and environmental aspects. That report also provides an overview of upcoming studies on the impact of technology on navigation. Montello (2005) provides an interdisciplinary overview of navigation, including types of navigation, cognitive processes and environmental factors involved, the impact of technology and aging, and practical applications such as designing navigation aids and evaluating spatial abilities in different populations.

The use of global navigation satellite systems (GNSS) for outdoor navigation has become widespread in recent years. Technology and techniques of location and navigation are evolving, allowing better precision in locating people under complicated and hard settings. The scientific community is becoming increasingly interested in the application of indoor positioning systems (IPSs) with increased accuracy and decreased response times as a result of these developments (Simoes et al., 2019). Indoor navigation is the activity of navigating to specific locations in indoor environments by users (e.g., robots, humans, or drones). Many scholarly articles have been written on indoor navigation, including positioning and mapping methods, user interface design, and practical applications in fields like medicine, retail, and the arts.

Weiseman (1981) explores architectural legibility and how it affects people's ability to navigate through constructed environments. The study assesses the usefulness of various navigational aids, such as signage and landmarks, in navigating individuals across complex situations. Weisman proposes that architects should promote readability in their designs to facilitate navigation and avoid user disorientation. The research sheds light on the significance of design and navigational aids in facilitating navigation in the built environment. Similarly, Borenstein, Everett & Feng (1996) explores the advantages and limits of dead reckoning, odometry, and landmark-based techniques and provides examples of how they might be utilized for navigation. The research also compares various mobile robot localization sensors, including encoders, accelerometers, and gyroscopes. The conclusion was made that precise and robust mobile robot positioning in complicated situations frequently involves the combination of many algorithms and sensors.

Sensor

Tracking Sensor and Machine Learning.

Glanzer & Walder (2010) proposes an indoor navigation method based on sensors that track the pedestrian's movements and magnetic field detection. Without the use of external devices, the system analyzes the data using machine learning to determine the pedestrian's location and orientation. Experiments revealed that the system was highly accurate, and it could have applications for the visually impaired and location-based services. Tóth (2016) provides a comprehensive insight to the components that comprise the ILONA system, including wireless access points, inertial sensors, and a server-side database housing map and positioning information. Sensor data was fused using a particle filter algorithm to provide an indoor position estimate for the user. The study goes on to detail the deployment and evaluation of the ILONA system in a variety of real-world indoor settings, such as a hospital, a shopping mall, and an office building. With the support of wireless access points and deep learning algorithms, Ayyalasomayajula et al. (2020) propose a system for indoor navigation that can precisely pinpoint the user's location within a building. The system gathers signal strength data from nearby access points and predicts the user's location using a convolutional neural network. A custom dataset was created for training and testing the system, and the deep learning-based system outperformed traditional methods in terms of accuracy.

Accelerometer, Gyroscope and Magnetometers.

Sensors such as accelerometers, gyroscopes, and magnetometers are proposed by Atzori et al. (2012) for use in an indoor navigation system. An indoor map is generated using image processing techniques, sensor fusion methods, and a mapping system, and the user is then given directions using this map. Carboni et al. (2015) also suggested smartphone sensor such as accelerometer and gyroscope without using Wi-Fi or Bluetooth beacons due to expensive infrastructure-based indoor navigation systems and difficult to build and maintain, making them unsuitable for many applications. Kalman filter was applied to fuse sensor data to estimate location and orientation. Jackermeier and Ludwig (2018) study the accuracy and limitations of Pedestrian Dead Reckoning (PDR), a navigation technique that involves using a combination of inertial sensors, such as accelerometers and gyroscopes, under actual situations. The performance of PDR-based systems compared to ground truth measurements obtained through manual surveys, and evaluated the effects of several factors, such as user behavior, sensor placement, and environment complexity. It has been concluded that PDR-based systems are not a one-size-fits-all solution, and future research should focus on hybrid systems that integrate PDR with other localization approaches to enable more robust and accurate indoor localization.

Smartphone Sensor.

To monitor occupants of a smart building while they are in the Texting or Pocket carrying modes, Chehreghan et al. (2023) tested a smartphone-based sensor-based indoor positioning system (IPS). Three distinct trajectories, including one that is complex and another that is rectangular, make up the system's implementation. Models based on acceleration and angle data were used to calculate an approximate stepping distance. The proposed system can improve the effectiveness and functionality of location-based services in smart buildings by better understanding the user's spatial information within the building's complex environment.

Augmented Reality

Mulloni et al. (2011) performed a research study on indoor navigation using portable devices with augmented reality and activity-based guidance with the use of Sensor fusion, activity detection, and a 3D indoor environment model. Activity-based instructions helped the user to visualize and navigate and suggested to be used in different healthcare, education, and entertainment. Koch et al. (2014) suggests combination of natural markers and augmented reality technologies as a means of indoor navigation and maintenance and argues that using natural markers for indoor navigation can be both inexpensive and straightforward and suggested that an augmented reality app supplements physical landmarks like posters and signage with additional digital data to aid in interior navigation. Koch and researchers emphasized that the proposed technology has the potential to be employed in a variety of applications to aid with indoor navigation and facility management. Huang et al. (2020) propose an Augmented Reality (AR) based system which takes snapshots of the user's surroundings and superimposes virtual navigation aids, such as arrows and instructions, on top of them to bring the user to the location of their intended destination. In addition, a unique marker system was designed to be deployed in the real world to provide more landmarks to the AR system. Verma et al. (2020) point out that the lack of natural landmarks and the increased complexity of interior environments provide challenges for conventional indoor navigation systems and suggested the system that incorporates computer vision, image processing, and augmented reality technologies to provide a dynamic way to navigate unfamiliar territory. It also included a marker system for use in the real world to serve as anchor points for the AR technology.

Rubio-Sandoval et al. (2021) presented augmented reality and semantic web technologies for mobile interior navigation. A semantic web ontology for indoor spaces, an augmented reality mobile app, a backend system that organizes data and creates navigation instructions, and a user interface that presents navigation information comprise the methodology. The semantic web ontology describes indoor things and relationships, and the mobile app uses augmented reality to guide users. The user interface clearly displays real-time navigation directions from the backend system based on the user's location and destination which gave accurate and easy-to-follow navigation instructions, indicating the viability of augmented reality and semantic web technologies for mobile indoor navigation. Wakchaure et al. (2022) presents a unique application that uses pedometer, indoor navigation, and augmented reality to propose an exit pathway with the shortest path and minimum time to its users wanting to leave a multi-storied building in an emergency. The application leverages the sensors available on a cell phone, with customized daily walking step-length assessment and emergency information, to help a well-timed evacuation operation.

Magnetic Maps

Gozick et al. (2011) propose an indoor navigation method based on magnetic field mapping. The system creates a map of the magnetic field in the environment and guides the user to their destination using a magnetic sensor, a calibration process, and a navigation algorithm. The user enters their destination, and the system generates a route based on the magnetic field map, providing visual and auditory navigation cues. The system achieved high accuracy in indoor navigation, and it could be useful in emergency response, military operations, and personal navigation.

Map-based angular motion

To determine the user's location and orientation in both indoor and outdoor environments, Kaiser et al. (2013) offer a pedestrian navigation system that relies on a map-based angular motion model. A map-matching technique is integrated into the system to further enhance the precision with which the user's location is estimated using sensors like GPS, compass, and accelerometer. The system has both visual and audible clues to aid with navigation, and the interface is straightforward. For precise indoor navigation using mobile devices, Link et al. (2013) suggest a solution consisting of a system that create a graph-based representation of the inside environment followed using the mobile device's sensors to monitor the user's position and orientation in real-time and compare it to the indoor map.

BIM and IFC

An approach for indoor navigation based on Building Information Modeling (BIM) data is proposed by Isikdag et al. (2013) which explains how to transform building information modeling (BIM) data into a navigable model by extracting geometry and topology data and augmenting it with navigation-related metadata. Iskidag & researchers elaborate on how this orientable model can be utilized to meet numerous indoor navigation needs, including but not limited to real-time positioning data, directional guidance, and wayfinding support. The paper provides a case study of the proposed strategy in action inside a hospital setting to show how easily and effectively it may help people with impairments navigate the facility. Boysen et al. (2014) demonstrated how to generate indoor navigation information from Industry Foundation Classes (IFC) files, which are commonly used in building information modeling (BIM). Boysen and researcher use the IFC files to extrapolate details about the built environment, including room dimensions, connections between spaces, and the positioning of essential elements. Based on this data, a graph-based indoor navigation model is created for subsequent route planning and orientation. The proposed method was evaluated using real-world data from several buildings, and the results show that the generated navigation information was effective for indoor navigation.

Liu et al. (2021) provide a comprehensive review of the literature on the use of IFC in indoor navigation research. According to Liu and researchers, the open standard for the exchange of building information models known as IFC can be leveraged to aid in indoor navigation by providing specifics about the indoor environment. The paper goes on to detail the benefits and drawbacks of using IFC for indoor navigation, and it concludes that this method has the potential to increase the precision and dependability of indoor navigation systems, especially in complex settings like hospitals and airports.

Image Matching

Image matching and 3D map-based indoor navigation has been proposed by Li & Wang (2014) by developing a 3D map of the indoor environment and use image matching to match user-captured photos with the map for accurate indoor navigation. The approach supports real-time position monitoring and wayfinding. The proposed strategy may improve indoor navigation, particularly in complicated indoor situations, and wayfinding.

Bluetooth Beacon

Li (2014) suggested an approach with the use of Bluetooth beacons throughout the indoor environment to provide location information and measure the user's device's distance from the beacons using the Received Signal Strength Indicator (RSSI). A least square algorithm was used to transform the distance data to 3D coordinates. The suggested technology delivers precise indoor positioning without the need for elaborate infrastructure or costly hardware, which could make it useful in several contexts, including location-based services and indoor navigation. For indoor navigation and proximity advertising, Samuel et al. (2021) detail the creation of an Android app that uses Bluetooth Low Energy (BLE) technology. Samuel and researchers first introduce the concept of BLE technology and its advantages over other wireless communication technologies for indoor applications. They then describe the design and implementation of the Android application, which uses BLE beacons placed at various locations within a building to provide indoor navigation guidance to users. Proximity advertising, in which users see ads that are relevant to them based on their location and previous web history, is also discussed in the paper.

Linked Data

According to the Szász et al. (2016), traditional indoor navigation systems are not interoperable, making data sharing between systems and applications difficult and proposes a method for developing indoor navigation services that uses Linked Data to standardize and interoperate indoor navigation data The proposed method entails developing a Linked Data model for indoor navigation data such as building layouts, points of interest (POIs), and navigation paths. A RESTful API for accessing and querying the Linked Data model was also being developed.

Triangulated Irregular Network and Graph

The research suggested by Xu et al. (2016) utilizes a Triangulated Irregular Network (TIN) to generate graphs and crowd simulation to create indoor evacuation routes. Laser scanning point cloud data was used to create an indoor TIN model. The TIN model generates evacuation routes by graphing the indoor environment. Crowd simulation was used to predict evacuee behavior and plan evacuation routes to reduce congestion and ensure safe and efficient evacuation.

Voice Technology

Accessible routes for people with disabilities are described in detail in the study article by Harriehausen-Muhlbauer (2016), who details how the "Wheelscout" mobile navigation app makes use of voice technology. The paper explains the architecture of the software, which uses speech recognition to accept navigation orders through voice and calculates barrier-free routes based on variables such as accessible sidewalks, ramps, and elevators. According to the study's findings, the app's built-in voice technology is a useful tool for facilitating barrier-free navigation for individuals with impairments, and that additional advancements in speech technology could improve accessibility and usability.

Semantic Model and Dijkstra's Algorithm

Using an indoor ontology and Dijkstra's algorithm, Yuan et al. (2019) proposes a system for indoor navigation in multi-level buildings using the indoor ontology to define spatial relationships and infer semantic relationships between different areas of the building. Dijkstra's algorithm was used to calculate the shortest path between the current location of the user and the desired location, considering semantic relationships. The system included a user interface that displays building maps and navigation instructions.

Image Processing and Machine Technology

Birla et al. (2020) introduces a mobile application that utilizes a mixture of image processing and machine learning algorithms to help users navigate cluttered indoor spaces. It takes pictures of the user's surroundings and uses image processing to figure out what things like walls, doors, and landmarks are. The user's location is then predicted using machine learning algorithms and they are directed to their destination.

5G Based

A pilot experiment called L5IN was carried out by Schuldt et al. (2021) using a 5G-powered, smartphone-sensor-based indoor navigation app for pedestrians that eliminates the need for traditional infrastructure. Beginning with a survey of the building and processing of current construction plans, the project intends to develop an autonomous application for internal navigation. With sensor fusion, 5G network signals, and architectural plans, precise location can be determined; the next stage in fusing BIM and 5G is real-time 3D navigation. Schuldt and researcher emphasize 5G's potential for delivering indoor location and navigation data in contexts where infrastructure-based approaches may fail due to multipath propagation and non-line-of-sight reception.

3D Scan of Building

In recent years, there has been a surge of interest in the development of 3D models for use in a variety of contexts, including but not limited to video games, virtual, augmented, and mixed reality, 3D GPS navigation, solar potential analysis, and 3D Geographic Information Systems. Ninety-five percent of respondents to a survey conducted by the European Organization for Experimental Photogrammetric Research said they were most interested in seeing building information in 3D within city models (Fuchs et al. 1998). In recent years, there has been an exponential increase in the demand for photorealistic three-dimensional models of buildings (Wang et al. 2011). Both Stamos and Allen presented a common ground-based LiDAR-based 3D building modeling (2002). This is a bottom-up method that computes and classifies points using principal component analysis (PCA), cluster merging, surface fitting, and boundary extraction. Principal component analysis is used (PCA).

A 3D scanner is a way for capturing the exact size and shape of a real thing as a computer-stored 3D digital representation. It does this by generating "point clouds" of data from the surface of an object, which are collections of individual data points.

(RapidForm, 2012). Objects can be brought into a virtual workroom via a 3D scan, thereby ensuring their physical integrity. It is also possible to perform quality control checks during the physical restoration and reverse engineering processes with the help of such scans [Wachowiak & Karas, 2009; Vilbrandt et al., 2011).

There is a growing demand for 3D spatial information about indoor environments in a variety of applications, including risk and disaster management, human trajectory identification, and facility management. The development of more advanced hardware, software, standards, methods, and applications specifically for indoor modeling and mapping has resulted from scientific and technological advancements in 3D spatial data acquisition and 3D city and building modeling (Gunduz, Isikdag & Basaranera, 2016). According to Meouche et al. (2013), acquired data from sensors can help create semantically rich digital building models and models like BIM. In order to create 3D geometries that would serve as the foundation for a BIM, Yoon et al. (2015) used point clouds produced by laser scanners. In order to create accurate reconstructions of indoor spaces, also known as digital twins, that are suitable for application use, it is necessary to have accurate data in the third dimension (3D) (Lehtola, Nikoohemat & Nüchter, 2020)

Digital Twin

In addition to the emergence of novel economic models like the sharing economy, driverless cars, digital currency, and savvy marketing, there has also been a rise in interest in forward-thinking concepts like ecological preservation and health care. The rapid development of the Internet, big data, Artificial Intelligence (Artificial Intelligence), blockchain, the Internet of Things (IoT), and 5G wireless technologies is the backdrop against which all of this is taking place. (Deng, Zhanga & Shenab, 2021). The process of digital transformation will inevitably result in the creation of a digital twin of the organization. Professor Grieves of the University of Michigan's product lifecycle management department first introduced the idea of a digital twin to his students in 2003. Digital twins consist of real-world and digital products, as well as the links between them. The term "digital twin" refers to an electronic representation of a physical object that is identical to the original in every way possible (Grieves and Vickers, 2017)

Rustinov & Sorokin (2015) describes a strategy for identifying the most suitable technology for constructing an indoor localization and tracking system. Rustinov & Sorokin argue that there are numerous technologies available for indoor localization, including Wi-Fi, Bluetooth, RFID (Radio Frequency Identification), and ultrasound, and that picking the most suitable technology for a given application might be difficult. An approach was proposed to evaluate the accuracy, range, and scalability needs of the application with the strengths of the existing technologies. Rustinov & Sorokin detail how the systems were assessed using characteristics like precision, range, scalability, cost, and maintenance simplicity. The proposed method entails a thorough examination of the application requirements as well as an assessment of the capabilities of the available technologies.

Even though GPS is the primary solution for outdoor positioning, no distinctive solution for indoor positioning has emerged despite the business enormity. In recent years, the application of methods for indoor localization has developed into an increasingly critical component in an extensive variety of uses and environments, such as human services, homecare, checking, following, and numerous other applications. The field of Indoor Positioning systems and conditions has garnered a significant amount of attention and investment from both academics and organizations (Dhobale et al., 2019). The Indoor Positioning zone is packed to the brim with important commitments. Hence, the author of this research explores the usage of 3Dscanningn of real environment, digital twin, computer vision and augmented reality in indoor navigation in RFM building during emergency.

III. RESEARCH METHODOLOGY

Research Strategy and Methods

Prior to choosing the research design, methodology, and instruments/methods to be employed, the Author first devised a strategy for carrying out the study based on the research problem stated in the introduction.

The logical, methodological framework with all the research steps taken to in this research is performed based on Figure 3.1.

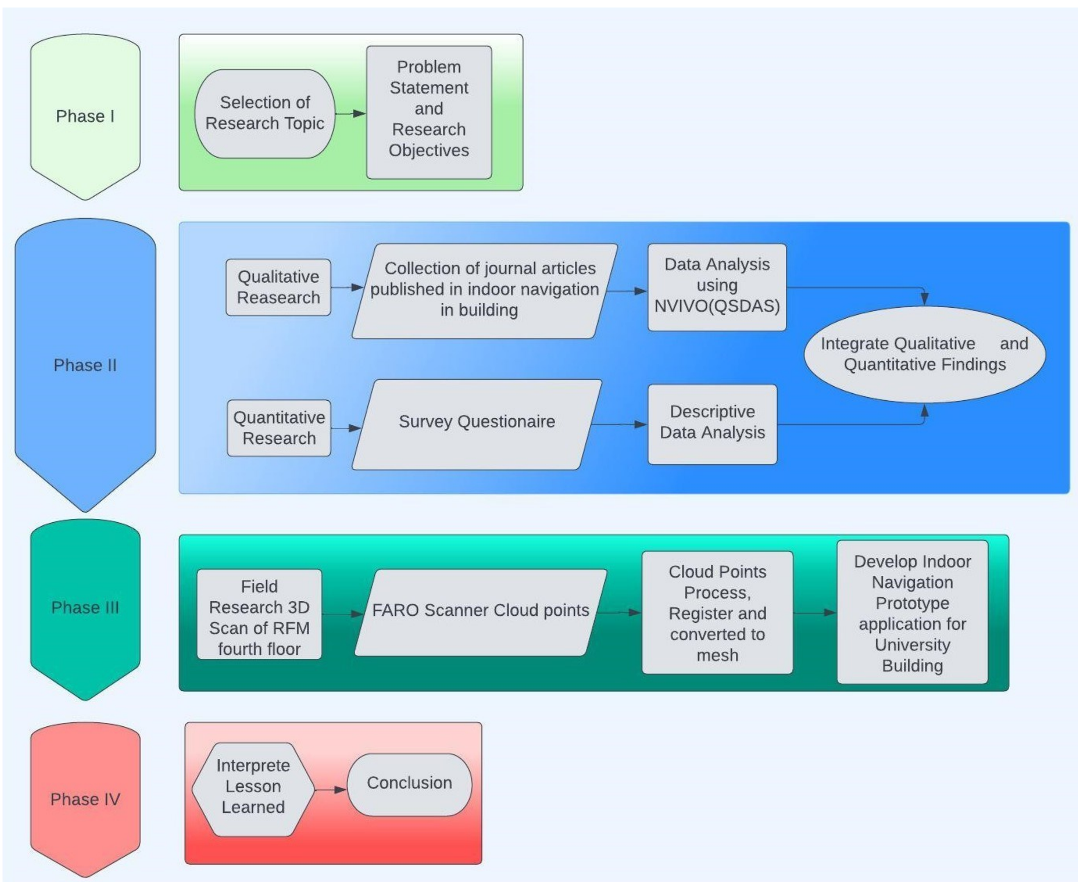


Figure 3. 1

Research Methodology

Figure 3.1 shows that the research was performed in four phases. In the beginning, the research problem was identified based on literature review. To fulfill the requirement of the degree, the research is performed with multiple methods such as qualitative and quantitative. Qualitative research was performed for systematic literature review. The Author used Qualitative data analysis software (QDAS) to assess those journals' articles for the next step of the research. QDAS helps researchers interpret qualitative data analysis. While there are several qualitative data analysis programs out there, the author used NVivoTM for this study because of its widespread use in academic institutions. QDAS software NVivo allows users to graphically represent and capture new findings in the text. This shows literature gaps (that is, areas in which not much research has been done). This method makes it easy to store and analyze field literature (Shenton, 2004).

Further, quantitative research was performed to know the awareness of the indoor navigation and its benefits in the RFM building during emergency. Considering the findings of both qualitative, as well as quantitative research, Phase III was performed to survey the RFM building fourth floor. Then a prototype indoor navigation application was developed to navigate in various locations. At the final phase, the data was interpreted for lesson learned and a conclusion was made.

Data Collection

At first a qualitative research method has been utilized which involves the systematic literature review of indoor navigation and the technology that has been utilizing for the indoor navigation. The author used article galaxy as a search tool for journal articles. The Article Galaxy Search is a crossref based simple search that includes over 130 million records from hundreds of publishers throughout the world. The information contained in this database comes from a wide range of disciplines, including medicine, technology, the life sciences, the chemical sciences, the physical sciences, and more (Article Galaxy, 2012). Further, to minimize and filter the article, google scholar has been used to search appropriate article. The keyword “Building+Indoor+Navigation” has been utilized to search appropriate journals and time of publication was set as 2010 to 2023. The articles searched in both Article Galaxy Search tool and Google Scholar have been compared for better results.

The author utilized quantitative research method with survey instrument to collect responses of the students who either have classes or labs in the RFM Building. They were asked to participate in this study as research subjects. As per Institutional Review Board (IRB) rule, any human and social research shall be approved by the IRB board. The research, IRB#8567, (Appendix A) has been approved by the Texas State IRB. An online questionnaire (hosted by Qualtrics Texas State University) (Appendix B) was designed for conducting the survey. There were 14 questions and students took 5 minutes to complete those questions online. Emails were sent to all the students to participate in the survey. Further flyers with the QR scan code (Appendix C) were placed in the designated place to invite students to take part in the survey.

As detailed in Figure 3.1 phase III was performed through field survey scanning the fourth floor of the RFM building using a FARO scanner to create a virtual 3D building as shown in Figure 3.2. The cloud points were collected from the fourth floor of RFM building.

Figure 3.2

Faro Scanner

Figure 3.3

3D Scan of RFM Building by FARO Scanner

Figure 3.2 shows Faro Scanner S70, the main instrument to scan 3D of the RFM building and collect cloud points and panorama images. The collected data cloud point was registered in FARO scene software to create 3D virtual model of the building. To cover the fourth-floor walkaway only the Scanner was shifted to 19 position and all cloud points were taken from those positions and in total 429,314,675 points cloud was collected. Figure 3.4 below shows the panorama images collected from 19 station points of Faro Scanner.

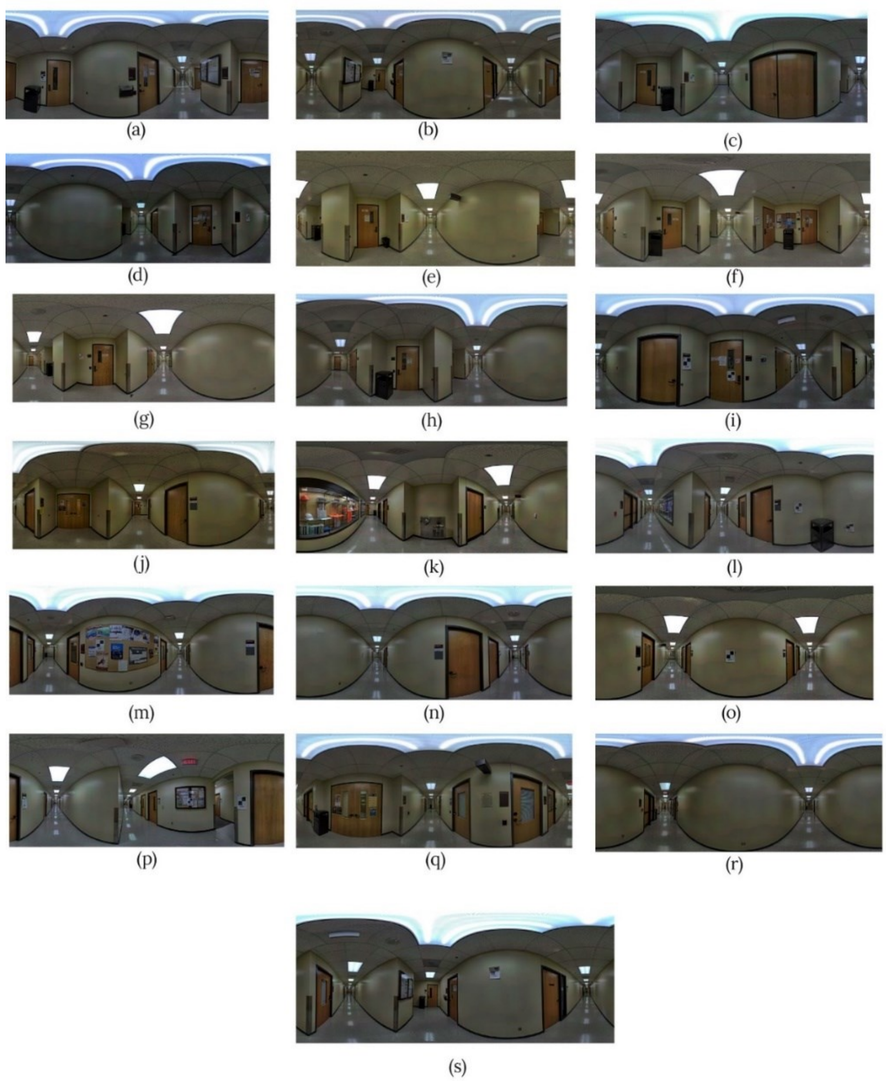


Figure 3.4

Panaroma Images at Different Scan Position

IV. Result and Data Analysis

Phase II

Qualitative Analysis

A systematic literature review of indoor navigation involves evaluating and synthesizing previous research on the topic. The objective is to identify patterns, trends, and gaps in the literature and provide a comprehensive overview of the current state of the art in indoor navigation. A review is characterized by a systematic search of the scientific literature employing defined inclusion and exclusion criteria, followed by a structured analysis of the selected studies. Journal articles on indoor navigation discuss positioning and mapping, user experience and interaction, and application in healthcare, retail, and museum. Indoor navigation publications are published in the Journal of Location Based Services, International Journal of Geographical Information Science, Journal of Sensors, Journal of Navigation, Journal of Ambient Intelligence and Humanized Computing, and Journal of Mobile Information Systems. Table 4.1 shows the number of articles that have been published based on the Article galaxy in different years.

Table 4.1

Number Of Publication in Different Journal (Article Galaxy)

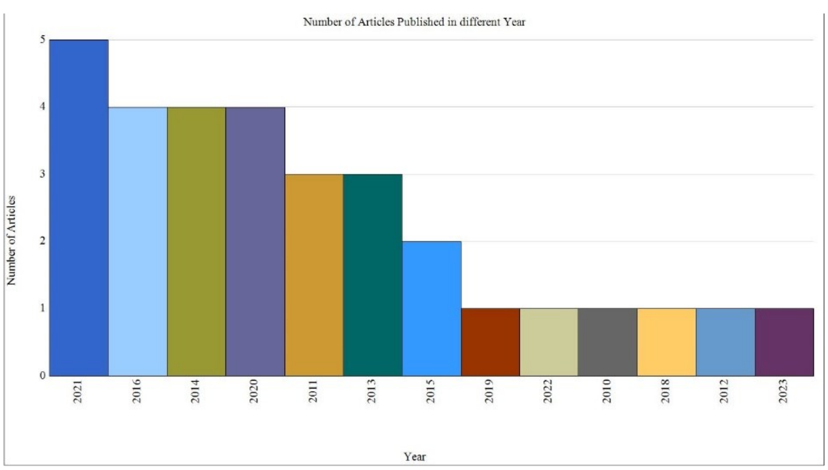
S. N.	Time of Publication	Field of Study	Number of Publication
1.	Up to date	All Field	34,600
2.	2001 to 2022	All Field	29,100
3.	Last 10 years	STEM	12,100
4.	Last five years	STEM	6470
5.	Last year	Engineering	44

The study of indoor navigation is expanding all the time, as Table 4.1 demonstrates, and the journal that contains the word "indoor navigation" has been published in a variety of different subjects. In addition, the targeted search was conducted in Google Scholar, and the result showed that there were 44 journals and conference papers related to the topic. The author carried out an in-depth review of those publications and then chose 31 articles that were directly relevant to the research for the thesis.

The number of publications that are connected to the concept of indoor navigation and the technologies that have been employed for wayfinding and localization are displayed in Figure 4.1. The number of publications is arranged in descending order by the most recent publication count. It can be observed from the chart that the year 2021 had the maximum number of publications, which was 5, and that the years 2010, 2012, 2018, and 2019 had the lowest number of publications.

Figure 4.1

Number Of Journal Articles Published (2010 To 2023)



According to the findings of the literature research, several technologies have been employed to assist people in navigating their way through the inside of buildings. It is important to have a good grasp on both the system for indoor navigation and the technologies that can be used for it. Figure 4.2 shows that a word cloud was made in NVIVO word search query feature to find the most frequently used words and phrases related to indoor navigation. In order to do an analysis of the word frequency, the number 500 was used for a minimum of six characters. The act of converting unstructured material into a format suitable for structured data makes it possible to recognize major patterns and gain valuable insights.

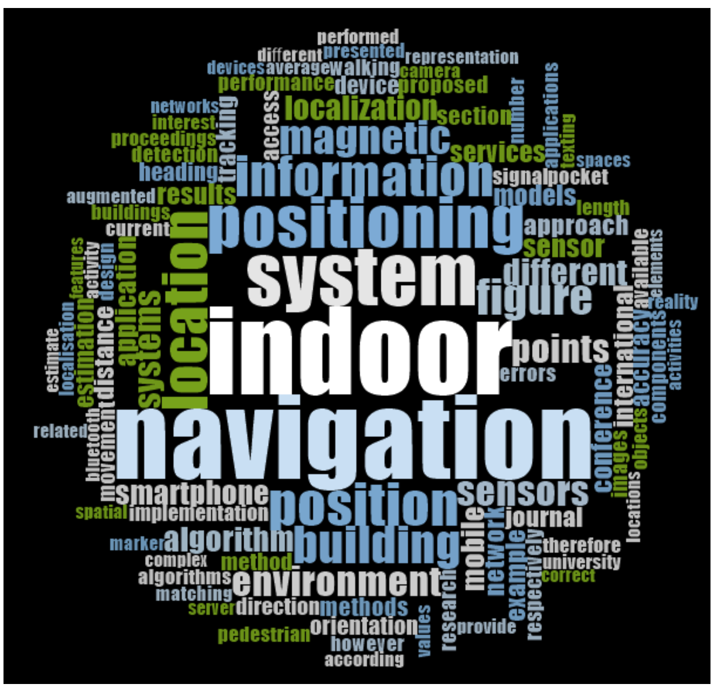


Figure 4.2

Word Cloud of Indoor Navigation

From research into the relevant literature, author learned that many different technologies have been looked at to see if they could be used in the field of indoor navigation. The coding was created with the technology that is accessible within NVIVO, and a hierarchy chart wizard was developed. Figure 4.3 presents an illustration of the many different technical developments that have been included in indoor navigation. Figure 4.3 displays the distribution of research platforms used by academics during the past few years. The vast bulk of this study was conducted using smartphones with sensors and augmented reality headsets. When it comes to finding your way around an indoor space, magnetic maps, linked data, and semantic maps aren't exactly the go-to options.

Figure 4.3

Hierarchy Chart Wizard of Different Technology Applied for Indoor Navigation

A comparative chart diagram with the number of publications is made for sensor and augmented reality. This can be seen in Figure 4.3, which shows that sensors and augmented reality are most commonly used in indoor navigation. The data presented in Figure 4.4 reveals that the field of developing indoor navigation has seen publication in a total of seven publications dealing with augmented reality and eight journals dealing with sensors.

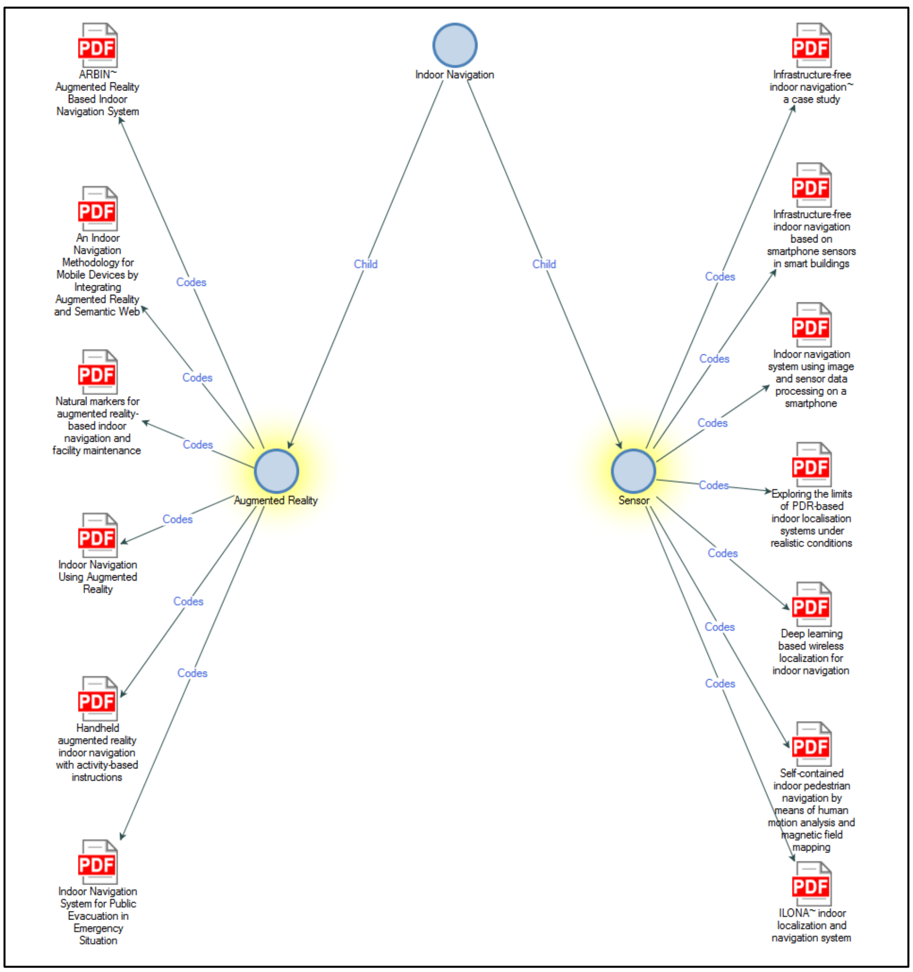


Figure 4.4

Comparative Chart Diagram of Augmented Reality and Sensers

Quantitative Analysis

In addition, a quantitative survey (Appendix B) was carried out by means of Qualtrics to examine the levels of difficulty and knowledge exhibited by the students with regard to indoor navigation and the digital twin. The results of the survey are offered in the form of descriptive statistics on respondents' demographic information, as well as their level of awareness regarding indoor navigation in RFM buildings and their level of knowledge regarding digital twins. The author received a total of 67 responses, of which 63 were considered complete and therefore included in the data utilized for the analysis and results of this study.

Demographic Response.

Thirty percent of the respondents (19) were at the senior level, twenty-six percent (16) were at the master's level, sixteen percent (10) were at the junior level, thirteen percent (8) were at the sophomore level, eleven percent (7) were at the freshman level, and three percent (2) were at the doctoral level. Figure 4.5 illustrates that most of the participants' major degree is in Construction Science and Management.

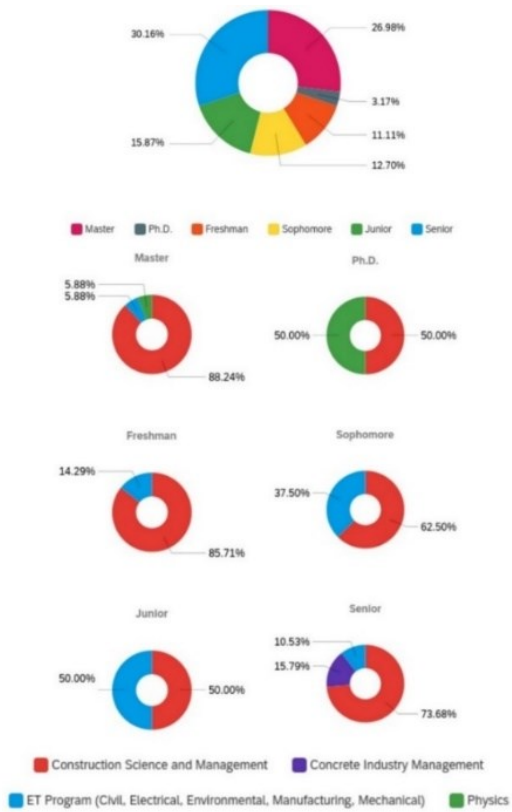


Figure 4.5

Respondent's Major Degree and Study

Also, the students were asked how long they spend in RFM classrooms and how many times they move from one classroom to another during the day. 43 percent of students attend classes for four days, whereas 31 percent attend classes for two days, as shown in Figure 4.6.

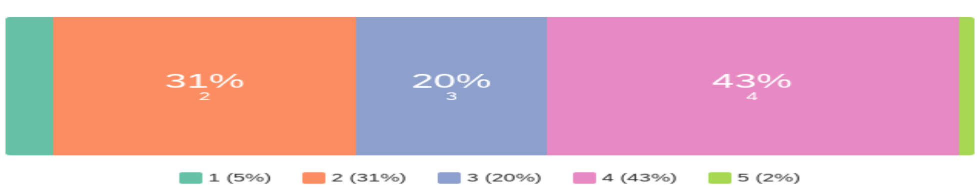


Figure 4.6

Respondent's Classes in a Week

Similarly, Figure 4.7 shows students who have classes for two, three and four days often change classes and most of the students have to change two times per day.

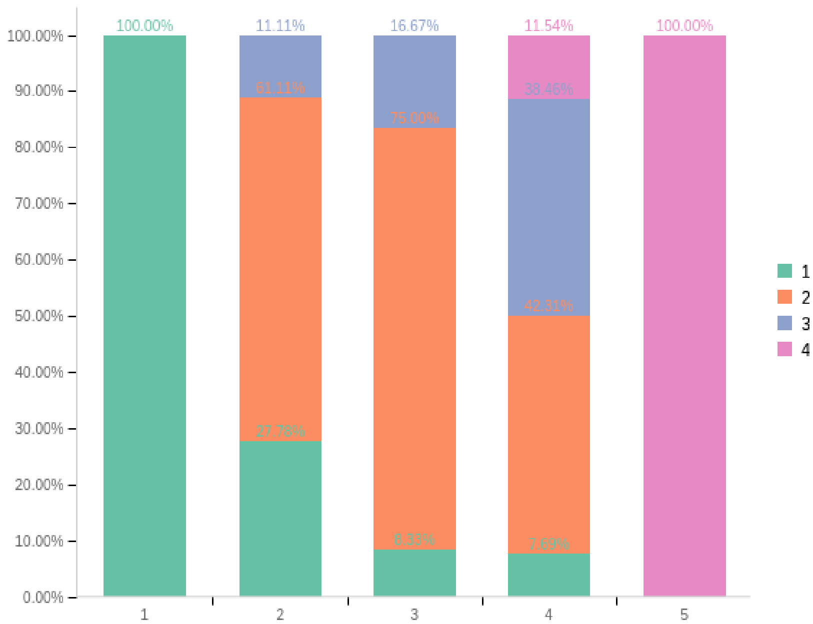


Figure 4.7

Number Of Classes Change in A Day

Students' Wayfinding Difficulty and Accuracy Level.

The students were asked how difficult they believed it was to find their classes in the RFM building during the first week of the semester, as well as after four weeks of attending classes there. Table 4.2 shows that 38 percent of respondents thought it was pretty hard, while 34 percent thought it was pretty easy. Also, 72 percent of the people who answered the survey said that it was easy for them to find lessons in the RFM building after four weeks.

Table 4.2

Difficulty Level of Respondent's Finding Classrooms

S. N.	Difficulty Level	In your opinion, how easy was it to find your classrooms during the first week of a semester in the RFM building?	In your opinion how easy was it to find your classroom after 4 weeks in the RFM building?
1	Extremely difficult	4.84%	0.00%
2	Somewhat difficult	38.71%	12.90%
3	Somewhat easy	33.87%	14.52%
4	Extremely easy	22.58%	72.58%

Students also inquired as to how well they knew where the stairwell and elevator were in the building, both for routine use and in the event of an emergency. Table 4.3 shows that about 60% of respondents can find the exit and 56% can find the stairs or elevator that led to the classroom. This table shows that 40% of the people who answered the survey have trouble finding the stairs or elevator to get to class or leave the building.

Table 4.3

Accuracy Level of Respondent's Locating Nearest Staircase

S. N.	Accuracy Level	In your opinion, how accurately you would locate nearest staircase/elevator to attend your classroom or lab in the RFM building?	In your opinion, how accurately you would locate nearest staircase/elevator to exit from the RFM building?
1	Not accurately at all	3.23%	3.23%
2	Slightly accurately	40.32%	37.10%
3	Very accurately	30.65%	32.26%
4	Extremely accurately	25.81%	27.42%

Student's Awareness in Indoor Navigation and Digital Twin.

Most of the information in this section is about the students who were already familiar with the ideas of indoor navigation and digital twin. According to the information in Table 4.4, more than half of the respondents (56%) have never heard of interior navigation before, while only about 5 percent say they are familiar with it.

Table 4.4

Respondent's Familiarity with the Indoor Navigation Application

S.N.	Familiarity	How familiar are you with the indoor navigation application?
1	Not familiar at all	56.45%
2	Slightly familiar	24.19%
3	Very familiar	14.52%
4	Extremely familiar	4.84%

They were likewise questioned regarding their familiarity with the term "Digital Twin". According to Table 4.5, more than 81 percent of respondents are unfamiliar with the phrase, whereas only 19 percent are aware of the phrase.

Table 4.5

Respondent's Awareness with Digital Twin

	Awareness	Are you aware of the phrase "digital twin"?
1	No	80.95%
2	Yes	19.05%

Effectiveness of indoor navigation mobile applications

With the students, it was queried about how helpful it would be to have a mobile app like Google Maps for finding your way around inside. Figure 4.8 displays that 74%

of respondents think indoor mobile navigation would be useful. Considering these findings, it is clear that there will soon be a demand for indoor navigation software.

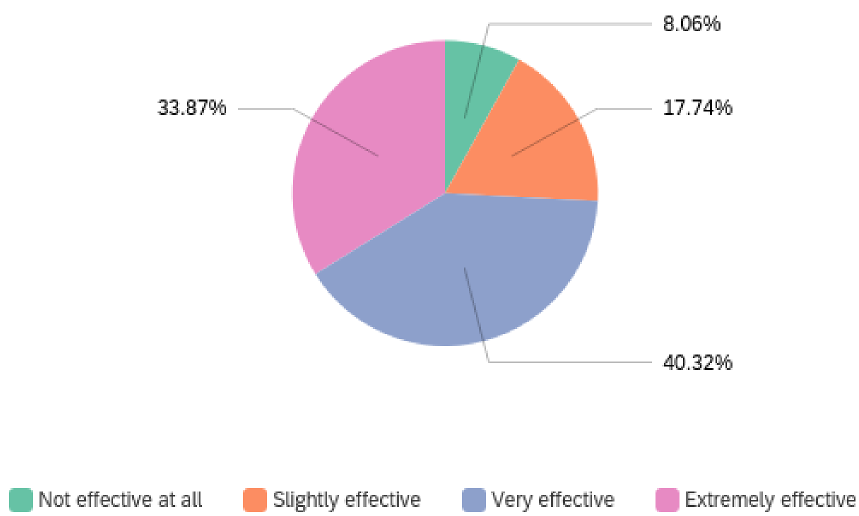


Figure 4.8

Effectiveness of Mobile Application like Google Maps

Also, information about the "digital twin," "interior navigation," and "indoor position" was included in the Qualtrics form to let people know how these things could help in an emergency when trying to find your way around a big building. Table 4.6 shows that almost half of the people who answered like to use indoor navigation to find their classroom, and 40 percent like to use it to find their way in an emergency. It also shows that still five percent and eight percent of respondents do not choose to utilize in order to identify classrooms or laboratories or for navigation purposes during times of emergency, respectively.

Table 4.6

Respondent's Frequency of using Indoor Navigation

S.N.	Frequency	Based on the Digital Twin information provided, how likely will you prefer to use indoor navigation to locate your classroom/lab?	Based on the Digital Twin information provided, how effective would it be to navigate the exit during a fire and any emergency?
1	Extremely unlikely	4.76%	7.94%
2	Somewhat unlikely	7.94%	20.63%
3	Somewhat likely	36.51%	31.75%
4	Extremely likely	50.79%	39.68%

Phase III

RFM fourth floor building 3D Model

The data from the 19 raw scans that were collected by 3D scanners were imported into Faro Scene, where they were preprocessed, registered, the results of the registration were validated, post-processed, and analyzed, 3D models were created, reports were generated, and the data was exported to a variety of formats. A variety of techniques, including feature extraction, matching, and optimization, were utilized in order to successfully align the several scans that were going to be combined into a single, seamless 3D model.

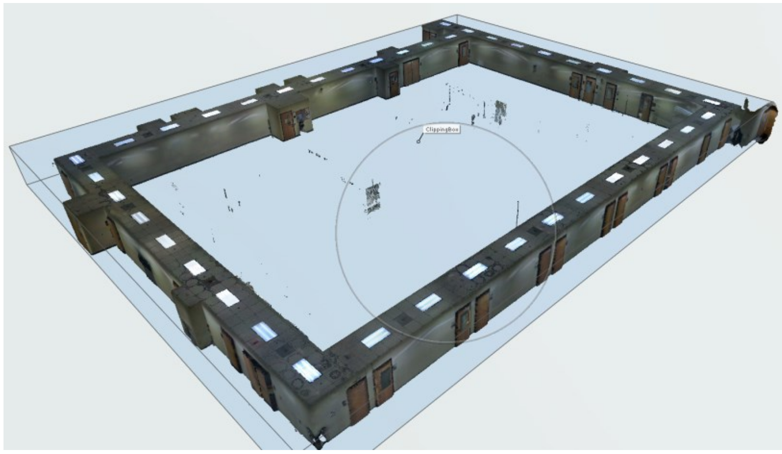


Figure 4.9

Processed and Registered RFM Fourth floor 3D Model

The registered 3D model was then exported into several different file types, such as e57, rcs, wrl, dxf, fls, pts, ptx, las, and spw. The RFM floor was exported as an e57 file and a las file so that a mesh could be created using the observed scan and the point cloud files. The Autodesk Recap software was used to perform the processing on the exported e57. Figure 4.10 illustrates the 3D model when it is in the X-ray mode, which enables the user to delete any unneeded point files and identifies the areas of the structure that need additional points so that a mesh may be created.

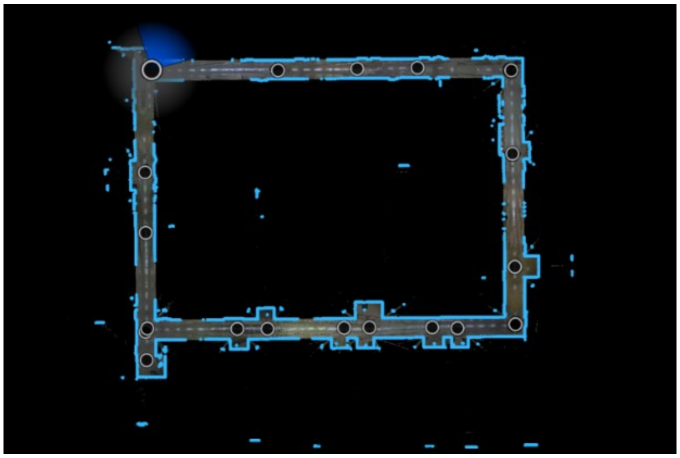


Figure 4.10

Smooth 3D model in Autodesk Recap

The Autodesk Recap helped to filter and remove the unwanted cloud points which were observed through glass on the door and windows. Filter 4.11 shows the Smooth model after removal of unwanted cloud points.

Figure 4.11

Scan Model in Autodesk Recap

Mesh models are essential to convert 3D models into BIM models or objects to be used in Unity. In the market there are different software tools that can create mesh models from the point cloud model. In this research different mesh models were created using software tools such as Faro Scene, and Pointfuse. Figure 4.12 shows the mesh model created by Faro Scene which shows that the structure is not clear as seen in real structure.

Figure 4.12

Mesh Model Created in Faro Scene

Figure 4.13 shows the mesh model created by Pointfuse which is better than that created by Faro Scene. Further, Figure 4.14 shows the wireframe with the Mesh which defines how the surface model is created from the cloud points captured by the Faro scanner.

Figure 4.13

Mesh Model Created in Point Fuse

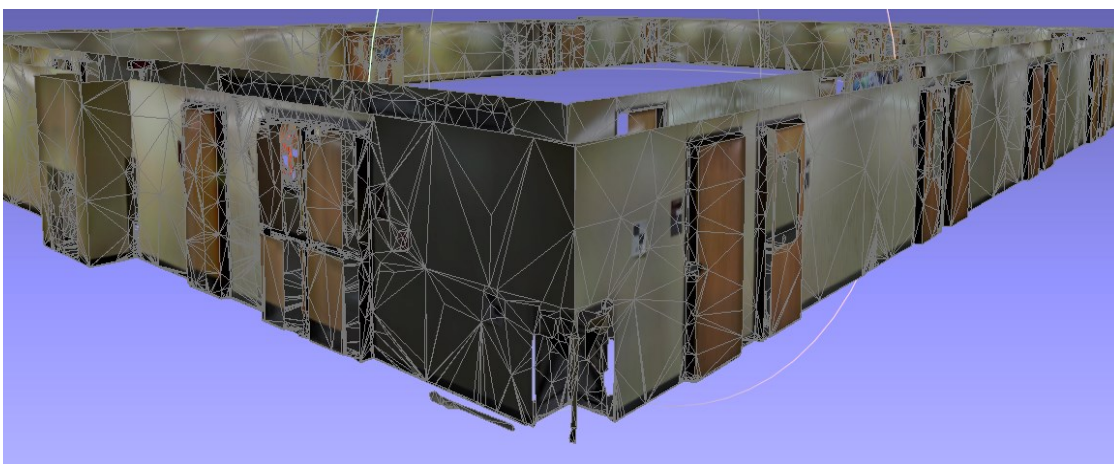


Figure 4.14

Wireframe with Mesh Model

Development of Prototype Indoor Navigation

A literature review and qualitative analysis demonstrate that many types of technology have been put into use in a variety of indoor settings. Different fields are doing research right now to try to come up with solutions that are better than what

Google Maps offers. The author of this study utilized SLAM (Simultaneous Localization and Mapping), VISLAM (Visual-inertial SLAM), augmented reality frameworks such as ARCore, and the Vuforia area target generator.

With the help of advancements in image processing technology, computer vision is an intriguing new alternative to traditional methods of finding things inside buildings. SLAM is a technique that defines a process called simultaneous localization and mapping, which involves the concurrent and real-time generation of a point cloud map of the environment and the approximation of a spatial position within this map. ORB-SLAM is a method that enables localization to be completed by comparing high-contrast spots in the environment that is around the subject. In order to accomplish this, two-point clouds are required. One is constructed at the same time that a real-time scan of the surroundings is being carried out, and the other is made afterward. It is possible to identify the position of something by comparing the distances between the spots on two different clouds. (Mur-Artal, Montiel & Tardos, 2015)

With the assistance of the Leica Cyclone REGISTER 360 PLUS, the scan that was captured by the Faro Scanner model is transformed into a Vuforia support e57 file. In order to generate an area target with Vuforia, the converted file was first submitted into the Vuforia Area Target Generator. The mesh model and the Area Target were brought into Unity by the import process. For the purpose of this app prototype, the floor of the model was chosen to serve as the area target. The Area target was placed appropriately in accordance with the data model, and its position in the model's pathway was maintained.

Unity components such as "NavMesh" and "NavMeshAgent" were implemented in order to locate the path within the application. When a NavMesh is established, it serves as a stand-in for the surface along which a human being can walk, and a NavMeshAgent represents the individual who is walking along this surface in the direction of some preset objective. Both of the components have a comprehensive selection of modifiable parameters, which enables a variety of simulation scenarios to be developed. The prototype built a NavMesh to cover the region that was available by making use of the area target meshes that were imported. Using Dijkstra's Algorithm, the NavMesh feature of Unity automatically determines the shortest path from the location of the device's camera to the intended destination. This calculation is performed in real time. At long last, information obtained through augmented reality was incorporated into the area targets.

The research had several limitations, so the part of the simulation that needed to be done in Unity couldn't be done. The process, on the other hand, was sped up collaborating with INDOAR viewAR. The Unity SDK file that was supported by Unity was gathered, and a mesh model of an RFM building that included an area target feature was imported into the Unity SDK. Following that, an automatic simulation feature was developed in order to construct a prototype app for interior navigation. The prototype of the smartphone application is shown in front view in Figure 4.15(a). Students are given the ability to search many locations within the prototype application thanks to the interior navigation capability. Also, the view that appears when you press the indoor navigation button in the front view of the mobile application may be seen in Figure 4.15(b). The query for the area target that has been set as the corridor of the floor is displayed on the little mobile icon. For the purpose of localization, the mobile was moved toward the corridor. Figure 4.15(c), which displays the option to choose the location of the fourth level, can be seen once the localization process has been completed. The only destination that was set to check for the prototype was number six.

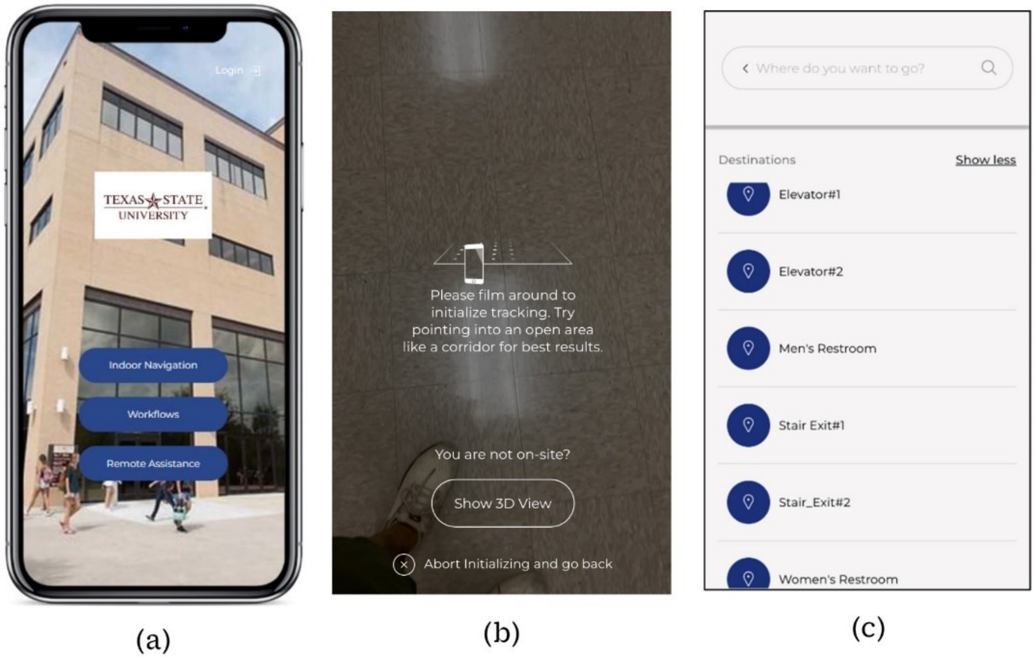


Figure 4.15

Prototype Mobile App View

To validate the prototype application, the author selected destination Elevator#1 from the search page labeled "where do you wish to go?". Figure 4.16 illustrates how the program might provide augmented reality (AR) blue lines to guide users to their destinations. Figure 4.9 illustrates that the distance from the current position to the distance shown at the bottom of the screen decreases from 48 meters to 24 meters to 7 meters to 2 meters. This information is provided by the prototype. When the site is close by, it also displays the location's name at the bottom of the screen. In the demonstration, this name is Elevation#1.

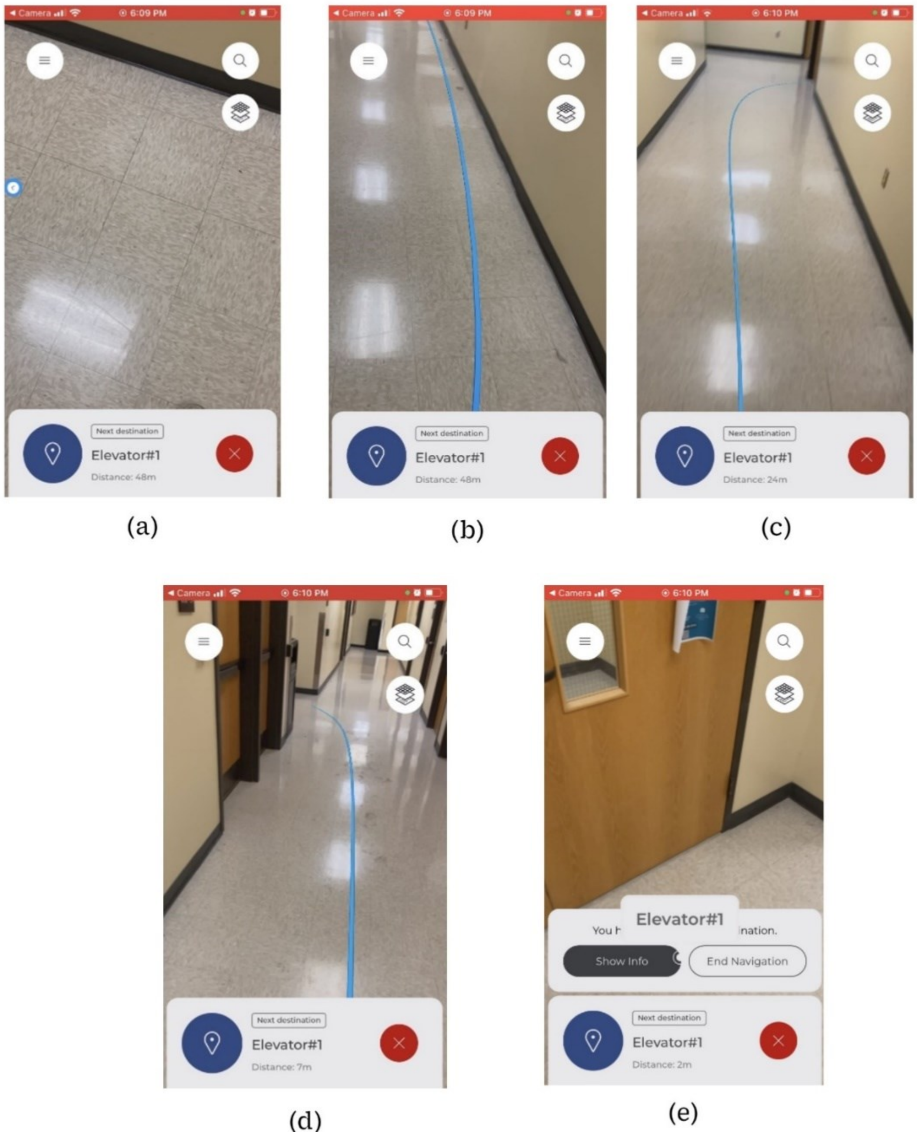


Figure 4.16

AR Direction Towards Selected Destination

From the demonstration it has been observed that it worked well for the fourth floor. Every floor of the RFM building is almost the same hence the app was tried on the 2nd floor of the RFM building. However mobile app did not recognize the floor and localization did not occur.

V. Lesson Learned

The systematic literature review in indoor navigation undertaken in this research offered knowledge regarding patterns, trends, and gaps in the literature, as well as a thorough summary of the state of the art in indoor navigation. Furthermore, it has come to light that the IEEE, the professional home for the engineering and technology community worldwide, has been organizing annual conferences on the topic of "International Conference on Indoor Positioning and Indoor Navigation (IPIN)" since 2010.

In the market there are different 3D scanner devices to capture real environment and convert it into the virtual environment. Choosing the right device which is compatible to generate area target to capture images of natural features is important. Further, the software compatible with the devices never provides satisfactory result for example mesh created by FARO scene was not clear to be used in Unity.

During the demonstration of application, it has been observed that the direction line, blue line, used to fade and come. It has been learned that those faded lines happened due to missing cloud points during the scan. The blue dark dot points in figure 4.10 show that enough number of cloud points to create proper mesh whereas some spacing between those blue points create cloud points taking far points which shows no lines. Hence, it has been observed that the station's location should be closed as far as possible to collect the proper number of cloud points.

VI. Conclusion and Discussion

The systematic review shows that different technology has been applied to indoor navigation. Researchers have used different technology to figure out where things are and how to get around inside. Researchers highlighted a few important parts of a typical indoor navigation system which include the cost of implementation, how easy it is to use and install, and how efficient, accurate, and portable it is.

This research has demonstrated the feasibility of using an augmented reality (AR) indoor navigation software in a university setting. The localization is accomplished by employing point clouds that have been taken from a previously scanned area. It has been demonstrated that extremely precise localization is achievable by making use of the area targets that are provided by Vuforia.

Based on the results of the usability test, employing visual cues like a line, sound, and place name at the destination is a highly natural way to navigate, but there are still a few modifications that need to be performed before it can be used at the university.

The prototype provides a good basis for mapping further use cases. For example, new students who can independently search for the nearest exit and are directly navigated there.

The result of the survey shows that the few respondents felt difficulty in locating classrooms and exits and were willing to use application if provided in the future.

VII. Limitation of the Research

Every research has its own limitations due to certain circumstances. This research also consists of limitations which are described in detail in further sections. One of the major limitations of this research is it focuses on the fourth floor of RFM building only. During preparation of this research proposal, it was planned to scan the whole RFM building. When the 3D survey was performed of fourth floor plan, the cloud points collected were huge and it took many hours to process in the computer. Hence, due to limitation of the computer processor, the author decided to limit this research within the fourth floor instead of the entire RFM building.

Further, the questionnaire survey was sent through email to all the students of the RFM building, which is about 900 students, but only 67 responses were collected even though the survey was open for four months. Hence, the result of the questionnaire cannot be generalized.

APPENDIX SECTION

APPENDIX A: APPROVAL PACKET OF IRB#8567

TEXAS STATE UNIVERSITY

The rising STAR *of Texas*

In future correspondence please refer to 8567

October 31, 2022

Sushmit Sharma Bhattarai
Texas State University
601 University Drive.
San Marcos, TX 78666

Dear Sushmit Sharma, Bhattarai,

Your application titled, 'Exploring the usage of 3D scan and digital twin in indoor building navigation during emergency." A study over how motivations on dating apps affect intimacy and self-disclosure." was reviewed by the Texas State University IRB and approved. It was determined there are: (1) research procedures consistent with a sound research design and they did not expose the subjects to unnecessary risk. (2) benefits to subjects are considered along with the importance of the topic and that outcomes are reasonable; (3) selection of subjects is equitable; and (4) the purposes of the research and the research setting are amenable to subjects' welfare and produced desired outcomes; indications of coercion or prejudice are absent, and participation is clearly voluntary.

In addition, the IRB found you will orient participants as follows: (1) Signed informed consent is not required participation implies consent. (2) Provision is made for collecting, using, and storing data in a manner that protects the safety and privacy of the subjects and the confidentiality of the data; (3) Appropriate safeguards are included to protect the rights and welfare of the subjects; (4) Participants will not receive compensation.

This project was approved at the Exempt Review Level

Check the IRB website frequently for guidance on how to protect participants. It is the expectation that all researchers follow current federal and state guidelines.

The institution is not responsible for any actions regarding this protocol before approval. If you expand the project at a later date to use other instruments, please re-apply. Copies of your request for human subject's review, your application, and this approval are maintained in the Office of Research Integrity and Compliance.

Report any changes to this approved protocol to this office. Notify the IRB of any unanticipated events, serious adverse events, and breach of confidentiality within 3 days.

Sincerely,

Kaitlenn Ledford

Kaitlenn Ledford
IRB Compliance Specialist
Research Integrity and Compliance
Texas State University
CC: Dr. Krishna Kisi

OFFICE OF RESEARCH AND SPONSORED PROGRAMS
601 University Drive | JCK #489 | San Marcos, Texas 78666-4616
Phone: 512.245.2314 | *fax:* 512.245.3847 | WWW.TXSTATE.EDU

TEXAS STATE

INFORMED CONSENT

Study Title: Exploring the usage of 3D scan and digital twin in indoor building navigation during emergency.

Principal Investigator/Graduate Assistant:
Sushmit Sharma Bhattarai
Email: hsy4@txstate.edu
Phone: 512-665-1123

Principal Investigator/Faculty Advisor:
Dr. Krishna Kisi
Email: kpkisi@txstate.edu
Phone: 512-245-7577

Sponsor: N/A

This consent form will give you the information you will need to understand why this research study is being done and why you are being invited to participate. It will also describe what you will need to do to participate as well as any known risks, inconveniences, or discomforts that you may have while participating. We encourage you to ask questions at any time. The bottom of this form explains the electronic consent for this research to decide whether to participate or not to participate in this research.

PURPOSE AND BACKGROUND

You have been asked to participate in a research study to know the importance of indoor building navigation in university building and how the latest technology of 3D scan and digital twin can provide solution to indoor navigation system. We invite you to take part in a research study because you have been using RFM building for your class or lab.

PROCEDURES

If you agree to participate in the study, you will be asked to take online questionnaire survey prepared in Qualtrics. There are fourteen questions, and it is anticipated to take between 5 and 8 minutes of your time. You will have an opportunity to read the Informed Consent at the beginning of the survey via Qualtrics. Your responses to the survey will be anonymous. Your responses will only be used for research purposes.

RISKS/DISCOMFORTS

There are no reasonably expected risks associated with participation and no risks greater than those ordinarily encountered in daily life. Participation in the study is totally voluntary. You can agree to take part in the study and later change your mind. Your decision not to participate will not be held against you. You may ask all the questions you want about the study before you decide. Your decision to participate or not will have no impact on your standing in the class. There will be no penalty if you choose not to participate in the study.

BENEFITS/ALTERNATIVES

There will be no direct benefit to you from participating in this study. However, the information gained from this study could result in developing indoor building navigation system in RFM building.

EXTENT OF CONFIDENTIALITY

The surveys will be anonymous. The option "Anonymize Response" in Qualtrics survey will be turned on to disable respondents' IP addresses, geographical data, and contact information. The members of the research

team, the Materials with Intelligence group, and the Texas State University Office of Research Compliance (ORC) may access the data. The ORC monitors research studies to protect the rights and welfare of research participants.
Data will be kept for three years (per federal regulations) after the study is completed and then destroyed.

PAYMENT/COMPENSATION
There are no costs or compensation for participation.

PARTICIPATION IS VOLUNTARY
You do not have to be in this study if you do not want to. You may also refuse to answer any questions you do not want to answer. If you volunteer to be in this study, you may withdraw from it at any time without consequences of any kind or loss of benefits to which you are otherwise entitled.

QUESTIONS
If you have any questions or concerns about your participation in this study, you may contact the Principal Investigator, Sushmit Sharma Bhattarai at hsy4@txstate.edu or Krishna Kisi at kpkisi@txstate.edu.

This project IRB#8567 was approved by the Texas State IRB on October 31, 2022. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB Chair, Dr. Denise Gobert 512-716-2652 – (dgobert@txstate.edu) or to Monica Gonzales, IRB Regulatory Manager 512-245-2334 - (meg201@txstate.edu).

ELECTRONIC CONSENT: Clicking on the button below indicates that: (a)You have read the above information, (b)You voluntarily agree to participate, and (C) You are 18 years of age or older.

Email Recruitment Script

To: [Use this line for individual addresses or your own address if BCC line is used]
From: Sushmit Sharma Bhattarai

BCC: [Use this line when sending the same email message to multiple addresses]

Subject: Research Participation Invitation: Exploring the usage of 3D scan and digital twin in indoor building navigation during emergency

This email message is an approved request for participation in research that has been approved by the Texas State Institutional Review Board (IRB).

You have been asked to participate in a research study that focuses on the importance of indoor building navigation using 3D scan and digital twin during emergency. We invite you to take part in this research study to know your perception regarding this study. Your participation in this study is completely voluntary, and your decision to participate or not will have no impact on your standing in the class. There will be no direct benefit to you from participating in this study. There will be no penalty if you choose not to participate in the study.

If you agree to participate in the study, you will be asked to take online questionnaire survey prepared in Qualtrics. There are fourteen questions, and it is anticipated to take between 5 and 8 minutes of your time. You will have an opportunity to read the Informed Consent at the beginning of the survey via Qualtrics. Your responses to the survey will be anonymous. Your responses will only be used for research purposes.

To participate in this research or ask questions about this research please contact Sushmit Sharma Bhattarai, Principal Investigator, via email at hsy4@txstate.edu.

This project IRB#8567 was approved by the Texas State IRB on October 31, 2022. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Denise Gobert 512-716-2652 – (dgobert@txstate.edu) or to Monica Gonzales, IRB Specialist 512-245-2334 - (meg201@txstate.edu).

APPENDIX B: AN ONLINE QUESTIONNAIRE (HOSTED BY QUALTRICS TEXAS STATE UNIVERSITY)

Block 1

INFORMED CONSENT

Study Title: Exploring the usage of 3D scan and digital twin in indoor building navigation during emergency.

Principal Investigator/Graduate Assistant:
Sushmit Sharma Bhattarai
Email: hsy4@txstate.edu
Phone: 512-665-1123

Principal Investigator/Faculty Advisor:
Dr. Krishna Kisi
Email: kpkisi@txstate.edu
Phone: 512-245-7577

Sponsor: N/A

This consent form will give you the information you will need to understand why this research study is being done and why you are being invited to participate. It will also describe what you will need to do to participate as well as any known risks, inconveniences, or discomforts that you may have while participating. We encourage you to ask questions at any time. The bottom of this form explains the electronic consent for this research to decide whether to participate or not to participate in this research.

PURPOSE AND BACKGROUND

You have been asked to participate in a research study to know the importance of indoor building navigation in university building and how the latest technology of 3D scan and digital twin can provide solution to indoor navigation system. We invite you to take part in a research study because you have been using RFM building for your class or lab.

PROCEDURES

If you agree to participate in the study, you will be asked to take online questionnaire survey prepared in Qualtrics. There are fourteen questions, and it is anticipated to take between 5 and 8 minutes of your time. You will have an opportunity to read the Informed Consent at the beginning of the survey via Qualtrics. Your responses to the survey will be anonymous. Your responses will only be used for research purposes.

RISKS/DISCOMFORTS

There are no reasonably expected risks associated with participation and no risks greater than those ordinarily encountered in daily life. Participation in the study is totally voluntary. You can agree to take part in the study and later change your mind. Your decision not to participate will not be held against you. You may ask all the questions you want about the study before you decide. Your decision to participate or not will have no impact on your standing in the class. There will be no penalty if you choose not to participate in the study.

BENEFITS/ALTERNATIVES

There will be no direct benefit to you from participating in this study. However, the information gained from this study could result in developing indoor building navigation system in RFM building.

EXTENT OF CONFIDENTIALITY

The surveys will be anonymous. The option “Anonymize Response” in Qualtrics survey will be turned on to disable respondents’ IP addresses, geographical data, and contact information. The members of the research team, the Materials with Intelligence group, and the Texas State University Office of Research Compliance (ORC) may access the data. The ORC monitors research studies to protect the rights and welfare of research participants.

Data will be kept for three years (per federal regulations) after the study is completed and then destroyed.

PAYMENT/COMPENSATION

There are no costs or compensation for participation.

PARTICIPATION IS VOLUNTARY

You do not have to be in this study if you do not want to. You may also refuse to answer any questions you do not want to answer. If you volunteer to be in this study, you may withdraw from it at any time without consequences of any kind or loss of benefits to which you are otherwise entitled.

QUESTIONS

If you have any questions or concerns about your participation in this study, you may contact the Principal Investigator, Sushmit Sharma Bhattarai at hsy4@txstate.edu or Krishna Kisi at kpkisi@txstate.edu.

This project IRB#8567 was approved by the Texas State IRB on October 31, 2022. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB Chair, Dr. Denise Gobert 512-716-2652 – (dgobert@txstate.edu) or to Monica Gonzales, IRB Regulatory Manager 512-245-2334 - (meg201@txstate.edu).

ELECTRONIC CONSENT: Clicking on the button below indicates that: (a)You have read the above information, (b)You voluntarily agree to participate, and (C) You are 18 years of age or older.

Default Question Block

Please check your enrollment status. Which of the following describes your degree?

Graduate Degree

- Master
- Ph.D.

Undergraduate Degree

- Freshman
- Sophomore
- Junior
- Senior

Please check your study major.

Construction Science and Management

Concrete Industry Management

ET Program (Civil, Electrical, Environmental, Manufacturing, Mechanical)

Physics

How many days a week do you have classes in Roy F Mitte Building (RFM)?

1

2

3

4

5

How often do you have to change your classrooms and labs during a day?

1

2

3

4

In your opinion, how easy was it to find your classrooms during the first week of a semester in the RFM building?

Extremely difficult

Somewhat difficult

Somewhat easy

Extremely easy

In your opinion how easy was it to find your classroom after 4 weeks in the RFM building?

Extremely difficult

Somewhat difficult

Somewhat easy

Extremely easy

In your opinion, how accurately you would locate nearest staircase/elevator to attend your classroom or lab in the RFM building?

Not accurately at all

Slightly accurately

Very accurately

Extremely accurately

In your opinion, how accurately you would locate nearest staircase/elevator to exit from the RFM building?

Not accurately at all

Slightly accurately

Very accurately

Extremely accurately

How familiar are you with the indoor navigation application?

Not familiar at all

Slightly familiar

Very familiar

Extremely familiar

If the 3D indoor navigation of the building with classroom/labs/staircase/elevator is available at the front lobby of the building, how likely will it help to find your desired room when the semester starts?

Strongly disagree

Somewhat disagree

Neither agree nor disagree

Somewhat agree

Strongly agree

How effective would it be to have indoor navigation mobile application with classroom layout of RFM building similar to direction tool as provided in Google Maps?

Not effective at all

Slightly effective

Very effective

Extremely effective

Are you aware of the phrase "digital twin"?

No

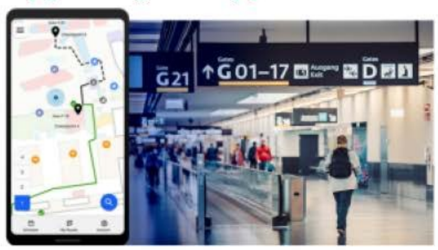
Yes

Block 3

This page is just for introducing digital twin. Please proceed for remaining questionnaire on the next page .

Digital twin can help in indoor mapping system for smart building management. It organizes computer-aided design (CAD), building information modeling, site scans, and operational datasets into floor aware indoor maps to support facilities, workplace operations, maintenance applications, and various use cases.

Further Digital twin can also help in indoor positioning system that allows you to locate yourself and others inside a building in real time. Similar to GPS, it provides indoor maps and location services to help you navigate to any point of interest or destination.



Block 2

Based on the Digital Twin information provided, how likely will you prefer to use indoor navigation to locate your classroom/lab?

Extremely unlikely

Somewhat unlikely

Somewhat likely

Extremely likely

Based on the Digital Twin information provided, how effective would it be to navigate the exit during a fire and any emergency?

Not effective at all

Slightly effective

Very effective

Extremely effective

Powered by Qualtrics

APPENDIX C: FLYERS WITH THE QR SCAN CODE FOR SURVEY

HAVE YOU EVER LOST IN RFM BUILDING?

The purpose of this research study is to know the importance of indoor building navigation in university building and how the latest technology of 3D scan and digital twin can provide solution to indoor navigation system.

Participation in the study is totally voluntary.

This project IRB#8567 was approved by the Texas State IRB on October 31, 2022.

If you have any questions, concerns, complaints, you may email to the research team at: hsy4@txstate.edu or kpkisi@txstate.edu

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