An Analysis of Symbol Design for an Indoor Navigation System

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Abstract

This report outlines the development and testing of a proof of concept for a mobile map application designed for indoor navigation of Delaware Technical Community College, Stanton Campus. The college campus is a multistory, split level building with several additions and reconfigurations. Currently, no maps exist for the building's interior making it difficult for students and faculty to navigate. A mobile location based map navigation application is proposed. Design of such applications for indoor navigation (especially for multistory buildings) have received little attention in the literature. Using input from students and faculty, a proof of concept map application was designed. The application included designing three route visualizations of the campus building's interior. Testing involved new and existing students following a route wearing a head-mounted camera. Time to complete and accuracy of following a route were recorded and analyzed to identify the most efficient map design.

An Analysis of Symbol Design for an Indoor Navigation System

Have you ever been lost finding your way around a building? This is an ongoing challenge at the Stanton Campus of Delaware Technical Community College. The following project develops and evaluates the symbology and cartographic design for a mobile indoor navigation system for the college. The Stanton campus is a complicated building to navigate. No maps are currently available for the building's interior. Due to the lack of available maps, faculty and staff volunteer to stand inside the main entrance of the Stanton campus and help direct students to their classes. During large events in which visitors come to the school, faculty and student volunteers often enlist to escort visitors to their destinations within the school. Students regularly voice their complaints s about being lost, ask for directions, or express the difficulty they have finding their classes every semester. Given the confusion brought on by unavailable maps, the research is intended to demonstrate the need for navigational assistance on the Stanton Campus as well as provide a suggested solution. Secondary outcomes of this research is to set the stage for college-wide discussion of mapping needs and introduce GIS as a useful tool for the college for navigational purposes.

The main focus of this project is on the point symbol design, map design and route design of a complex, multi-story building. While there is a lot of guidance available on the technical requirements of implementing an indoor navigation system, there is also a great deal of research available on the symbol design process, much of which is used in developing this proof-of-concept mobile application. However, there is very little information available on the overall map design for indoor navigation, particularly for complex, multi-story buildings.

Scope of Problem

Delaware Technical Community College has four campus locations. They are (listed from north to south in the state) the George campus in Wilmington, the Stanton campus in Newark, the Terry

Campus in Dover and the Owens Campus in Georgetown. The Stanton campus consists of a single building with eight wings that are lettered from A-G, shown in Figure 1. There are two possible entrances to the building complex that are manned by security guards. The entrances consist of a main entrance in the A wing and a secondary side entrance in the C wing. Wings A-E are two-story and wings F & G are one story. The first floor of the A wing is split into two levels by a set of stairs the lower of which is the ground level where the main entrance is located. This raised level, on the south-east side of the building begins the A and B wing split-level orientation. This configuration causes a lot of confusion for students and visitors because the second floor of the A and B wings are not the same level as the second floor of the C, D and E wings.

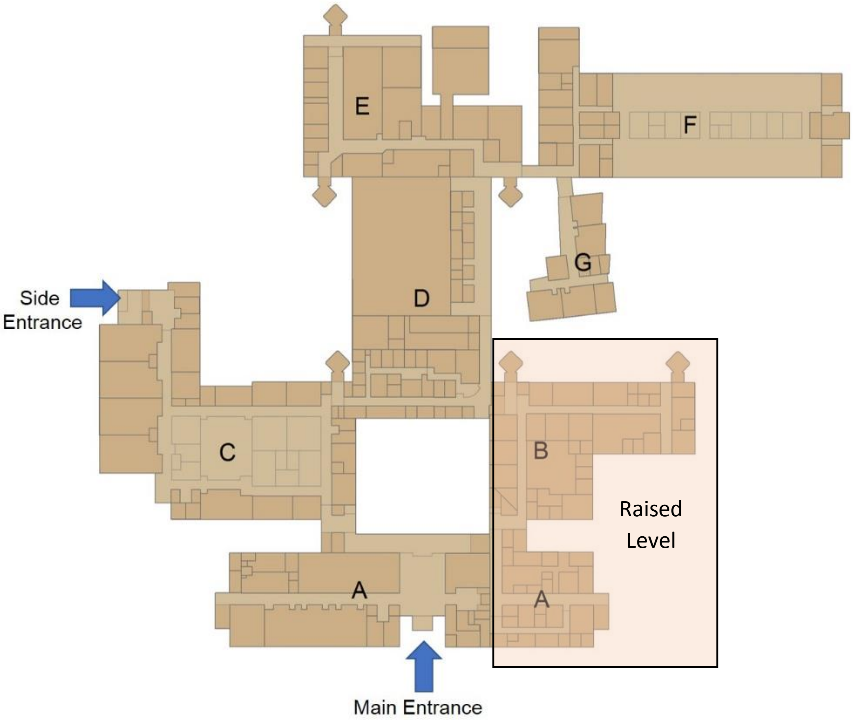


Figure 1: Delaware Technical Community College, Stanton Campus first floor layout

As Delaware Technical Community College has moved to a “one-college” structure students are often travelling between campuses and have to orient themselves more frequently to the various campus layouts. As was explained previously, both the Stanton and Wilmington campuses are made up of complex, connected building structures while the Terry and Owns campus resemble more traditional college campuses with multiple buildings and a large expanse of outdoor space. Historically, the college campuses operated independently of each other. A “one-college” structure was established in 1995 (Delaware Tech Magazine, 2014) which has facilitated many changes over the past 20 years, the most recent of which has been college-wide alignment of all educational programs. Due to the close proximity of the campuses, students who live throughout the state are offered greater flexibility with the option of attending multiple campuses. As an academic advisor and instructor in the Civil Engineering Technology program, the author of this paper notices there are now more students switching campuses each semester in order to get the classes they need on the schedule they desire. This means more students that are “new” to a campus each semester.

Currently, each of the four Delaware Tech campuses has a downloadable campus map in PDF format. The maps, shown in Figure 2, are symbolized with locations of buildings, parking, walkways and public safety locations. The printable maps are visually appealing, but include non-standard symbology, inconsistent information between the campus maps, and the maps are not necessarily accurate. The inconsistency between maps can cause confusion for the growing number of students and faculty who attend multiple campuses. For example, in Figure 2Figure 2A, notice that different symbol colors are used for parking and for open space versus the colors used in Figure 2B, 2C, and 2D. Also note that there are two buildings in Figure 2A that are shown in blue rather than green like the rest of the buildings on the same campus map. There is no identified reason for the color difference. On Figure 2B the location of public safety emergency phones and the locations of first aid kits are displayed. This contrasts sharply to the Stanton Campus map (Figure 2C) and Wilmington Campus map (Figure 2D) where this information is omitted. Due to this discrepancy, part of this project’s needs assessment includes an inventory of the current campus maps to ensure there is a comprehensive list of features to be identified on the Stanton Campus map that will be included on the mobile map application.

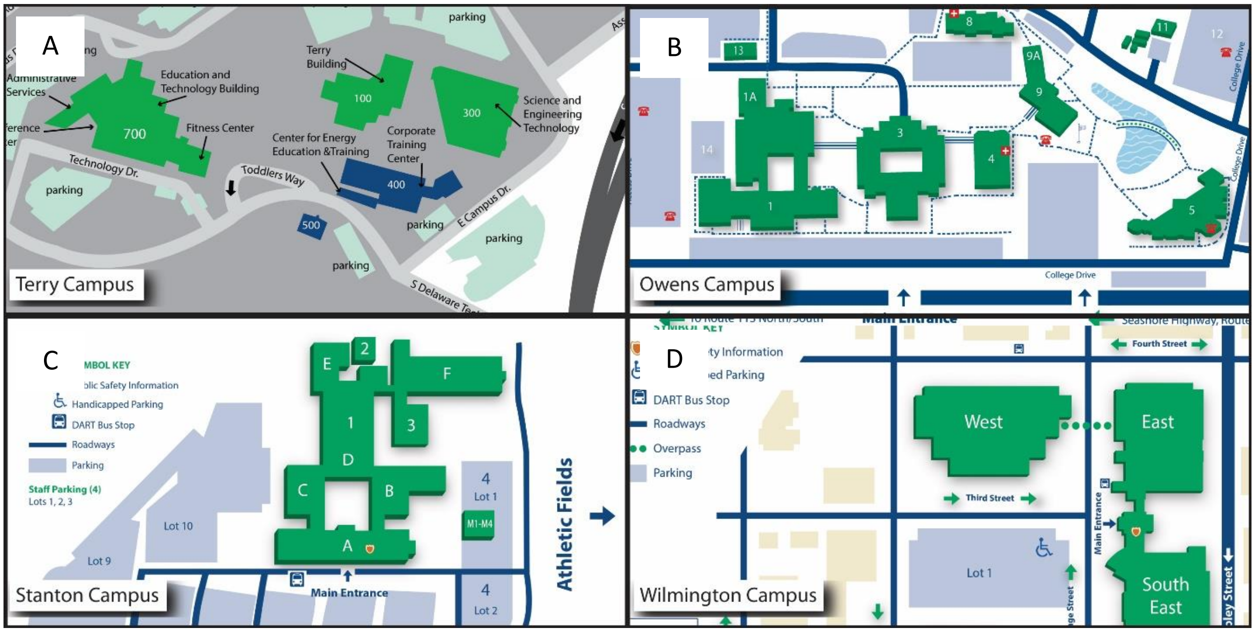


Figure 2: Comparison of Delaware Tech's Four Campus Maps (Delaware Technical Community College, 2014c; Delaware Technical Community College, 2014a; Delaware Technical Community College, 2014b; Delaware Technical Community College, 2014d)

Although this project focuses on the interior of the building, the final product will include exterior elements in order to provide a reference to the main entrance of the building and correct accuracy issues of the current Stanton campus map. In the left side of Figure 3, notice the dark blue line symbolizing roadways. Compare the roadway locations to the aerial image on the right side of Figure 3. Recognize that the roadways are drawn next to lot #7, 6, 5 and 2 in locations where there are grassy islands rather than roadways. Notice also that the aerial image shows roadways connecting to parking lots #8, 9, and 10, as well as a roadway circling around the rear of the campus. These roadways are omitted from the campus map. To ensure a comprehensive campus map, site engineering plans, architectural plans and aerial imagery will be consulted throughout map development.

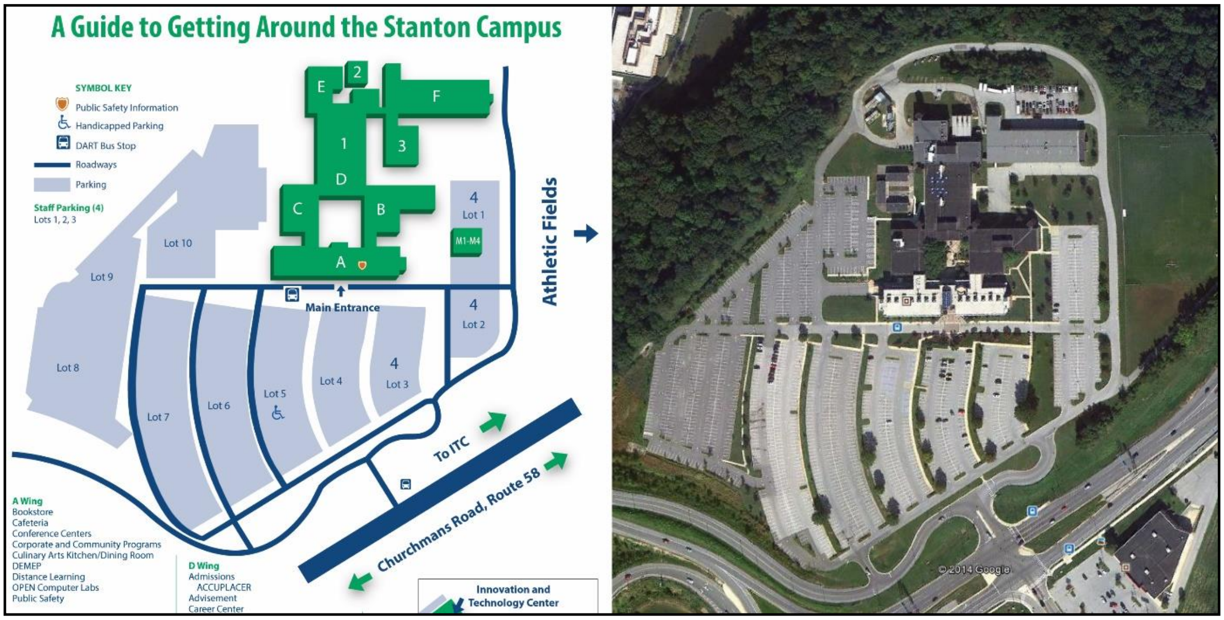


Figure 3: Evaluation of Stanton Campus Map. The current campus map is on the left (Delaware Technical Community College, 2014b) with an aerial image of the campus on the right (Google Maps, 2011).

Literature Review

This section reviews current research on the design and development of indoor navigation systems. For example, two articles (Gotlib & Marciniak, 2012a; Gotlib, Gnat, & Marciniak, 2012b), discuss the stages in the evolution and design of a mobile application developed for an indoor navigation system. The stages include: choosing a spatial data model, selecting an appropriate cartographical presentation, determining appropriate indoor positioning methods, and defining routing options.

Spatial Data Model

Tomlin (1990) defines a cartographic, or spatial, model as “The complete body of data for a given geographical study area… comprised as map layers” (p. 364), as well as “a methodology for organizing data” (p. 372). No standard spatial data model currently exists for indoor navigation maps. Hagedorn, et al. (2009) explains that a spatial data model for indoor navigation should consist of 3 components: thematic elements which include the building and building parts, geometry elements which describe 2D and/or 3D geometry and routing elements to define transportation throughout the building. Gotlib et al. (Gotlib & Marciniak, 2012a; Gotlib, Gnat, & Marciniak, 2012b) suggests several existing data models that could be used as a foundation for developing an indoor navigation data model. These data models include ESRI's Building Interior Spatial Data Model (BISDM), Industry Foundation Classes (IFC), and the City Geography Markup Language (City GML).

Review of the BISDM reveals that the model was created to incorporate both the buildingSmart IFC Model and City GML model, making it a very comprehensive model for the interior of a building. The IFC data structure is used by the Architecture, Engineering & Construction (AEC) industry for "sharing construction and facility management (FM) data across various applications used in the AEC/FM industry" (buildingSMART International Ltd., 2016). The CityGML model is used to visualize and share virtual city 3D models. It incorporates five different levels of detail for viewing data at different scales. CityGML 2.0 is the official standard of the Open Geospatial Consortium, Inc. (Kolbe, 2012).

The BISDM was developed as a tool for using GIS in a variety of building management and planning applications (BISDM Members, 2011). It was developed by a committee of both private and public sector participants. The most current model is version 3.0, which includes a comprehensive data structure for a building and its interior elements like building outline, floors, rooms, fixtures, structural components, building systems and equipment. Although it includes integration with the CityGML model, the BISDM does not include any exterior site features.

Advertised as the "next generation of the BISDM" (PenBay Solutions, 2014), the Facilities Information Spatial Data Model (FISDM) extends the BISDM to include both interior and exterior features. The model is developed specifically for facilities management and provides very limited exterior site features. When evaluated by the author, it was determined that the exterior features do not provide enough detail for a campus map. Specifically, the FISDM includes elements like landscaped areas, pavement and waterbodies, but does not include features such as ADA accessible parking or ramps.

To meet the needs of the exterior elements on campus, ESRI's Local Government Information Model (LGIM) was reviewed (ESRI, 2015). This extensive model includes data set structure for standard government operations such as capital planning, fire services, land use planning, law enforcement and utility system management. In addition, it contains a data set structure called "FacilitiesStreets" which provides a structure for simple interior building features and a broad set of exterior features. The model is provided with several sample applications, one of which is a campus base map that demonstrates the use of the LGIM to map the exterior layout of a college campus.

Further research unveiled the Campus Routing Data Model Draft that is currently under development and testing by ESRI (2014). This model provides a suggested structure for a campus network which can be used for routing. It does not include modeling of the building itself.

The research gathered about spatial data models for indoor navigation were very general in nature and would have been strengthened by a case study or demonstration of how the data models applied to a real world project. Based upon the recommendation of Hagedorn, et al. (2009), this project will require 3 different data models. One for the exterior campus base map, one for the interior building base map and one for routing.

Cartographic Design Considerations

This literature review continues discussion with the selection of an appropriate cartographic design. The design component of this mobile application includes the design of the point symbology, interior building layout, and the elements necessary for effective navigation.

Design of Point Symbology

Research has suggested many methods for developing standardized symbol sets for various applications and organizations. Commonalities between the methods researched comprise identifying and evaluating existing symbols, grouping symbols by theme, proposing an initial symbol design, evaluating the symbols, and revising accordingly. Robinson et al., (2012) expand upon these methods in a study to develop symbol standards for the Department of Homeland Security's Customs and Border Patrol. Their study adds a needs assessment as the first step to aid in identifying problems with the currently used symbols. Their study also demonstrates using card sorting activities to help group symbols and establish a symbol set structure.

In a study conducted by Roth et al. (2010), card sorting was shown to be an effective method for organizing map symbols into categories that can be used to create themed symbol sets, which leads to improved map legend structure and symbol recognition. Card sorting is an exercise in which participants organize objects, text or pictures into categories. According to their study, there are three types of card sorting activities: open, guided, and closed. An open sort allows for participants to create their own categories. Open sorts are typically conducted in the pre-design phase as they generate basic categories. A closed sort provides the set of categories in which items are sorted. Closed sorts are typically conducted in the post-design phase as a way to evaluate the final categories. The guided sort provides some level of criteria in which to sort by, but still allows participants to create their own categories. Guided sorts can be used throughout the design process.

In the study conducted by Robinson et al., (2012), an open card sorting activity was conducted after the needs analysis stage using the organization's existing symbols in order to establish symbol groups by theme. Voting sessions with the participants were used to gather a consensus to form an initial symbol set structure and determine how to handle symbols with design flaws. A second, closed card sorting activity was used to ensure the new symbol set structure was adequate. Their study utilized an online card sorting application. From a personal interview with Justine Blanford, the online application was very beneficial because it allowed participants to save their work and come back to it at their convenience (personal interview, December 13, 2015). This project uses the steps outlined by this study as a framework for the point symbol design stage. This project will include both an open and a closed card sorting exercise using a web based application to define symbol sets.

Once the open card sorting exercise has completed, attention will turn toward desinging the symbology. In terms of designing point symbols, there are several visual variables that play a part in the overall appearance, acceptance and recognition of a point symbol. Bertin (1983) and Spence (2007) discuss the visual variables to include size, value (or lightness), texture, color, orientation and shape. These visual variables can be used to help differentiate individual symbols as well as visually group symbol sets.

MacEachren (1995) and Grinderud, et al. (2009) explain three types of point symbols that are typically used for nominal data. The three types are geometric, associative and pictorial. Geometric symbols, such as squares, circles and triangles are typically used on small-scale maps and do not generally relate to what the symbol is intended to represent. Associative symbols relate to culturally understood themes, such as a cross to represent church locations. Pictorial symbols (or pictograms) are a simplified drawing of the object represented and tend to be used more on large-scale maps. On a campus map, pictorial symbols could be used to represent many of the special purpose rooms and landmarks such as the gymnasium, cafeteria, emergency phones and waste centers.

Researchers Kilkoyne (1973), Phillips (1973) and Forrest & Castner (1985) show that pictographic symbols are more easily recognized as their intended object than geometric symbols. The visual variables of these pictographic symbols also influence recognition. Forrest and Castner's (1985) study shows the need for pictographic symbols to be encased in a frame for quickest identification on a map. Their study also shows that more solid pictographic images were preferred to hollow images.

Although pictographic symbols are recommended for quick identification on a map, their design for a mobile screen is a critical consideration for a navigation application. Morrison and Forrest (1995) conducted a study on map and symbol design for a digital screen. Symbols that were shown to be easily recognized in print were then viewed in map context on a digital screen. Three different symbol sizes were studied: 5.5 mm^2., 7.0 mm^2., 8.5 mm^2. The study showed that the largest symbols performed best presumably because pictorial symbols tend to have a greater amount of detail that does not transfer well to a digital screen due to resolution limitations. Although the largest symbols demonstrated the easiest recognition, they took up too much space on the small screen. The study recommends to select the minimal necessary cartographic data, to simplify the detail in pictographic symbols and to use a medium size symbol on a digital map. Symbol size as well as other visual variables will need to be considered throughout the design process. The findings of these studies will guide symbol design throughout this project.

Interior Building Layout

Building map and route design will be guided by the following research. Garner and Radoczky (2006) reported on project NAVIO (Pedestrian Navigation for Combined Indoor-/Outdoor Environments). The study was conducted to learn how people follow maps. A group of 24 undergraduates were asked to follow a single route depicted by either a schematic map, a simplified street map, or a standard city map. All but one of the students were successful in following the map they were provided, but the schematic map resulted in the most time consuming navigation. The schematic map was produced using only perpendicular or 45° intersections. All road curvature was eliminated and replaced with 90° or 45° angles. Due to this, distortion in distance was present. The study favored a simplified street map. It maintained the topologic relationships of paths, therefore maintaining distances between intersections. The map only included the paths, streets, street names, park names and other landmarks.

A weakness of the Gartner and Radoczky study is the small sample set of students who participated and the fact that those who were local were not distributed between the three different map types. The findings of the study would have been stronger with an evenly distributed set of students who were both familiar and not familiar with the area, which will be done in the evaluation stage of this proposed project. The study does make a strong point that map design will "influence the generation of the user's mental map" (Gartner & Radoczky, 2006) of an area, making the role of a cartographer quite significant.

Design of digital maps for pedestrian navigation is discussed in detail by Radoczky (2007). The research shows that a map designed for navigation is preferred over an architectural floor plan when navigating indoors. The article also states that in both indoor and outdoor maps, depiction of proper topology is more important than precision of the map as long as distortion is minimized. This is supported by two additional studies: Agrawala & Stolte (2000) and Klippel, Tappe, Kulik & Lee (2005). Other noted findings of Radoczky (2007) are location enabled mobile maps should be egocentric, containing a you-are-here marker in the center of the screen depicting the user's real-time location, they should have north marked and should use symbology known in the region. The article also states that in order to clearly depict a building, it should be displayed with a multi-scaled map showing varying levels of detail which will result in more detail showing when zoomed in and less detail showing when zoomed out. A weakness of Radoczky's (2007) research is omission of recommendations when depicting a multi-story building, which this project explores.

Navigation Route Design

The purpose of a map and navigation system is to aid users in developing their own cognitive map of the area. It is widely accepted that a cognitive map is made up of three types of knowledge: survey, landmark, and route (Siegel & White, 1975; Cheng & Pérez-Kriz, 2014). Landmark knowledge allows people to identify their location by referencing unique objects at fixed locations. A deeper understanding comes from the ability to combine a sequence of locations to define a route. The highest form of spatial cognition occurs with survey knowledge, when an individual can integrate various landmark and route knowledge to create a mental image of the area (Werner et al, 1997; Cheng & Pérez-Kriz, 2014).

There are two types of landmarks when designing a route: decision and maintenance. Decision landmarks are cues provided at critical junctures and turning points. Maintenance landmarks are cues to assure a user they are still on the correct route (Presson & Montello, 1988). Since indoor navigation typically consists of short straight distances, multiple turns and changing of floors, Radoczky's (2007) research suggests that indoor navigation requires a higher density of landmarks than outdoor navigation. These findings are supported by Hölscher, et al.'s, (2006) study of pedestrian navigation in a multi-level building which found that participants demonstrated disorientation when changing floor levels. This occurred most when the stairs changed direction more than once and the stairwell was isolated without visual access to an orientation reference or the outside. The study proposed that landmarks placed at floor changes would reduce the disorientation. Xu, et al., (2010) built upon this study by further studying participants navigating in a virtual office building. They tested the participants on their ability to find a location with landmarks placed throughout the office and then repeating the task but without landmarks. The study showed that participants found their location in the time allotted 45% less when there were no landmarks. Therefore, mapping landmarks along routes is critical to the usability of the navigation application.

Positioning Methods

There are currently a variety of location based services (LBS) being used for indoor applications. These systems are also referred to as Interior Positioning Systems (IPS). These systems use mobile devices to sense location. This can be done using one or a combination of different methods. Some systems use various types of radio frequencies emitted by transmitters such as the cellular phone network, Wi-Fi hotspots, Bluetooth beacons or RFID tags to triangulate location. Other systems use the mobile device's built in phone sensors, such as the accelerometer, gyrosocope and compass to identify a position within a building (Indoor Atlas Ltd., 2015). Another is a vision based system that uses visual features of the surrounding area and/or visual markers such as QR codes to identify location (Barberis, Bottino, Malnati, & Montuschi, 2014). Various LBS developers have been deploying services over the past couple years that use a part of or a combination of the afore mentioned methods, some boasting location accuracy to within 1 meter (Indoor Navigation Products, 2015). Some of the available systems are Meridian, Infsoft, Cartogram, Eyedog, IndoorAtlas and Geometri.

In a personal interview with Michael Healander from GeoMetri, an Indoor Mapping, Positioning and Analytics company, it was suggested to use Indoor Atlas to develop the prototype (personal communication, November 17, 2015). Indoor Atlas is free and requires no beacons or wi-fi (Indoor Atlas Ltd., 2015) and only uses only the sensors in a smart device to determine location. To set up the system, an image of the building is created first. Next, the image is georecitfied. Then, the image is uploaded to the Indoor Atlas web tool and the developer walks through the building collecting field information which calibrates the map.

For full implementation of a final product, GeoMetri offers a more robust IPS with a variety of positioning methods that work together for a high accuracy system (GeoMetri, 2015). IndoorAtlas and GeoMetri are also the only commercial solution currently on the market that works directly with ESRI products and provides support for development of an indoor navigation application running on an ESRI platform (W. Hall, personal communication, November 11, 2015).

Routing Options

Routing options fall into two categories. The first is the technical requirements for a routing system. The second is determining the various routes available to navigate from point A to point B. This proposed proof-of-concept project will utilize a single route for testing, so there is no need for evaluating routes at this time. Additional research on routing options will need to be conducted when the proof-of-concept is adopted for development.

The technical requirements for a routing system vary depending upon the IPS and software being used to develop the map. Several of the commercial IPS systems available on the market include routing abilities. Many of them provide an app that can be loaded on a smart device and carried through a building in order to record a route. Some of the applications also allow for identification of decision points and landmarks. Although this is a simple and direct method of creating a route definition, the routing typically needs to be hosted and maintained by the IPS system for a fee, which could potentially limit the scalability of the navigation system depending upon the budgetary restrictions at play.

This proof of concept intends to demonstrate a system that is fully scalable to meet the college's future needs. In 2013, the University of Washingon was faced with the same challenge (GISi indoors, 2013). Here, CAD drawings of their campus and buildings were used to create a comprehensive GIS including "door location, non-door entrances, stops, route lines from entrances to all rooms, route transitions to traverse floors, and room points as destinations" (GISi indoors, 2013). They also developed routes from the centerlines of hallways and stairways to create a 3D network using ESRI's Network Analyst Extension.

From an interview with Wolfgang Hall of ESRI, I learned that Network Analyst Extension requires hosting on ArcGIS Server, and cannot be hosted through ArcGIS Online. He added that ArcGIS Server works well on Amazon Web Services and would be a good, inexpensive solution to develop a proof of concept (personal interview, November 10, 2015).

To conclude, design of an indoor navigation system has three steps. The first step is the identification and development of the data model. Since no standard data model for indoor routing is present, selection from several existing building models is necessary. The second step is the cartographic presentation including point symbol design, building map design and route design. Existing research suggests that the point symbol design process includes identifying and evaluating existing symbols, a needs assessment, card sorting activities to group symbols by theme, initial symbol design, symbol evaluation and symbol design revisions. Point symbols should be designed as simplified pictorial images at a medium size to be recognized easily on a small mobile screen. Additional research shows that building and route design should be simplified, maintain topology and minimize distortion. Furthermore, research contains general cartographic recommendations for visualizing simple, one-story buildings. Lacking in the overall body of research are solid methodologies for visualizing complex or multi-story buildings. Routes should be designed with landmarks at all decision points, changes in floor level and along the route for maintenance. The third step include selection of a positioning system; identification of a routing system and evaluation of the map.

Goals and Objectives

The goal of this study is to develop a proof of concept for a mobile map application with indoor navigation for Delaware Technical Community College, Stanton Campus. The main focus of the project is on the point symbol design, map design and route design of this complex, multi-story building. The specific objectives of this study are as follows:

- Develop recommended point symbols for common indoor features.
- Explore various visualization styles for representing a multi-story building.
- Select a spatial data model for use in a building navigation system.
- Implement an indoor positioning service.
- Create an indoor navigation route.
- Develop a proof of concept mobile application.

A secondary goal of this project is to set the stage for college-wide discussions of mapping needs and opportunities to support student success at all of our campus locations. The research methodology followed throughout this project is intended to provide a framework and suggestions for developing mapping applications for all four campuses. This project is also intended to introduce GIS as a tool for the college.

Methodology

The research methodology for this project consists of six overall stages. The first stage is to conduct a needs assessment to ensure a useful and comprehensive mobile app is developed. The second stage is to select or develop a spatial data model. The third stage is to develop the appropriate symbology. The order of the symbology development begins with the initial design of the point symbols. Next, the building visualizations are considered. The route design concludes the symbology. The fourth stage is selection of an interior positioning system. The fifth stage involves mobile application development. The sixth stage focuses on evaluating a single navigation route for each of the multi-story building representations in a trial to conduct a quantitative analysis of their effectiveness for indoor navigation.

Needs Assessment

The first step in any design project is to conduct a needs assessment, which consists of evaluating the current college/campus maps, identifying the target audience for the final map application, simulating common mobile map application scenarios, and surveying the students and faculty on their perceived needs.

A preliminary needs assessment was performed for this project as part of GEOG 583 – Geospatial System Analysis and Design. The assessment evaluated the current college/campus maps, architectural plans, site engineering plans and aerial imagery to develop a comprehensive list of features to be included in the navigation map application. The assessment also identified the target audience and simulated typical scenarios where a mobile campus map application may be used. The primary users were identified as students (prospective, new, and disabled) and visitors (parents, professionals, and emergency responders).

As evaluated in the preliminary needs assessment, a typical scenario for a student user may be to access the math center for homework help or tutoring. The map app would allow the student to find the best route from their current location. If the student was disabled, they could click an option to avoid stairs which would direct them via elevators instead of stairs. The user could click on the math center symbol to access the math center’s web page for their hours and contact information. Similar scenarios were evaluated to find admissions, the registrar, financial aid, classrooms, career services, student services, veteran services, the bookstore, bathrooms, the gym, the cafeteria, emergency phones, public safety offices, and emergency exits.

Features and tools that were deemed necessary from these scenarios were included in a survey sent to the Stanton Campus students and faculty where they were asked to rank the features in order of importance. The survey had 196 responses, 82% of which were students. The top desired feature is the ability to search for locations of room numbers, then services for students, followed by a “you are here” feature. The complete results are listed in Table 1. In this same survey, they were asked to rank school services to be located. The top services are the Open Computer Lab, Emergency Exits and Admissions. The complete results are shown in Figure 4. The survey results, displayed in Figure 5 shows that the map app concept is considered valuable, helpful, problem solving and necessary by a majority of respondents. 60% of the respondents are likely or very likely to use the app, but 70% said they would not pay for the app. The results show that the app would most likely not produce any revenue to offset development costs, so the most economic options were considered.

Table 1
Features Ranked in Order of Importance

Rank	Feature
1	Ability to search for locations of room numbers.
2	Ability to search for locations of services for students.
3	“You are here” feature.
4	Turn-by-turn directions with ADA accessible options.
5	Vocal turn-by-turn directions.
6	Ability to save a route.
7	Ability to print a map.
8	Distance/Mileage tracking.
9	Links to department or service webpages.
10	Identification of evacuation routes by wing, by floor and for ADA Access.

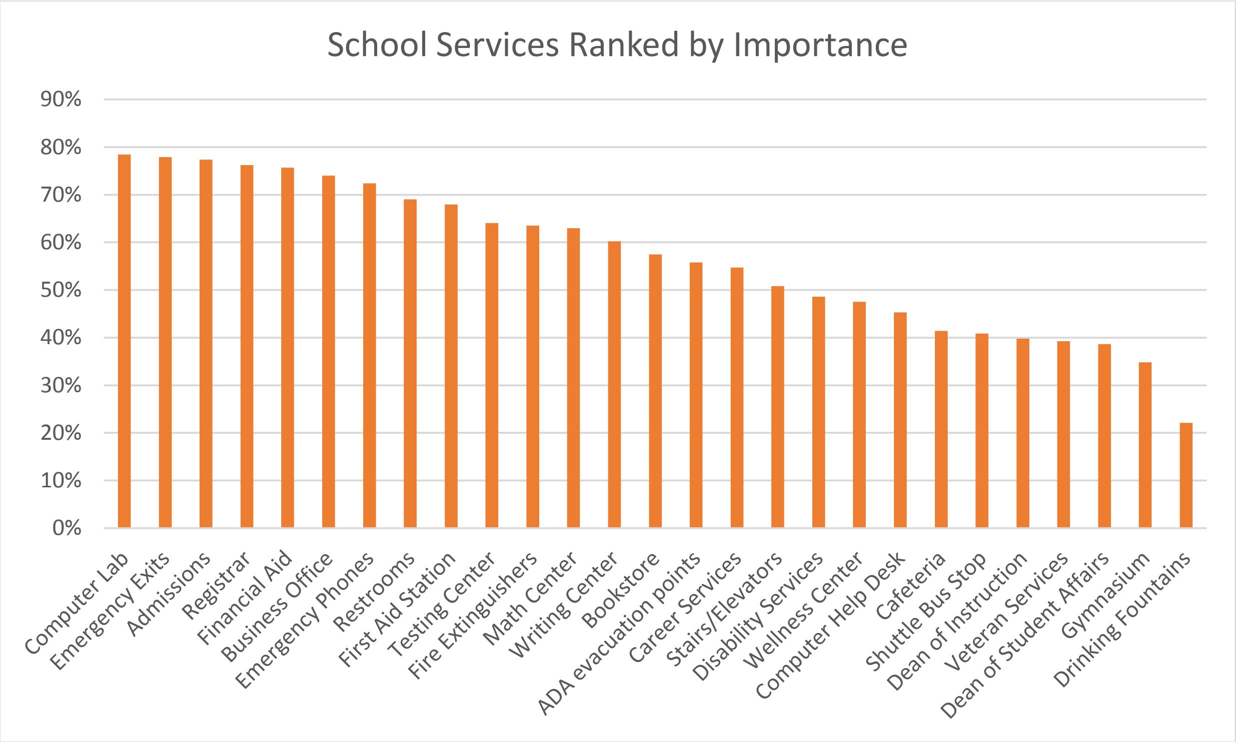


Figure 4: School services ranked by importance

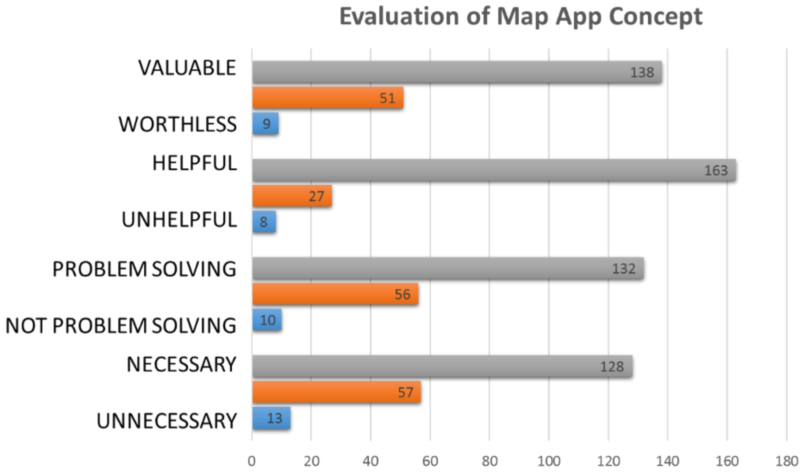


Figure 5: Evaluation of map app concept

Spatial Data Model

The contents of each of the existing spatial data models identified in the literature review were compared to the findings from the needs assessment to develop the three required data models. The exterior campus base map uses the “FacilitiesStreets” dataset from ESRI’s Local Government Information Model (LGIM). The interior building elements required more detail than was included in this model, so the building map elements use the “Buildings” feature dataset from ESRI’s Building Interior Spatial Data Model (BISDM). For routing, ESRI’s Campus Routing Data Model Draft is being used. Modifications were made to each of these models to customize them for this project. Specifically, an interior space topology was created to ensure data integrity. The domains in each geodatabase were customized for the features that exist at Delaware Tech. Keys were added to all of the attribute tables that were the same data type between models to allow for joins and relates. A Landmarks feature class was added to both the interior and exterior data models to allow for landmarks to be symbolized to aid in navigation. The final 3 data models with their respective feature classes are shown in Figure 6.

Campus Buildings

- Architectural Area
- Architectural Fixture
- Asset
- Building
- Conveyance Area
- Conveyance Path
- Conveyance Point
- Floor
- FloorplanLine
- FloorSection
- InteriorSpace
- Landmarks

Campus Base Map

- Curb Ramp
- Landmarks
- Landscape Area
- Parking Space
- Pavement Marking Line
- Pavement Marking Point
- Pole
- Site Amenity Line
- Street Pavement
- Trail
- Tree
- Waterbody

Campus Routing

- Corridors
- Doors
- Network Dataset

Figure 6: Final spatial data models

Point Symbol Development

Symbol development for this project began using the findings from the needs assessment and the surveys to conduct an online card sorting exercise. This first card sorting exercise was deployed as an open card sort asking participants to sort and group the list of school services and other building features developed in the needs assessment. The card sort was conducted with feature name and description only; no symbols were included at this stage. The study participants were Delaware Tech engineering technology students who major in Architectural, Civil, or Environmental Engineering Technology or Geographic Information Systems Technology. This group of students was selected because of their knowledge of mapping.

The online card sorting tool used was part of a subscription service through usabilityTEST.com. The card sorting tool provides simple setup and customization and allowed for deployment via a website link that would not require sign-in to keep the results anonymous. The tool also provided the results in a variety of different formats such as a distance matrix and a dendogram. The user interface provides a default set of written instructions upon startup.

Initially, when the card sort was deployed there was very little participation from the Delaware Tech students. After the first week there had been close to 30 card sorts sessions started, but only nine completed. A student explained that he didn't understand how to use the card sorting tool and that the default set of written instructions was not enough explanation. In response, a brief instructional video was created to explain the purpose of the card sort and demonstrate its functionality. The video can be viewed at https://youtu.be/XlZa6NMlvWc. After providing video instruction, the participation grew. There were a total of 26 completed cart sorts. The results created the initial symbol groups as shown in Figure 7.

The next stage of point symbol development was a quantitative evaluation of the recognition of the selected point symbols. Based upon research showing that pictorial symbols are more easily recognized as their intended object than geometric symbols, this project focused on creating pictorial symbols for the building features and landmarks necessary for navigation. In this stage students ran through a series of online surveys to determine which symbols were best recognized.

Student and Faculty Services

- Registrar
- Admissions
- Advisement Center
- Financial Aid
- Business Office
- Veteran Services
- Career Center
- Disability Support Services
- Workforce Development
- Human Resources
- DEMEP
- Student Government
- Dean’s Offices
- Faculty Offices

Student Community

- Study Spots with plugs
- Study Spots
- BYOL Spots

Campus Safety

- Emergency Exit
- ADA Evacuation Point
- First Aid Station
- Emergency Assistance Phone
- Fire Extinguisher
- Automated External Defibrillator (AED)
- Public Safety Reception
- Public Safety Office

General Amenities

- Vending Machine
- Drinking Fountain
- Pay Phone
- ATM Machine Kiosk
- Self Service Kiosk
- Waste Center
- Sign/Bulletin Board
- Digital Signage

Academic Help Centers

- Open Computer Lab
- Computer Help Desk
- Testing Center
- Science Student Learning Center
- Math Success Center
- Math/Physics Tutoring Center
- Writing Center

Transportation

- Shuttle Bus Stop
- DART Bus Stop
- Dart Bus Schedule Stand
- Staff Parking
- Parking
- ADA Parking

Campus Features

- Library
- Bookstore
- Gymnasium
- Wellness Center
- Cafeteria
- Conference Center
- Classrooms

Access ways

- Stairs
- Elevator
- Main Entrance
- Walkways

Personal Needs

- Women’s Restroom
- Men’s Restroom
- Lactation Room

Figure 7: Initial symbol groups from open card sorting exercise

Symbols to be evaluated were both designed and collected for each of the features in the card sort. The symbols were selected from a variety of sources, beginning with the current Delaware Tech campus maps. Additional symbols were included from symbol sets such as the AIGA Symbol Signs which contains 50 passenger/pedestrian symbols developed in partnership with the U.S. Department of Transportation for use in “airports and other transportation hubs” (AIGA, 2015). Symbols were also collected from the Department of Homeland Security using “The Symbol Store” which is a prototype web-based symbol database hosted by Penn State University’s GeoVISTA Center that allows search by metadata such as category, agency, or symbol description (FGDC, 2012; GeoVISTA, 2012). Symbols were also collected from pedestrian navigation apps currently on the market from companies like Meridian, Infsoft, Cartogram, Eyedog, Indoor Atlas and Geometri.

The selection of symbols was modified by color and outline shape to fit into their symbol categories. The colors for symbols in the campus safety and transportation categories were selected from the existing Delaware Tech maps. The colors for all other categories were derived from the Delaware Tech branding standards manual. The symbol groups for campus features and academic help centers were designed with the same colors, as were general amenities and student community areas. Both sets of symbol groups were clustered together in the results of the open card sort. This led to the design decision to maintain the same colors within each set. Each symbol group was finalized by standardizing an outline shape for each group.

The symbol sets were also modified by size to be viewable on a mobile device. Currently the smart phones on the market range from the highest resolution Quad HD displays with of 1440 by 2560 pixels and a pixel per inch (PPI) ratio of 577, to the more standard HD display with 720 by 1280 pixels at 300 PPI (A., 2015). Point symbols for this project were designed for a 300 PPI resolution since there are currently more phones on the market at this scale. Based upon the research and suggestions of

Morrison and Forrest (1995), the point symbols were sized to be viewed approximately 0.25 in^2. (7.0 mm^2.) on a 300 PPI mobile screen.

The selection of symbols was presented to study participants in an anonymous online survey format. The participants were provided a single page with 3 different symbol choices for each feature and asked to select the symbol that best represents a specific feature name. Following the Organization for International Standardization's ISO 3864 (2002), symbols with a 67% or better recognition rate are acceptable. In this study, recognition rate is calculated using the following formula:

Recognition Rate (%) = (No. of correct responses / No. of participants) * 100

There were 62 features tested, by 37 participants. 42 symbols were recognized at the 67% or greater rate.

The 20 remaining symbols were evaluated, some were re-designed, then they were put forth in a second survey. The symbols used in the second survey were selected using the following criteria:

- A single symbol for a feature was used if it was selected by the majority of respondents in the first test, but less than 67%.
- Two symbols for a feature was used if they were recognized relatively equally (i.e. 51% and 49%) on the first test.
- Additional symbol options were designed for features that did not have any symbols that were recognized at a significantly higher rate.

The second survey was an open-ended evaluation in which the participants were provided a symbol and asked to “explain what the symbol communicates”. There were nine participants who recognized 15 symbols at a 78% or better rate. This leaves 5 symbols that will need to be re-designed in a future study.

Following the process laid out by Robinson et al., *(2012)*, the final step in point symbol design included a second closed card sorting exercise. In this exercise, participants were provided with the symbol and description, as well as the previously agreed upon categories. There were 30 student participants. Two symbols (Career Center and Library) were the only two symbols that were categorized differently in the closed card sort then they were in the open card sort. Career Center was originally grouped with "Student and Faculty Services" in the open card sort, but in the closed card sort the majority of participants grouped it with "Academic Support Centers". Library was originally grouped with "Campus Features", but the closed card sort resulted in 17% "Student Community Areas", 30% "Campus Features" and 37% "Academic Support Centers". Both of these symbols were omitted from the final map to be re-evaluated and re-designed in the future. The symbols shown in **Error! Reference source not found.** are a sampling of the final symbols in their groups.

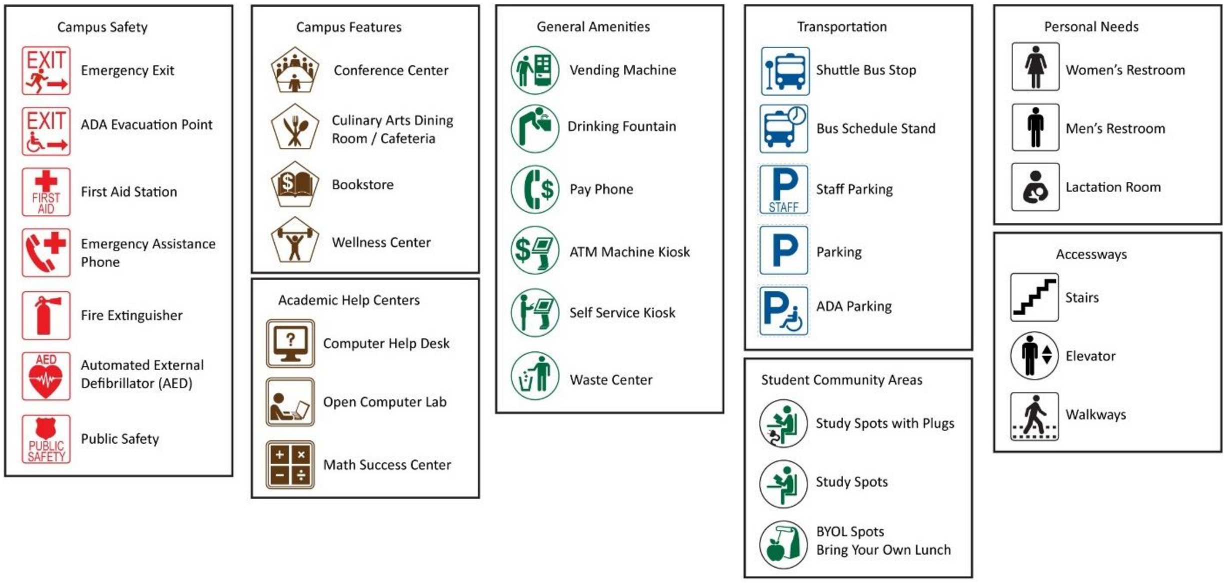


Figure 8: Final symbol set

Building Map Design

There were three different visualizations developed. The first is a simplified architectural floor plan displayed in two-dimension. Rooms were color coded by a use category that correlates with the symbol categories previously created. An example of the visualization used in Map 1 is shown in **Error!**

Reference source not found.. The second map was designed as a more symbolic and abstract map meant to focus more on the corridors as routes and less on the classroom structure. For this map each of the room symbols were located at their doorway access location along the hallways. This map is also displayed in two-dimension and follows the same color scheme as Map 1. An example of the visualization used in Map 2 is shown in . The third map developed uses the same simple architecural plans as Map 1, but developed into a three-dimensional map. An example of the visualization used in Map 3 is shown in Figure 11.

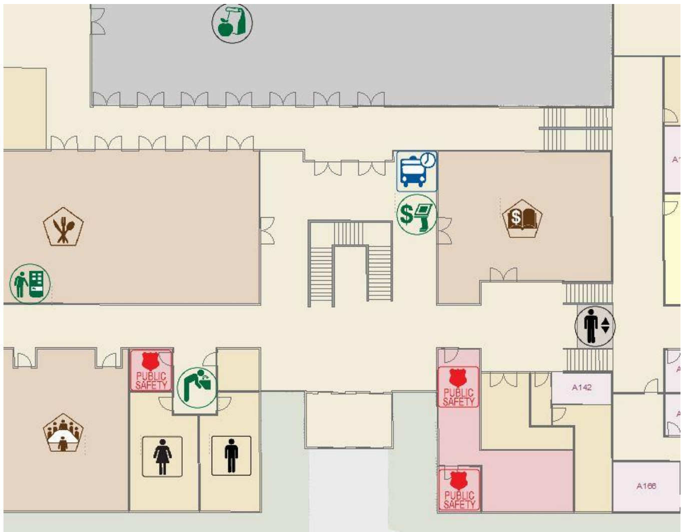


Figure 9:First floor main entrance as visualized in Map 1.

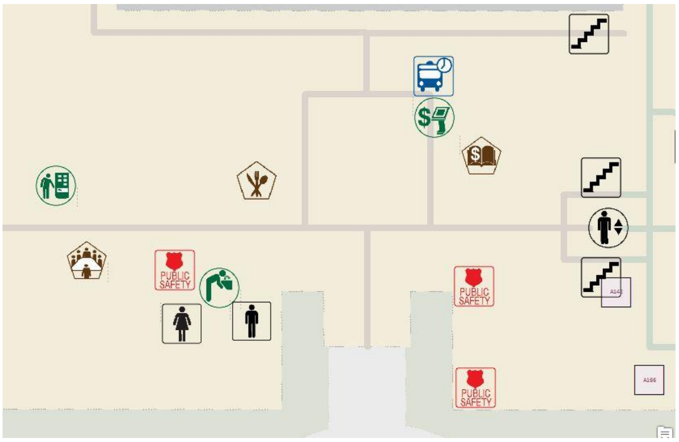


Figure 10: First floor main entrance as visualized in Map 2.

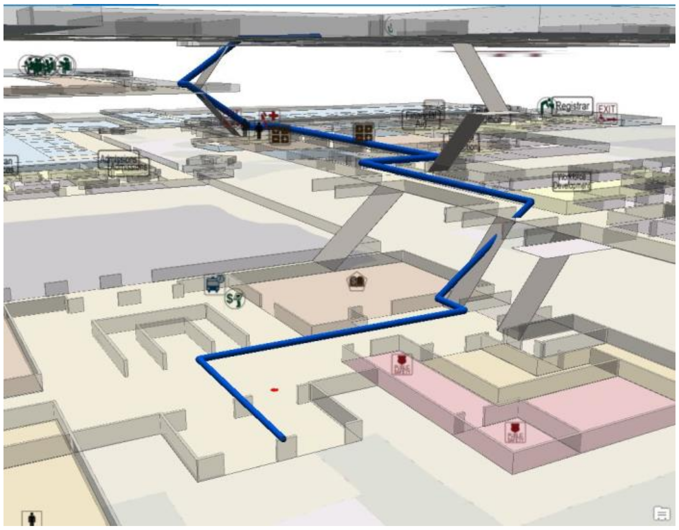


Figure 11:First floor main entrance as visualized in Map 3.

The geometry for all three maps were derived from the same data. The college administration provided AutoCAD files for the site and some sections of the building. They also provided floor plans as PDF files for other sections of the building. The PDF files were georectified and digitized in AutoCAD and merged with the other CAD data. The data in the CAD files were then ground truthed to ensure all the details were correct. This included locating doors, identifying door swings, measuring hallways and classrooms. The floor plans for each of the floors were finalized in AutoCAD first then the Data Interoperability extension in ArcGIS Desktop was used to import the geometry to GIS.

Each of the maps and their associated geodatabases were developed and symbolized in ArcGIS Desktop. They were developed to display with a varying level of detail as the user zooms into the map, as shown in the series of images in .

Figure 12: Series of maps showing the level of detail changing from zoomed out state on left to zoomed in state on right.

Maps 1 and 2 were developed in ArcGIS Desktop, but Map 3 was created by converting the Map 1 document into an ArcGIS Pro project. The floor elevations are exaggerated by three times for clarity between levels. The polygons for the walls are shown using an extrusion. ArcGIS Pro is a fairly new product on the market. It was found to be very user friendly and easy to learn from the perspective of an ArcGIS for Desktop user.

Route Design

For the purposes of this proof of concept, a single route was designed. The route began at the main entrance of the school and traveled through the split-level portion of the building to the second floor. Landmarks were identified at all decision points and at selected points along the path and symbolized in the map, where possible. This route was selected because it also has comprehensive directional signange to support the route instructions.

The routing for all 3 maps was created using ArcGIS Network Analyst extension. All of the network geometry includes z-coordinate values to emulate moving from floor to floor. These z-coordinates are used to model the elevations of the network dataset, thereby making it a 3D network dataset able to solve for routes between different floors.

Interior Positioning System

For the purposes of creating a proof of concept that will require minimal set up, and minimal cost, this project proposed to use the indoor positioning system by Indoor Atlas. Geometri would be the best option because of their built-in integration with ESRI products, but they do not offer any free or low-cost trials for a proof-of-concept. Geometri's positioning system is built partly on the code from Indoor Atlas, who offers a free trial of their system. Indoor Atlas' technology uses a combination of Wi-Fi and magnetic field variations with smart phone sensors such as the accelerometer, gyroscope and compass to identify a position within a building (Indoor Atlas Ltd., 2015).

The positioning system was easy to set up. The process was to upload an image of the floorplan and georectify it on their online map. The advanced features of the online map allowed input of latitude and longitude coordinates to ensure accuracy. Then through their mobile app, collect signal data to create a magnetic field map for each floor plan. The last step is to test the positioning.

Unfortunately, when testing the positioning locations were identified incorrectly a number of times along the route. Many of the walls in this area are metal and limit Wi-Fi signals, phone signal and therefore internet access. This is a known issue with Indoor Atlas because it needs to communicate constantly with the cloud servers to develop an accurate magnetic field map (Indoor Atlas Ltd., n.d.). The school will need to invest in some infrastructure improvements and add a couple more Wi-Fi hotspots in this wing to allow for positioning to work.

This setup and test was completed on version 1.0 of Indoor Atlas' services. They just recently released an update to their services and released SDK 2.0 which claims to be able to locate within 1-2 meter accuracy and also includes an automated floorplan detection feature. Future tests should be conducted in newer sections of the building where the Wi-Fi is more consistent to determine if this is a viable system for future development.

Mobile App Development

Difficulties with the positioning system led to the decision to develop an application that did not include positioning. It was determined that it was better to have users test the application by just following a route with turn-by-turn instructions rather than have the user be informed that they are in the wrong location by an inaccurate positioning system.

The first step of application development is to make the data model and visualizations originally developed on a desktop computer accessible externally. This was accomplished by publishing the map data as a service hosted with ArcGIS for Server 10.3.1 on amazon Web Services. The campus base map, building map 1 and building map 2 were all published as feature services from their respective ArcMap documents. This made the map symbology available as a REST service accessible via a unique URL (ESRI, 2015). The 3D network dataset was published as a network analysis service with routing operations enabled. The 3D visualization in map 3 was exported from ArcGIS Pro as a web scene to ArcGIS Online. Initially, an attempt was made to publish the data as a scene service from ArcGIS Pro through Portal for ArcGIS on Amazon Web Services. After several days of working with ESRI technical support to deploy Portal for ArcGIS with ArcGIS Web Adaptor and ArcGIS Data Store, plus configure the Internet Information Services (IIS) to allow the hosted data to be public, a solution was not found. Ideally, the 3D wall structure should have been converted to a multipatch element, which is ESRI's native 3D feature type. Instead, the walls were created as an extrusion which "is the process of stretching a flat 2D shape vertically to create a 3D object" (ESRI, 2012). Extrusions are not true 3D data and are limited by their 2D geometry. Unfortunately, multipatch elements "can only be published as web scene layers if your active portal is Portal for ArcGIS 10.3.1 or later with ArcGIS Data Store" (ESRI, 2016) Using a web scene from ArcGIS Online provides an acceptable visualization, but multipatch elements would look more realistic and would provide better control over the orientation of the vertical faces of the walls and eliminate gaps (ESRI, 2008).

Initial intentions were to develop mobile apps on the Android platform using ESRI's AppStudio for ArcGIS. This is a fairly new offering from ESRI to build cross-platform native apps. Creating a simple map application from their templates was quite simple and the outcome is a really nice looking app with limited functionality. Routing is not yet a function included in any of the map application templates, so customizing the app to include routing was necessary. This was attempted by using the desktop version of App Studio. As a beginner programmer, the AppStudio Qt Creator was very challenging to work with. The documentation available was difficult to navigate. Other options were explored.

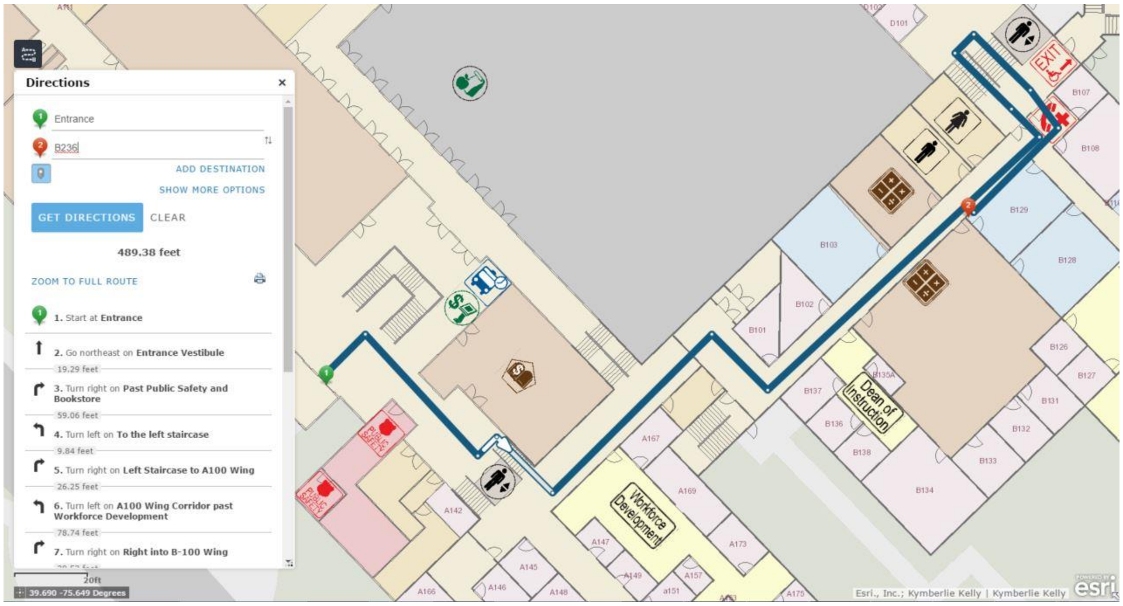
The next product attempted was development using Android Studio with the ArcGIS Runtime SDK for Android. Although this too was a new platform to explore, the documentation was much easier to follow. The tutorials are thorough and several simple Android map applications were easily created. When trying to access the published services for this project, there were permissions issues that would not allow the services to display when the app was tested on an Android device. Eventually after two weeks and ESRI support the application did finally load the feature services.

Due to the difficulty encountered in trying to develop a native Android application, the decision was made to develop a web application with routing capabilities, which would load on any device with internet access. Web applications are not capable of providing positioning services, which is why this format was initially not considered. Since the positioning services will not work inside the college, web application development would pose no issues.

The applications for Maps 1 and 2 were created with Web AppBuilder for ArcGIS (Developer Edition) v 1.3. Both maps provided a “directions” button for users to select a starting point and an ending point. The button widget was programmed with a custom geocoding service to locate room numbers within the building. It was also programmed to access the published routing service to create turn-by-turn directions as shown in **Error! Reference source not found.**.

Map 3 proved to be much more challenging. Using the BETA version of Web AppBuilder (Developer Edition) V2.0, which just came out of BETA on March 31st. The 3D visualization was exported from ArcGIS Pro as a web scene to ArcGIS Online and integrated in a 3D web app without routing capability. Web AppBuilder 2.0 does not yet include support for 3D routing, only 2D routing. The app loads with some minor visual issues on most web browsers, but when loaded on a mobile device the image appears but navigating the map is close to impossible. This was tested on an iOS device as well as an Android device with similar results.

In an attempt to provide a 3D routing app, a 3D web app was also developed using the ArcGIS API for JavaScript 4.0 BETA 3 which supports both 2D and 3D. The routing implementation works by selecting locations on the map rather than with a directions widget. Unfortunately, just as with the other 3D web app, when loaded on a mobile device the functionality is limited.



Directions

Entrance

B236

489.38 feet

1. Start at **Entrance**
2. Go northeast on **Entrance Vestibule**
   19.29 feet
3. Turn right on **Past Public Safety and Bookstore**
   59.06 feet
4. Turn left on **To the left staircase**
   9.84 feet
5. Turn right on **Left Staircase to A100 Wing**
   26.25 feet
6. Turn left on **A100 Wing Corridor past Workforce Development**
   78.74 feet
7. Turn right on **Right into B-100 Wing**

Figure 13: Map 1 web application showing routing and turn-by-turn directions.

Testing & Evaluation

The final stage of the project was to test the route and map applications. Due to the limited functionality of map application 3 on a mobile device, only map applications 1 and 2 were tested. The route was tested by a total of 14 study participants. Participants consisted of 6 students who have been at the school for more than a year and presumably know their way around the school. The second group of participants were students and visitors who are new to the school. Most of this cohort have never been in the building before and therefore have little knowledge of how to navigate the complex split-level school building. The distribution of the participants is shown in Figure 14. The participants wore a head mounted camera to record their activity. The videos were then observed as they followed the route on the map application for moments of uncertainty and for veering off the route. Times were recorded from start of navigation to finish, and the participants were interviewed after for their thoughts.

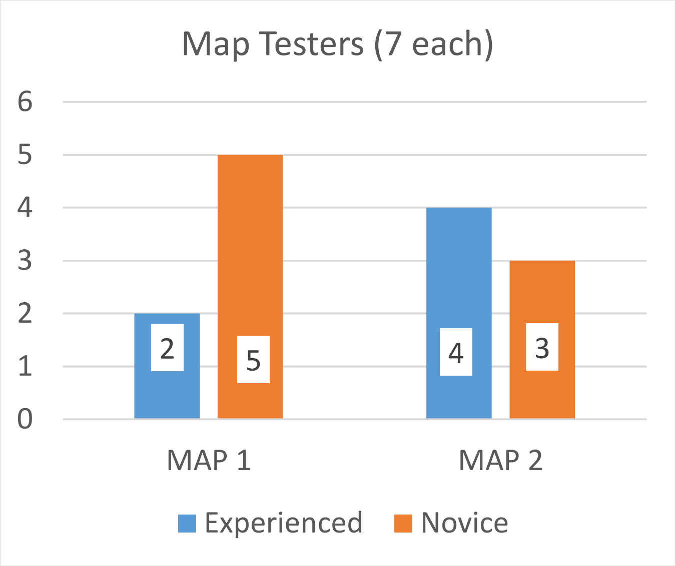


Figure 14: Distribution of map testing participants

The data collected from the study is shown in Table 2. With only 14 participants, the quantitative data collected is not really statistically valid, but it interesting to note that the average time to complete the route only differs by 30 seconds. Although participants using Map 1 took longer, they veered off course less, a total of three times with Map 1 and five times with Map 2. These differences are fairly insignificant with the small sample set. More telling is that a majority of participants veered off course at the top of the first flight of stairs using either map. This spot seems to be the most confusing along the route but has the best signage at that decision point.

Table 2
Testing Data

	MAP 1	**MAP 2**
Average Route Time	4:29	3:59
Ave. Time to Begin Walking	15 seconds	13 seconds
Total Veer off Course	3	5
Veer at Beginning	0	1
Veer at Top of Stairs (A-wing)	3	2
Veer at Top of Stairs (B-wing)	0	2

From their interviews, a majority of the participants found the map easy to use. Nine of the participants mentioned confusion at the stairs and requested better visualization of the stairs. When asked to suggest improvements, eight of the participants requested a "you are here" feature so the map would display where a user is walking along the route.

Conclusion

Testing of the app at the end was limited by the ability to get participants into the building when it wasn't heavily populated. This was not a problem that was foreseen. The first 4 participants completed the test on a Saturday. Even though there are significantly less people in the building on a Saturday, the participants still encountered several people along the route who were either distracting or offering to give directions. The rest of the participants completed the test on a Saturday in which the school was closed to the public. These testers were completely undisturbed while following the route. If future testing is to be conducted, it is recommended to be completed on another day when the school is closed to the public to provide the least amount of distraction.

If the college elects to implement this GIS system, there are 7 symbols that will need to be re-designed and re-evaluated. Additionally, with the release of a newer version of Indoor Atlas's positioning system, additional tests should be completed to determine if this is a viable option for positioning on campus.

Hearing the feedback from the participants about the confusion at each of the stairs, it is hypothesized that a 3D map app will reduce that confusion significantly. With the ability to develop 3D web maps just recently becoming available, it is likely this function will soon be available on a mobile device. At that point, the comparison of the different visualizations should be studied further. Additional studies on best way to communicate floor changes and how to limit disorientation after changing floors would be helpful to strengthen the growing number of indoor navigation applications being developed.

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