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Developing a simulator of a mobile indoor navigation application as a tool for cartographic research

Abstract. Solutions designed for indoor navigation are extremely rare compared to outdoor navigation; however, the potential for development is, therefore, very high. Several pilot projects exist in airports, universities, hospitals, and shopping centres. The difficulties in development are currently mainly due to the continuing low quality of indoor positioning and lack of widespread access to high-quality building models. A strong methodological basis for how the interior and exterior of buildings can be cartographically represented in navigation applications has also not yet been developed. Therefore, an attempt was made to design a virtual environment dedicated to supporting the design of indoor navigation applications. Authors present the results of a study aimed at creating a concept of a simulation environment accompanied by the assessment and preliminary validation of its technological feasibility in terms of the method and technology used – although it does not yet constitute a target study. The result was a fully functional prototype of a virtual test environment, which was successfully used in a pilot study on the effectiveness of different types of navigation guidance. The participants' behaviour within the desktop virtual environment was investigated and their opinions were collected through a questionnaire. This research proved the technological feasibility of the proposed concept and demonstrated the usefulness of the Unreal Engine game engine in building new tools to support the work of cartographers. The created environment will be further developed and used in indoor mapping research.

Keywords: indoor cartography, indoor navigation, map design, Unreal Engine, virtual reality

1. Introduction

The development of indoor navigation applications has been slowed and limited by particular practical and technological difficulties which have prevented the direct transfer of solutions known from other types of navigation. The main difficulty faced by the designers of indoor navigation systems is the lack of widely available technology for obtaining precise location information within buildings. When a user is indoors, the signal from the GNSS satellite network is limited or completely unavailable. In such situations, the only option is to use one of the other technologies available today (Marciniak, 2018); for example, positioning information using an already existing Wi-Fi network in the building, Bluetooth beacons, or mobile phones' inertial sensors (Sakpere et al., 2017).

An excellent example of the utilisation of the above technology is a US hospital, which, in 2015, became the first medical facility in the US to implement a navigation system in its building (Health IT Outcomes, 2015). An example of a development in indoor mapping is the InMapz application, which is widely available and constantly expanding the number of buildings it covers (InMapz, 2022); it allows static floor plans to be converted into digital twins through an automated process.

In addition to location, another essential piece of information used by navigation applications is the direction in which the person using the navigation software is "looking" at any given time. Most smartphones are equipped with a compass, which usually provides this information. However, this is sometimes problematic due to uncalibrated sensors or magnetic field interference caused by, for example, a nearby lift, electrical appliances, or other metal objects.

Another vital element that creates a significant difficulty in the implementation of indoor navigation is the need for digital building plans. For most buildings which have architectural and construction plans, the plans are usually only available as hard copies. CAD drawings are available for newer buildings, but, usually, there is no standard to define how to record information about the structure of rooms, corridors, or floors; although some standards do exist, for example, the IFC (Industry Foundation Classes). It is therefore necessary, to digitise and adapt existing plans or create them anew. Documentation of this type is not widely available, and the free mapping of building interiors is limited for several reasons. The best situation is in the case of new buildings, where the latest BIM (Building Information Modelling) methodologies and technologies have been applied during construction. However, using this data in a navigation application requires permits and carrying out several processes. Solutions combining BIM and GIS (geographic information system) technologies are promising, nonetheless (Isikdag et al., 2013).

The specificity of indoor navigation also generates a whole other set of challenges for cartographers and computer scientists. The representation of the building has to take into account three dimensions, at different levels of generalisation (Gotlib et al., 2020). Over years of cartographic development, the principles for the generalisation and cartographic presentation of open space data have been developed. The cartographic modelling of buildings has only been needed relatively recently, so the process of developing and testing the rules and principles for this area is still ongoing (Huang et al., 2018).

In the process of designing an indoor navigation application, it is crucial to understand how people and vehicles move and behave, which is different in buildings to what is familiar on streets and roads for cars, or even on pavements for pedestrians. Movement is much less orderly and also less predictable than for cars on roads; completely different factors determine whether people stop or turn around; movement can also be vertical (e.g., using a lift). Moving around a building is subject to different restrictions to those for cars on the road (e.g., opening hours, staff-only sections). There are also significant differences in the environment: starting with the lighting, the way the building is signposted, and changes in furnishings and décor.

Another aspect is the different ways in which users interact with the navigation application. In car navigation, the device used for navigation is mounted on a special holder within the driver's field of vision. In pedestrian navigation, the device is mostly held in the hand, and looking at the app's screen requires lifting the device and often involves stopping; otherwise, there is a risk of tripping or bumping into another person. In the case of in-car navigation, audio messages are only heard by the driver and passengers concerned. In the case of indoor navigation, the inconsiderate use of voice announcements would be annoying to those around. On the other hand, the amount of noise in a shopping mall or airport may prevent the audible message from being heard. The use of direct experience which is designed for car navigation applications is, therefore, of very limited use in pedestrian navigation.

The issues mentioned above are only a small number out of many examples which indicate the specificity of indoor navigation and the need for research. The development of state-of-the-art technological solutions to support the design of indoor navigation applications for high-quality cartographic information can be a crucial element in the development of cartography (Chen & Clarke, 2020).

2. The research environment concept and methodology

Due to the specificity of indoor navigation applications and the need for these applications to be properly cartographically designed, a concept was proposed consisting of the preparation of a research environment in the form of a simulator using game technology. The process of conducting multifaceted research (including on the perception of navigation messages and ways in which buildings are cartographically presented) will consist of simulating the navigation process in a virtual world, which allows for more efficient research and reduced costs compared to real-world tests (in an actual building and not its digital twin). A SWOT analysis comparing the two approaches has already been carried out (Kinateder et al., 2014b). When navigating in a virtual building, it is possible to generate multivariate graphic, auditory, and vibrational navigation cues along with multi-scale representations of the building, and identify areas causing wayfinding difficulties. The use of simulators does not eliminate testing in a real-world environment but complements it, and, in some aspects, allows for testing which is not possible in the real world, for example, for safety reasons. Good examples of this are the use of a driving simulator to test the impact of a car navigation display's placement on driver safety (Ishiko et al., 2014), and the social impact tests on the choice of escape route from a burning tunnel carried out in virtual reality (Kinateder et al., 2014a). It is also worth noting research that examines the effect of how a driver navigates at the level of spatial information recall (Khan & Rahman, 2018). Thanks to the virtual testing environment, it is possible to conduct multiple tests under identical conditions (lighting, level of congestion in the building, lift waiting time, etc.).

An important factor that can significantly impact this type of research is the level of immersiveness of the simulation environment. This is dependent on the graphics quality (Jelfs & Whitelock, 2000) and how realistic the accompanying sound design of the simulation is (Çamcı & Hamilton, 2020). In addition, how the simulation is controlled – with a mouse and keyboard or with a professional simulator equipped with appropriate sensors (e.g., pedals, steering wheel and gearstick in the case of a car) – also has a significant influence. Other issues related to the design of the navigation application can also be tested. For example, the quality of the positioning signal can be simulated, including various simulated configurations of its components. Data analysis (data mining) techniques can also be used in the design process (Sattarian et al., 2019). Analysing and understanding user movement will allow for better application design and can also be used in the design of buildings and physical signage in interiors.

The planned research environment could also serve as an educational environment in the future. There are well-known examples of the use of virtual reality in teaching geography (Šašinka et al., 2018). Building models in conjunction with a building viewing system, would be able to function as educational material for architects and interior designers, or as a training field for people with limited mobility.

The proposed concept would also be a simulator-integrated way to collect information about the effectiveness of different types of navigational cues, and to collect feedback on the feelings, perceptions, and preferences of users participating in tests. The research could be conducted through a diagnostic survey or focused interviews.

In the first research stage described in the master thesis by Łobodecki (2020), and in this article, only a simplified test study was carried out on a selected group of users to test the proposed solution from a methodological and technological point of view. The interaction with the virtual reality environment in the pilot study was based on a desktop environment with keyboard and mouse interaction, rather than head mounted VR googles. This is not yet a target study, but a preliminary validation of the method and technology used. For this reason, the following section refrains from presenting the detailed results collected in the research questionnaire. Instead, only basic information is presented to show the specifics of this type of survey. Conclusions from this stage were used to refine the technology and the proposed method for conducting research in a virtual environment. The results of specific research on, among other things, the perception of navigation directions using the proposed solution will be presented in another publication.

For testing purposes, a survey was conducted to compare different types of navigational guidance. Comparisons of this type have already been carried out in the past, but in a different environment and using different methods. An outdoor environment comparison between visual and audio guidance systems is available by Chittaro and Burigat (2005). In the case of indoor navigation, a survey of user preferences on how navigation directions are communicated was executed by De Cock et al. (2019). Also, the first studies on the use of virtual reality in indoor navigation analysis have been carried out (De Cock et al., 2022).

In the future, the prepared environment is expected to allow for a high quality, comprehensive study of these issues as well.

The initial aim of this study was to develop an environment for such testing rather than to conduct the testing itself, which will be carried out in subsequent stages.

3. Selection of game engine technology

The intensive development of three-dimensional visualisation technology is being driven mainly by the gaming industry. According to the *State of Polish Video Games Industry* (Kraków Technology Park & The Polish Gamers Observatory, 2020) report, the global electronic entertainment market is growing rapidly. In 2020, the number of gamers reached 2.7 million, which translates into industry revenues of US$ 175 billion.

Because games, in addition to being an advanced technology, are a form of creative art, the diversity of individual titles shows how much freedom electronic entertainment creators have. At the same time, the game development process primarily uses existing elements. A collection of such configurable elements forms software called a game engine.

Currently, Unity and Unreal Engine are the two most popular game engines in the industry (Toftedahl, 2019). Even though Unreal Engine has almost twice as many games released on the Steam platform,[1] Unity is almost ten times more popular then Unreal in Google searches (Google Trends, 2022), which indicates that it is the choice of individuals and hobbyists. Less popular engines, but still worth mentioning, are CryEngine, Godot, and GameMaker.

After analysing the literature (Christopoulou & Xinogalos, 2017; Ciekanowska et al., 2021), the decision was made to choose the Unreal Engine software, produced by Epic Games. This choice was dictated by several specific features of this engine. One particular feature of the Unreal Engine is the visual programming system (called Blueprint). Using this system to build a research environment prototype will make it easier for future researchers who are not programmers to continue the work. An additional advantage is that this engine allows the best visual effects to be achieved with the least amount of effort, as found in comparative tests (Stylized Station, 2021).

The Unreal Engine is a complete set of tools for, among other things, creating games and architectural visualisations. The engine is written in C++, and its developers have implemented mechanisms that support cross-platform capabilities. Supported platforms include Microsoft Windows, macOS, Linux, iOS, Android, Nintendo Switch, PlayStation 4, Xbox One, HTC Vive, Oculus Rift, and PlayStation VR, among others. The first version of the engine was released in 1998, so it has been in development for more than 20 years. In March 2015, the engine was made available for free to all developers. For commercial use, it is necessary to pay a royalty of five per cent of revenue after it exceeds one million dollars.

The prepared environment was tested in both an older version of the engine, 4.25, and version 5.0, released in April 2022.

4. Description of the developed research environment prototype

The Main Building of the Warsaw University of Technology was selected as the area for virtual testing. The choice was determined by its complexity and the availability of an advanced 3D model for this building, which allowed for advanced testing. The three-dimensional model of this building was created as a result of transformations carried out on source spatial data collected by the Department of Cartography of the Warsaw University of Technology during various scientific and implementation-type projects, including work related to the creation of the Property Information System of the Warsaw University of Technology (Gotlib & Gnat, 2018). The transformations were performed as part of a paper (Janicki, 2020) in which the author used the Unity game engine. The source data were provided in FBX[2] format, which resulted from the preparation of the database according to the Indoor Data Model (IDM)

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[1] A platform which sells games: store.steampowered.com

[2] FBX – one of the main 3D data storage formats for exchanging data between applications.

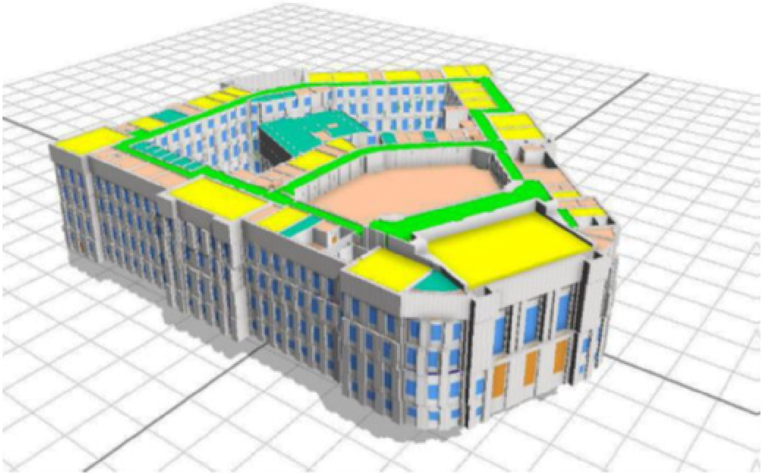

Fig. 1. The 3D model of the Warsaw University of Technology's Main Building, displayed in CityEngine software (Janicki, 2020)

developed by the Department of Cartography of the Warsaw University of Technology.

The model, prepared as described above, was used in this research with the authors' permission. For this purpose, it was initially exported from CityEngine (fig. 1) to a format designed for the Unreal Engine (.udatasmith and .udsmesh). This was possible thanks to the DataSmith functionality, first presented in conjunction with CityEngine, in 2017.

The export parameters were chosen to make the entire building model visible as a single object in the game engine. The final size of the model, including all the textures, was 97 MB.

The mechanics of moving around the virtual building model using a first-person view were

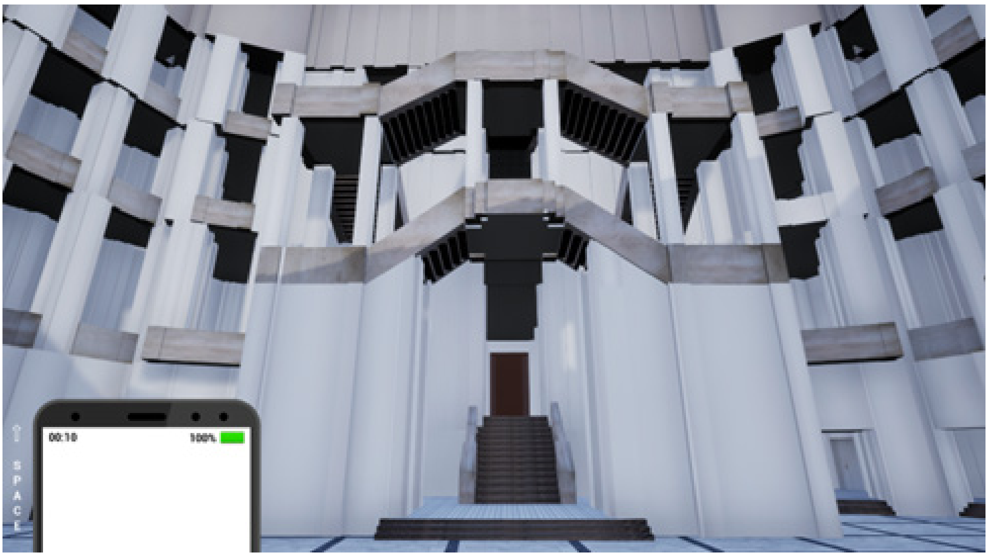

Fig. 2. First-person view inside the virtual building

implemented and assisted by the standard computer game control of a virtual character, using a keyboard and mouse.

The user moved around the virtual building using a first-person view (fig. 2). Moving was done by using the keys for the letters WASD (as in video games) or by using the arrow keys (which may be more convenient for those without gaming experience). Looking around was done by moving the mouse.

In addition, elements were created to mimic the various components of mobile navigation systems. Navigation clues were displayed on a partially visible virtual mobile phone. It was also possible to display a map of the building with the user's current position marked on it. Additionally, this map was oriented in the direction in which the virtual character was currently looking.

Upon completion of each stage of the experiment, a set of statistical data was sent, allowing a research analysis to be carried out. The data collected included the time taken to complete a stage or the number of additional prompts the participant needed to complete a task. The final element of the system was that the participants were able to freely provide their own comments and observations about the research process and the way it is navigated.

The environment described above created a prototype of the research application which was tested in this study. The term "research application" is understood here as an application that is used to conduct scientific research. The details and results of the tests carried out are described later in this paper.

5. Study design

As part of the testing environment, it was decided to test several types of navigation messages. The following types of guidance were designed and placed in the simulator:

– a graphic direction arrow similar to traffic signs, in two versions: large size and small size;
– a graphic direction sign, in different colours;
– an audio message;
– a text message.

It was assumed that the messages would be displayed by the test application (simulator) at different moments during the user's approach to the point at which the manoeuvre was to be performed (e.g. a fork in the corridor, a staircase). The following operating scenario was assumed:

1. On a desktop computer, the user launches the research application, after which, introductory information about the research and the rules for using the application is obtained. Additional statistical information, such as age and gender, is also collected at this point for research purposes.
2. A 3D model of the facility's interior is displayed, which the user can navigate freely using a keyboard and mouse.
3. The application delivers successive test routes to be followed and then navigates the user through the use of appropriate navigation messages (in different versions and at different points of their presentation), as well as enabling the display of an on-demand navigational support map in the form of a 2D visualisation.
4. The application monitors the user's behaviour and regularly uploads information to a database.
5. After the test runs, the application collects additional information from the user for research purposes, such as which type of navigational directions they preferred.
6. The researcher analyses the collected data.

6. The pilot study

In the initial part of the survey, participants were introduced to the context of the survey and how it would be conducted.

The user was then given tasks to complete which involved reaching various destinations. The user (test participant) took the different routes several times using different navigation messages.

In the experiment, four different types of navigation messages were prepared, which were limited to three functions:

– forward movement,
– movement to the left,
– movement to the right.

The first type of message was a graphic message resembling a road sign indicating a "mandatory direction of movement" (fig. 3) in two size variants.

The second graphical solution proposed used colour to distinguish left and right turns (fig. 4). Furthermore, a texture indicating the corresponding direction was additionally superimposed in order to make it easier to associate

Fig. 3. Navigation message in the form of arrows similar to road signs

Fig. 4. Colour-coded navigation message with direction indication

a particular colour with a direction, and also to enable people with daltonism to recognise the direction. The choice of colours was inspired by how directions are marked in nautical sailing (Czajewski, 1991).

The third type of message was a text message displaying text with a simple command "Turn left", "Turn right", or "Continue straight ahead" (in Polish: "Dalej prosto") (fig. 5).

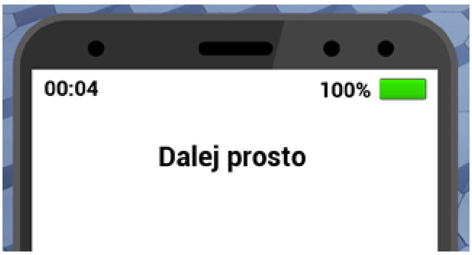

Fig. 5. Example of a text message (Message text: "Continue straight ahead")

The fourth and final type of message was a voice message, symbolised by the display of a speaker icon in the message box (fig. 6). At the same time, a voice instruction with the same content as the text message was played.

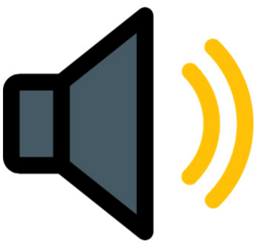

Fig. 6. Voice message indicator (source: flaticon.com)

Figures 7, 8, 9, and 10 show the appearance of the prepared research application when in use.

The upper part of the virtual mobile phone screen is displayed in the bottom left corner of the screen (fig. 8). Here, the various types of navigation messages appear. In addition, the time since the start of the current stage is displayed to motivate the user to complete the task more quickly.

When the SPACE bar is pressed, the rest of the phone is made visible, which simulates the user looking at their smartphone during navigation (fig. 9). The navigation map of the building is visible and oriented relative to the direction in which the user is looking. The map shows the user's current position and the route the participant should take. While the map is displayed, it is impossible to move, and each use of the map "consumes" (simulates) the battery power of the virtual phone. This functionality was aimed at getting the participants to follow the route as quickly as possible and rely mainly on the navigation messages rather than looking around the virtual building.

When the user reaches the door marked with a star (the destination – fig. 10), a summary of the survey's progress is displayed in the form of a series of stars indicating the number of successful tasks completed (fig. 11). It is also possible to abort the survey before it has been fully completed to give the user the option of reducing the overall survey time. In such a case, only fully completed stages are considered for further analysis.

In the prototype application, seven different stages were implemented, requiring the navigation of seven diverse routes using several variants of the navigation directions (tab.1). In target studies, the choice of routes should be carefully considered. Their difficulty, repeatability, and length are important. This is a complex issue and will be the subject of further research.

At the end of the study, a final screen was displayed thanking the user for participating in the study and presenting further survey questions concerning the following:

– the best type of navigation message as perceived by the user,

– the need for indoor navigation solutions,

– general comments and observations after participating in the survey.

In addition, participants could enter their email address to receive a summary of the survey results.

Fig. 7. Screenshot of the developed application from the experiment's starting point. A view of the 3D space from a first-person perspective is shown, as well as the interface elements: a virtual phone displaying navigational directions and text with supporting instructions (the text shown on this screen: "Move around using the WASD or arrow keys. Look around by moving the mouse.")

Fig. 8. Screenshot showing the appearance of the developed application

The developed prototype application displayed navigation messages when the player (participant) fulfilled two conditions. First, the participant had to be in the area which triggered the message (trigger box), for example, approaching a fork in the route. Second, the player had to

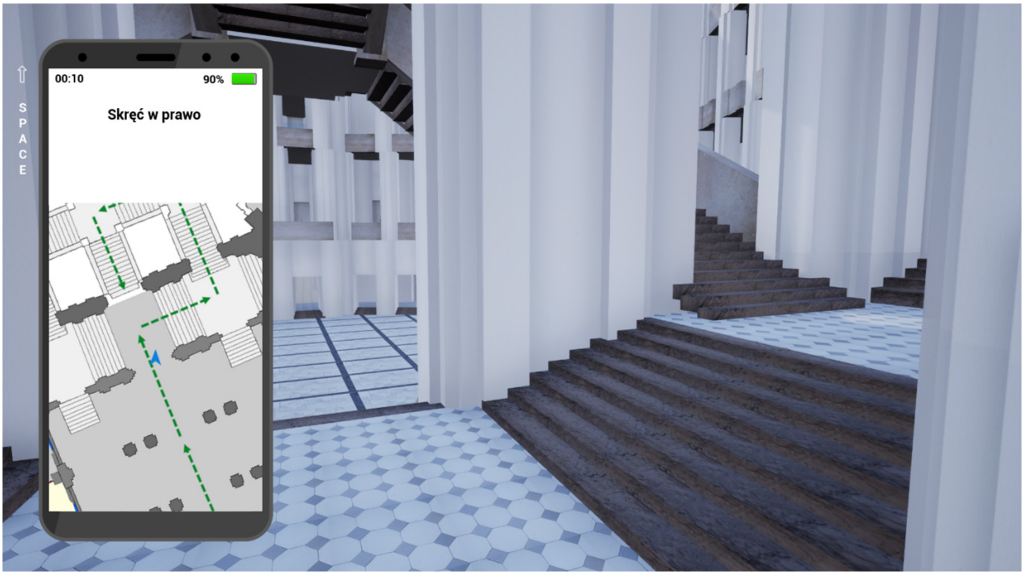

Fig. 9. The map tooltip displayed on user request (the text guidance on this screen is “Turn right”)

“look” in the right direction (using proper mouse operation). The frequency and size of the trigger areas varied between the different stages.

In addition to information about the participant, the application collected information about their behaviour, as shown in table 2.

In order to collect and save research data, three communicating components were used:

1. An add-on to Unreal Engine 4 called VaRest allowed HTTP requests of the POST and GET types to be sent quickly. The request was accompanied by a JSON language element con-

Fig. 10. Screenshot of a star indicating the destination of a stage. The Polish text reads: “Your task is to follow the directions to reach the door marked with a star”

Fig. 11. Screenshot displayed between each stage. On the application screen, the text in Polish reads, top to bottom: “Good job!”, “Get all the stars”, “Next”, “Finish the experiment before the end”

Table 1. Description of the implemented stages and the navigation message variants

Stage	Description	Navigation message variant
1	Introductory stage geared towards familiarising participants with the controls and principles of the application.	Large arrows
2	Cues are displayed immediately before the manoeuvre is required (before a turn, but not when the participant is already at it). A relatively small number of navigation directions.	Random
3	Guidance is displayed directly at a turn, with additional confirmation via the message “Continue straight ahead” when heading in the correct direction.	Random
4	A stage in which navigational directions are displayed along the entire route. At any point along the way, while going in the right direction, the participant sees messages confirming further directions.	Random
5	A route analogous to Stage 4, but with a minimum number of navigation directions; i.e. only before places requiring a manoeuvre.	Random
6	A complicated and elaborate stage using only a few navigation directions, and starting in a different place than the earlier stages. Due to the small number of navigation directions, situations having ambiguous further directions are possible.	Random
7	A special stage using extended text navigation directions. This stage requires the participant to stop, read a longer message, and then go to the next location based on the memorised information.	Text navigation directions based on landmarks

taining a set of data stored in the key-value form. This element was pre-populated with the data collected during the experiment.

2. A cloud-based application based on the Google Apps Script platform. The task of this application was to receive and process the raw data sent by the VaRest add-on and then save it to a spreadsheet.

3. A Google Sheets spreadsheet (Table 3), whose task was to collect the data on the implementation of each stage in a structured way.

7. Preliminary results of the pilot study

Students and acquaintances of the study’s authors, a total of 36 people, were invited to

Table 2. Summary of data collected by the research application on completion of each stage

Information collected	Description
Type of guidance	Types of randomly selected navigation directions.
Duration	The duration of the experiment in seconds. Duration for each stage and the total time of participation in the study.
Number of wrong turns	This number indicates how many times the participant went in the wrong direction for a given stage.
Number of map views	This number indicates how many times the participant needed to use the 2D map display for a given stage.
Time spent looking at the map	The duration in seconds the participant spent analysing the 2D map in search of the proper route.
Coordinates of the map display	Coordinates in the local XYZ system indicate where the participant displayed the 2D map within the building.

Table 3. Excerpt from the spreadsheet collecting the results of the experiment

No	Gender	Age	Related to reseach field	Guid-ance type	Total time	Guid-ance contact time	No of mis-takes	No of map views	Coordinates of map views	Was in the build-ing	Regular navia-gation apps user
1	woman	0 – 18	no	sign	55.82	25.64	0	0	[4741.910645, 3191.268799, 1412.161987] …	yes	yes
2	woman	40 – 60	no	sign	109.22	73.12	1	2	[4035.179688, 1638.719971, 1602.021729]	yes	yes
3	man	19 – 25	no	sign	29.68	2.51	0	5	[3767.577881, 2320.653564, 1496.961914] …	yes	yes
4	woman	19 – 25	no	sign	95.52	14.73	2	1	[3640.507324, 2674.232666, 1412.161987] …	no	no
5	woman	19 – 25	yes	sign	58.35	5.15	0	3	[4745.217773, 2962.134033, 1432.161987] …	no	yes
6	man	19 – 25	yes	sign	35.16	0	0	0	[ ]	yes	no
7	woman	19 – 25	yes	sign	40.17	0	0	0	[ ]	no	yes
8	man	19 – 25	yes	sign	90.40	8.09	4	3	[3570.364014, 2741.678223, 1432.201416] …	yes	no
9	woman	25 – 40	yes	sign	153.47	9.07	0	4	[4912.556152, 3242.214111, 1432.161987] …	yes	no
10	man	25 – 40	no	sign	93.55	34.96	4	11	[4912.556152, 3242.214111, 1432.161987] …	yes	yes

participate in the experiment. As in any survey, information about the participants' characteristics was collected first (gender, age, association with the field of surveying and mapping, familiarity with the building in which the survey was being conducted, regularity of use of navigation applications, etc.); then participants were given several tasks which consisted of navigating a virtual building and reaching a destination, during which the app monitored their behaviour. At the end of the experiment, the participants were asked what they felt was the best way to provide navigational information out of all those tested.

In the final phase of the pilot study, the participants were given the opportunity to make their own comments and observations about the study. Twenty out of the 36 participants who reached this stage took this opportunity. The most common comments are summarised in the table 4.

The results given here are fragmentary and should only be regarded as an example of the possibilities of the created test environment. Therefore, the full results of the experimental study of the users' perceptions are intentionally not described in this article. Further research requires the collection of an appropriately selected group of test participants, the refinement of the application based on the conclusions of the first stage of research, the methodological preparation of the survey, the inclusion of additional navigation cue variants, etc. Experiments of this type will be carried out in subsequent stages of the research.

For additional familiarisation with the developed prototype research tool described here, it is possible to download the zipped application files located at the following address:
https://drive.google.com/file/d/1Cm6aYJ6yhnrV3DtnvxlRq5HKliTnTkb6.

Table 4. Summary of the most common comments from the questionnaire at the end of the study

Comment
Mouse and keyboard control, and lack of experience with computer games, makes the survey very difficult.
Suggestion for introducing up or down stairs guidance messages.
At some stages the guidance messages were displayed for too short a time.
There was a clear indication of the predominance of graphic guidance messages over text and audio messages.
Noting the advantage of voice guidance when it was inconvenient to look at the phone, and also the usefulness of this message type for the blind people.

8. Conclusions and further work

The research and the technology has shown that it is possible to create an environment simulating an indoor navigation application in a relatively simple way. The use of game technology in combination with geospatial data opens up new research opportunities in the field of cartography, particularly in the field of studies on the user perception of maps and other geo-information products. The first comparative tests of wayfinding tasks, in which the virtual environment was directly comparable with the real environment, indicate that both environments can be comparable across all important aspects (Stachoň et al., 2022).

Analysis of the questionnaires completed by the users showed that the main drawback of the developed test environment was the complexity of the controls, which may make it difficult for people without gaming experience to participate in such a study. Improvements in this area could be achieved, among other ways, through virtual reality technology, for example, VR goggles and multi-directional treadmills, and additional training of individuals before the start of a study. A lack of skills in the gaming environment may also affect the study's outcome, which should be considered when formulating further study methodology.

The prototype application to simulate the navigation process presented in this thesis is not yet a complete solution. More reliable and extended analyses will be possible with the further development of the proposed research methodology and the precise preparation of test routes and navigation messages. The experiences gathered during the prototype's development, the observations of the participants, and the feedback collected from them, as well as the review of related literature, allow us to outline the future direction of research on the mapping aspects of indoor navigation application design, in particular research on the perception of navigation messages. In the context of the development of the proposed simulation environment, the possibility of changing the scale of the displayed 2D map within the simulator, the display of 3D maps, the use of different colours for navigation maps, different object signatures, etc., should be investigated. Furthermore, the presentation of an entire planned route on a map could significantly impact the level of orientation within the building space when following subsequent directions. The surroundings of the building should also be added, so navigation outside and inside the building can be integrated.

Another essential element of the simulator is the realism of the rendered 3D graphics. Among other things, a check should be made in subsequent tests as to whether the schematic model of the building shown in the simulator is sufficient to maintain the tests' reliability, and what effect using a photorealistic model would have on the perception of the participants. In addition, the model should be equipped with spatial orientation aids analogous to those found in the real world, such as directional signs, door numbers, and floor identifiers.

In order to make the simulation more immersive, it would be worth adding additional elements that can influence the users' perception. Among other things, it may be essential to simulate the sounds of the surroundings as well as simulate other people in the building to study their impact on the user's reactions and feelings.

The mechanics of moving from floor to floor also require special attention. It is necessary to provide a specific type of message for this type of manoeuvre and to exclude the risk of "falling" down the stairs, which in the current version of the application could occur and, thus, prolong the time it takes to travel the planned route. In addition, it is advisable to add the functionality of a lift ride, which is an integral part of navigating large buildings.

In conclusion, it can be said that the conducted study of the prototype original test environment showed that, despite some limitations, game technology could successfully be used at the stage of designing and testing cartographic aspects of navigation systems.

The developed prototype test environment was built in such a way as to allow its further development until a fully comprehensive simulation test system for navigation products is achieved. The described preliminary research proved the feasibility of the task and allows for the formulation of assumptions for subsequent research stages.

Participation of authors. D. Gotlib: general conception of the research and testing environment, supervision of the work, testing of the system, editing of the article's content. J. Łobodecki: development of the system prototype, system tests, conducting test studies, editing the article's content.

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Literature

Çamcı, A., & Hamilton, R. (2020). Audio-first VR: New perspectives on musical experiences in virtual environments. *Journal of New Music Research*, *49*(1), 1–7. https://doi.org/10.1080/09298215.2019.1707234

Chen, J., & Clarke, K. C. (2020). Indoor cartography. *Cartography and Geographic Information Science*, *47*(2), 95–109. https://doi.org/10.1080/15230406.2019.1619482

Chittaro, L., & Burigat, S. (2005). Augmenting audio messages with visual directions in mobile guides: An evaluation of three approaches. *Proceedings of the 7th International Conference on Human Computer Interaction with Mobile Devices & Services*, 107–114. https://doi.org/10.1145/1085777.1085795

Christopoulou, E., & Xinogalos, S. (2017). Overview and comparative analysis of game engines for desktop and mobile devices. *International Journal of Serious Games*, *4*(4), Article 4. https://doi.org/10.17083/ijsg.v4i4.194

Ciekanowska, A., Gliński, A. K., & Dziedzic, K. (2021). Comparative analysis of Unity and Unreal Engine efficiency in creating virtual exhibitions of 3D scanned models. *Journal of Computer Sciences Institute*, *20*, 247–253. https://doi.org/10.35784/jcsi.2698

Czajewski, J. (1991). *Locja śródlądowa morska*. Wydawnictwa Komunikacji i Łączności.

De Cock, L., Ooms, K., Van de Weghe, N., Vanhaeren, N., & De Maeyer, P. (2019). User preferences on route instruction types for mobile indoor route guidance. *ISPRS International Journal of Geo-Information*, *8*(11), 482. https://doi.org/10.3390/ijgi8110482

De Cock, L., Van de Weghe, N., Ooms, K., Saenen, I., Van Kets, N., Van Wallendael, G., Lambert, P., & De Maeyer, P. (2022). Linking the cognitive load induced by route instruction types and building configuration during indoor route guidance, a usability study in VR. *International Journal of Geographical Information Science*, 1–31. https://doi.org/10.1080/13658816.2022.2032080

Google Trends. (2022, August 23). *Comparision of phrases: "unreal engine" and "unity".* https://trends.google.pl/trends/explore?q=unreal%20engine,unity

Gotlib, D., & Gnat, M. (2018). Koncepcja i prototyp wielofunkcyjnego systemu informacji przestrzennej wspomagającego zarządzanie i użytkowanie nieruchomości Politechniki Warszawskiej. *Roczniki Geomatyki - Annals of Geomatics*, *16*(4(83)), 299–318.

Gotlib, D., Wyszomirski, M., & Gnat, M. (2020). A simplified method of cartographic visualisation of buildings' interiors (2D+) for navigation applications. *ISPRS International Journal of Geo-Information*, *9*(407), 407. https://doi.org/10.3390/ijgi9060407

Health IT Outcomes. (2015, June 30). *Robert Wood Johnson University Hospital launches Connexient's Medinav Navigator Edition 2.0 – first true indoor navigation in a hospital in North America.* https://www.healthitoutcomes.com/doc/robert-wood-johnson-launches-medinav-navigator-navigation-hospital-north-america-0001

Huang, H., Gartner, G., Krisp, J. M., Raubal, M., & Weghe, N. V. de. (2018). Location based services: Ongoing evolution and research agenda. *Journal of Location Based Services*, *12*(2), 63–93. https://doi.org/10.1080/17489725.2018.1508763

InMapz. (2022, September 12). *About InMapz.* https://inmapz.com/2015-10-05-14-35-32

Ishiko, H., Nakano, K., Zheng, R., Hagita, K., Kihira, M., Yokozeki, T., Takayanagi, M., & Yano, K. (2014). Evaluation of safety of navigation systems using a driving simulator. *Seisan Kenkyu*, *66*(2), 173–178. https://doi.org/10.11188/seisankenkyu.66.173

Isikdag, U., Zlatanova, S., & Underwood, J. (2013). A BIM-Oriented Model for supporting indoor navigation requirements. *Computers, Environment and Urban Systems*, *41*, 112–123. https://doi.org/10.1016/j.compenvurbsys.2013.05.001

Janicki, H. (2020). *Visualization of the Main Building of Warsaw University of Technology using a selected game engine* [Bachelor's thesis]. Warsaw University of Technology, Faculty of Geodesy and Cartography.

Jelfs, A., & Whitelock, D. (2000). The notion of presence in virtual learning environments: What makes the environment "real". *British Journal of Educational Technology*, *31*(2), 145–152. https://doi.org/10.1111/1467-8535.00145

Khan, N., & Rahman, A. U. (2018). Rethinking the mini-map: a navigational aid to support spatial learning in urban game environments. *International Journal of Human-Computer Interaction*, *34*(12), 1135–1147. https://doi.org/10.1080/10447318.2017.1418804

Kinateder, M., Ronchi, E., Gromer, D., Müller, M., Jost, M., Nehfischer, M., Mühlberger, A., & Pauli, P. (2014a). Social influence on route choice in a virtual reality tunnel fire. *Transportation Research Part F: Traffic Psychology and Behaviour, 26, Part A*, 116–125. https://doi.org/10.1016/j.trf.2014.06.003

Kinateder, M., Ronchi, E., Nilsson, D., Kobes, M., Müller, M., Pauli, P., & Mühlberger, A. (2014b). Virtual reality for fire evacuation research. *Proceedings of the 2014 Federated Conference on Computer Science and Information Systems*, 313–321. https://doi.org/10.15439/2014F94

Kraków Technology Park, & The Polish Gamers Observatory. (2020). *The state of Polish Video games industry 2020*. https://digitaldragons.pl/wp-content/uploads/2021/03/raport_2021_long_final_en_web.pdf

Łobodecki, J. (2020). *Development of a test environment for analysing the perception of users of indoor navigation applications using game technology* [Master's thesis]. Warsaw University of Technology, Faculty of Geodesy and Cartography.

Marciniak, J. (2018). *Using cartographic models of building interiors to improve the quality of the navigation process* [Doctoral dissertation]. Warsaw University of Technology, Faculty of Geodesy and Cartography.

Sakpere, W., Oshin, M. A., & Mlitwa, N. B. (2017). A state-of-the-art survey of indoor positioning and navigation systems and technologies. *South African Computer Journal = Suid-Afrikaanse Rekenaartydskrif, 29*(3), 145–197. https://doi.org/10.18489/sacj.v29i3.452

Šašinka, Č., Stachoň, Z., Sedlák, M., Chmelík, J., Herman, L., Kubíček, P., Šašinková, A., Doležal, M., Tejkl, H., Urbánek, T., Svatoňová, H., Ugwitz, P., & Juřík, V. (2018). Collaborative immersive virtual environments for education in geography. *ISPRS International Journal of Geo-Information*, *8*(1), 3. https://doi.org/10.3390/ijgi8010003

Sattarian, M., Rezazadeh, J., Farahbakhsh, R., & Bagheri, A. (2019). Indoor navigation systems based on data mining techniques in internet of things:

A survey. *Wireless Networks*, *25*(3), 1385–1402. https://doi.org/10.1007/s11276-018-1766-4

Stachoň, Z., Jochecová, K., Kvarda, O., Snopková, D., Ugwitz, P., Šašinková, A., Ježek, S., Kubíček, P., Juřík, V., Švedová, H., & Sasinka, C. (2022). The possibilities of using virtual environments in research on wayfinding [Preprint]. In Review. https://doi.org/10.21203/rs.3.rs-2045842/v1

Stylized Station. (2021, April 26). *Should I learn Unity or Unreal Engine?* https://www.youtube.com/watch?v=OH2sYJw52BQ

Toftedahl, M. (2019, September 30). *Which are the most commonly used Game Engines?* https://www.gamedeveloper.com/production/which-are-the-most-commonly-used-game-engines-