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F3

Faculty of Electrical Engineering
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Digital representation of building interiors for individuals with vision impairments

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Field of study: Open Informatics
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BACHELOR'S THESIS ASSIGNMENT

I. Personal and study details

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II. Bachelor's thesis details

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Digitální reprezentace interiérů budov pro osoby se zrakovým postižením

Guidelines:

Individuals with vision impairments (VI) need specific tools to acquire spatial knowledge of the environment they need to orientate themselves, such as building floors. Such knowledge is called a cognitive map of the spatial environment. Several methods exist to provide spatial knowledge to VI, ranging from verbal descriptions through interactive tactile maps to virtual reality. All these methods require a digital representation of the related spatial environment (digital twin).
Analyze the current state of the art in the development and processing of spatial data to create tactile maps and other representations (i.e., VR). Include the following approaches in your analysis [1-4]. Analyze the target user audience of individuals with vision impairments, focusing on their needs, preferences, and requirements related to spatial cognitive maps and haptic interaction. Develop or adapt an existing data infrastructure to enable the creation and maintenance of digital twins for generation representations suitable for VI. Develop a software tool for the management of data in this structure. Demonstrate the utility of the solution by modeling part of a real building and show that it can be used for the generation of different representations suitable for VI (preferably 3D printed tactile maps and VR). Evaluate the usability of the developed tool using a usability test with representatives of the target user audience (at least four participants).

Bibliography / sources:

[1] Holloway, L., Marriott, K., & Butler, M. (2018, April). Accessible maps for the blind: Comparing 3D printed models with tactile graphics. In Proceedings of the 2018 chi conference on human factors in computing systems (pp. 1-13).
[2] Palivcová, D., Macík, M., & Míkovec, Z. (2020, April). Interactive tactile map as a tool for building spatial knowledge of visually impaired older adults. In Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (pp. 1-9).
[3] Rottmann, S., Loitsch, C., & Weber, G. (2022). Accessible Mobile Map Application and Interaction for People with Visual or Mobility Impairments. In Proceedings of Mensch und Computer 2022 (pp. 119-127).
[4] Loitsch, C., Müller, K., Engel, C., Weber, G., & Stiefelhagen, R. (2020, September). Accessiblemaps: Addressing gaps in maps for people with visual and mobility impairments. In International Conference on Computers Helping People with Special Needs (pp. 286-296). Springer, Cham.

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Assignment valid until: **21.09.2025**

Ing. Miroslav Macík, Ph.D. Supervisor’s signature	Head of department’s signature	prof. Mgr. Petr Páta, Ph.D. Dean’s signature

III. Assignment receipt

The student acknowledges that the bachelor’s thesis is an individual work. The student must produce her thesis without the assistance of others, with the exception of provided consultations. Within the bachelor’s thesis, the author must state the names of consultants and include a list of references.

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Date of assignment receipt	Student’s signature

Acknowledgements

I would like to thank my supervisor, Ing. Miroslav Macík, Ph.D., for his lead and help during project realisation.

Declaration

I declare that I have prepared the submitted thesis independently and that I have cited all the literature used.

Prague, 24. May 2024

Abstract

For people with visual impairment (VI), prior exploration of unfamiliar places is an advantage before visiting a previously unfamiliar environment. For this group of people, it is particularly important to acquire spatial knowledge of the environment, a so-called cognitive map, in order to orientate with maximum efficiency and possible independence. The first challenge is that information for such training is less readily available. Another difficulty is that information, to be useful, must be tailored to the needs of specific people with VI. In addition to expected requirements such as relevance and completeness, it must be adapted to different forms such as textual description, tactile maps, audio format, etc.

A flexible data format and an editor that allows the data to be edited are needed to create such information sources. Our idea is to create an editor that allows the creation of datasets with a focus on indoor spaces without additional study of the nuances of the domain. In tandem with the popular open-source data format, the project is intended to simplify work with geodata, allowing to customise existing or newly created datasets for different tasks with a focus on people with VI.

Keywords: visually impaired, user-centred design, OpenStreetMaps, indoor navigation

Supervisor: Ing. Miroslav Macík, Ph.D.

Abstrakt

Pro osoby se zrakovým postižením (ZP) je výhodné studovat prostředí před jeho návštěvou. Pro tuto skupinu je důležité získat prostorové znalosti, tzv. kognitivní mapu, aby se mohly efektivně a samostatně orientovat. Prvním problémem je, že informace potřebné pro takové studium jsou obtížně dostupné. Dalším problémem je, že informace musí být přizpůsobena potřebám konkrétních osob s ZP, aby byla užitečné. Kromě očekávaných požadavků, jako je relevance a úplnost, musí být informace přizpůsobena různým formám, jako je textový popis, hmatové mapy, zvuková podoba atd.

K vytvoření takových informačních zdrojů je zapotřebí flexibilní datový formát a editor, který umožňuje data upravovat. Naším cílem je vytvořit editor, který umožní vytvářet datové sady zaměřené na vnitřní prostory bez nutnosti dodatečného studia nuancí této oblasti. Spolu s populárním datovým formátem s otevřeným zdrojovým kódem má tento projekt zjednodušit práci s geodaty a umožnit přizpůsobení stávajících nebo nově vytvořených datových sad pro různé úlohy zaměřené na osoby s ZP.

Klíčová slova: zrakově postižení, user-centred design, OpenStreetMaps, indoor navigace

Překlad názvu: Digitální reprezentace interiérů budov pro osoby se zrakovým postižením

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Chapter 1

Introduction

In this chapter, we define the motivation behind the project, why we focused on an indoor, and our goals during the project: what we planned to create and which tools we planned to use.

1.1 Motivation

Individuals with visual impairment (VI) or low vision (LV) have various difficulties when visiting unknown locations. Even with the existence of several tools for on-side navigation [24, 22, 10] beforehand study of a new location is still an important part of the preparation they accomplish [14, 1].

Studies show that people with VI develop cognitive maps for locations that they are visiting frequently [21, 13]. Furthermore, a study carried out by Herman, T.G., and Chatman [9] demonstrated that visually impaired individuals are capable of learning about their surroundings when provided with general details about paths, objects, and their interconnections within the environment. They memorise routes and landmarks, which help them travel more independently. But for unknown places, where the mental map doesn't exist, everything is much more complicated. Often information about the destination is incomplete or not accessible [14, 1, 21]. Also, this group of people has special needs in information [14, 11, 4], for example, a higher level of accuracy of localisation of possible obstacles. In the case of indoor locations, the situation is further complicated by the overall complexity of the buildings. There are many points of interest within one building in a relatively small area, which creates a potential problem of overloading the user with useless information.

Thinking about the cognitive map that people make for familiar places, one can quickly come up with the idea of creating such a map to explore an unfamiliar space in advance. If we can collect a dataset about the environment we would be able to process this information that way, so people with VI/LV will be able to create a cognitive map before even visiting the place.

To make this possible we need various detailed information about the buildings and their interiors. To create such information we need tools to process the information. Our project is intended to try to become such a tool, to allow easy processing of information so that it can be used for various projects aimed at visually impaired people: tactile maps, VR projects for people with VI, etc.

1.2 Goals of the project

To clarify our goal is not to solve the problem that affects the end-users (people with VI or LV), but to create a tool for developers who will be working on indoor geodata. We want to make datasets readable and understandable for more or less anybody willing to work with geodata.

The fundamental idea of the project is to create a set of tools which help to easily create an actual digital twin of building. We planned to implement quite a wide range of functions and since we assume that the application can be used without deep additional knowledge, we need to stick to the idea of accessibility of functionality for the user.

Our secondary goals in the course of work are to analyze possible solutions, justify why we have chosen the OpenStreetMap format for our work, define a stack of tools, which be used in the development, specify app requirements, implement a prototype and test our solution.

Our objectives are summarised in the following list:

1. Study the problem. Determine what tasks the application will perform and how it will be used.
2. Explore options for solving the problem. Choose a suitable one and justify why we have implemented it.
3. Prepare design specifications for the chosen solution.
4. Identify available services, which we can use in our solution. Decide on the technology stack. Create tools for editing and managing geodata files. Develop a prototype with this functionality.
5. Evaluate created prototype. Test our solution in the available way and rework the prototype based on the evaluation.

Now, after we define our motivation and goals, we will conduct an analysis of the problem and existing solutions. We will discuss tools, which will be used during implementations and will define the technology stack.

Chapter 2

Analysis

In this chapter, we will analyse the problem and possible solutions. We will explore the needs of visually impaired people, as our project is aimed at helping this group. We will discuss why we settled on our solution and specific format. Also, we will better define the target audience of the application.

2.1 Needs of Visual Impaired People

As studies [2, 1, 11, 21] show, people with visual impairments or low vision (VI/LV) have highly diverse needs depending on their routine, level of independence and interests. Summarising the main recurring points, the following is important for this group:

1. **Safety**

   Having in mind aspects affecting physical safety: permanent landmarks, traffic congestion and traffic patterns, places to ask for help, etc.

2. **Important landmarks**

   Entrances, exits, sidewalks, stairs, elevators, points of interest to meet needs like toilets, etc.

3. **Navigation**

   Potential permanent landmarks: points that can be used to determine one's position or orientation in space.

4. **Various information related to points of interest**

   People may come to a location for different reasons and depending on them they need different information about different points of interest.

People with VI/LV often remember these aspects when they frequently visit locations. According to studies [21, 13], they do it by developing cognitive maps. A cognitive map is an imaginary map created in the brain as a form of representation of the spatial environment [28, 27]. It is understood to be a mental representation that includes the positions of various locations and the directions and distances between them [7].

Respectively, unfamiliar routes and interiors don't have such representation in memory. Since a person doesn't have experience with it, it will be much harder to orient and navigate without the help of a cognitive map. In addition to this, they also need the information to be as up-to-date as possible [14]. Irrelevant or incomplete information is usually rather confusing than helpful in navigation [21]. Changes even in already-known routes can lead to a person getting lost [21].

People with VI/LV have wide needs for information about locations. To address this issue a location description dataset can be created and frequently updated to remain up-to-date. Such a dataset can be helpful for this group of people to build cognitive maps for visiting unfamiliar places and navigating there.

Studies show that interior of buildings [14, 1, 11, 21] have significantly less information available than outdoors, making it one of the most problematic parts of navigation for people with VI/LV, which is why we focus on indoors in our work.

2.2 Related Work

Solutions how to fulfil the navigation needs of people with VI/LV already exist. Firstly there are multiple technologies in on-side navigation. The study by Santiago Real and Alvaro Araujo [22] describes in detail the technologies used in such applications: GPS, RFID tags, Wi-Fi, etc. Examples of such applications are BlindSquare [16] or Lazzus [17]. In addition to special applications and additional navigation systems, more classical methods of navigation, such as tactile maps, are also widely used [5].

As evidenced by the study of Müller, Karin, et al. [14] most of the people with VI/LV tend to plan their trips in advance, especially when travelling to unfamiliar places. The most popular materials for planning are digital maps, textual descriptions, and assistants. There is already quite a lot of literature [14, 2, 4, 21] describing what information is most interesting to people with VI/LV. Based on this data, projects, whose goal is to enhance the accessibility and usability of existing location data, have been implemented. For example, speaking of textual descriptions, the work of Anken, Julia, et al. [1] tested short allocentric descriptions of sections of indoor buildings, which seems to be effective for people with VI/LV.

Even if there is relatively less information about indoor environment, projects like Accessible Maps [15] working on making this information more accessible to the public. Specifically, Accessible Maps do this by processing building plans and generating maps from them, which later can be used in various ways.

As conclusion, we can say that already exists multiple solutions how to navigate people with VI/LV or how to describe locations to them . However, implementation requires up-to-date datasets and the ability to work with them conveniently to meet the requirements of the audience. To try to solve this problem we started our project: a geodata editor, which would allow us to adapt the information to the needs of people with VI/LV.

2.3 Data representation

There are different data representation formats and systems to use for creating a dataset. The most popular ones are Geographic Information System, Building Information Modeling and OpenStreetMap.

2.3.1 Building Information Modeling

Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of an object. As such, it serves as a common knowledge resource for information about an object, forming a reliable basis for decision-making throughout its life cycle, from inception [3]. To put it another way, BIM is a 2D/3D representation of a building that includes all engineering information.

- Pros:
  1. **Modern**
     BIM is a modern system which means growing community and newest solutions.
  2. **Powerful**
     BIM allows to perform a powerful and detailed analysis for engineers.
  3. **Free**
     BIM is free to use and doesn't require usage of any proprietary components.
  4. **Legally required**
     Certain countries have legislation that requires the use of BIM in construction projects. So it is more likely to already exist for modern buildings.
- Cons:
  1. **Scope**
     BIM was designed to store and operate on very detailed technical information such as pipes and energy levels, which is not needed for indoor plans
  2. **Complex**
     BIM is a powerful software by the cost of complexity which means that it requires specifically trained professionals to work on any application using it

Conclusion: BIM is a great tool but it doesn't fit within our needs, we need a simple format to store 2D representations of building interiors and BIM is complex and designed for rather technical information.

2.3.2 Geographic Information System

A geographic information system (GIS) [25] is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface.

Being a very popular system, many projects are using GIS. The most popular one is ArcGIS. A part of it, ArcGIS Indoor, fits our needs the best since it was designed specifically for indoor representations.

- **P**ros:
  1. **Popular**
     ArcGIS Indoor is a popular tool which means that it has a big community and help if needed.
  2. **Powerful**
     ArcGIS Indoor provides lots of features out-of-the-box with a simple configuration.
- **C**ons:
  1. **License and cost**
     ArcGIS Indoor is a paid tool and it highly restricts our permissions to use it.
  2. **Proprietary**
     ArcGIS Indoor is a proprietary tool, meaning it's hard to write projects using it. This also restricts our possibilities of customization and rework of the tool itself.

Conclusion: ArcGIS Indoor is a good candidate but it will be hard to use it because of its proprietary format, source code and licensing.

2.3.3 OpenStreetMap Format

OpenStreetMap (OSM) is a project aimed at providing free, open-source and legal geographic tools, including a specific flexible data format. This format, being rather a set of rules, supports various data formats like JSON and XML. We chose to use XML because it's a default language used in OSM documentation and various community projects using OSM [19].

- **P**ros:
  1. **Popular**
     OSM Format is a popular tool which means that it has a big community and help if needed.
  2. **Simple**
     OSM Format is very simple consisting of only a few data models, which makes it simple and easy to integrate to any project and maintain it.

3. **Free and open**
   OSM Format is specifically aimed at allowing anyone to use it for almost any purpose without additional costs and restrictions.

- **C**ons:

1. **Blurred standards**
   Trying to achieve maximum flexibility, OSM Format gives recommendations but doesn't enforce strict standards. Sometimes, this leads to inconsistent data structure among different projects using OSM.
2. **Not feature-rich**
   Being simple, OSM format has only basic data models and lacks some bigger abstractions like buildings. Along with not enforced standards sometimes it's hard to extract complex data models from datasets.

Conclusion: OSM Format fits our needs but it requires additional effort to handle complex structures.

Conclusion

Weighting the pros and cons of each solution, OSM seems the most reasonable.

Considering existing projects in the same field, it will be reasonable to choose a solution which will not only exist independently but also correlate with existing ones. For example, project AccessibleMaps [15] is involved in indoor data sets development, which is available openly in OSM services, creating a way for potential integrations.

Another advantage is that the OSM model is well-documented [20] and easy to use. It has some issues, that we discuss in the section below, but overall it is a decent solution for indoor geographical data.

To sum up: simplicity, integrability and fulfilment of all implementation requirements of our project are the main arguments why we chose to use the OSM data model.

2.4 Detailed OSM description

OSM data model consists of three main structures: Node, Way and Relation. A Node represents a point in space. Its main attributes are position through longitude and latitude and its ID. Ways are formed from the existing Nodes. In general, every object, which in the top perspective is similar to the line, will be represented through Ways, for example, walls and roads. Relation is used to define logical or geographic relations between these different objects (for example a lake and its island, or several roads for a bus route).

For better understanding now we will discuss an example. Figure 2.1 shows a simple street diagram represented in the OSM data model structures.

The blue lines represent Ways. In the schema, they are used to define the road and building contours. Red circles are Nodes. In the schema, we use them to represent bus stops.

The purple rectangle represents the Relation between two parts of the building: inner and outer outline. This Relation unites two unrelated Ways into one complete element.

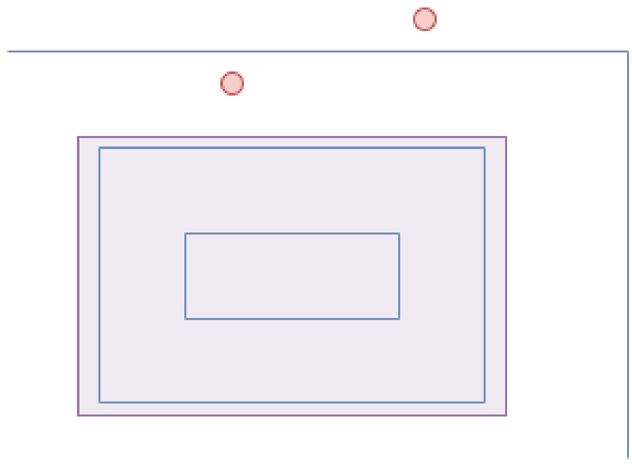

Figure 2.1: Simple scheme of OSM format representation

All OSM objects may have tags. Tag is a key value pair, which is the only way how to add any type of description to the objects. There is no strict limitation in tags and generally, it is not forbidden to describe any characteristics through any custom tags. However, there is a recommendation to use recognised tags describing basic things like object type or address. We will take this into account and in most cases use only a set of recognised tags for consistency with other projects.

Simultaneously with the simplicity of the OSM model realisation, it has some limitations. The main problem is that indoor parts of the building do not have a recognisable connection between each other. In other words, if we have multiple buildings in a single file it will be difficult to identify which building contains which room. The same situation is repeated in the connection of e.g. doors and rooms, windows and rooms, stairs and buildings and generally in all cases where potentially there can be an object-to-object relation.

In practice, several solutions can be implemented. For instance, the easiest way to identify which room belongs to which building is to introduce a new tag with an ID of the building. A more complex solution would be to add a Relation, which would represent the connectivity of the building elements.

Another problem with the OSM model is that objects like a door do not have fixed dimensions. Also, objects like vending machines will be represented by a single Node, which limits both size and mesh data.

The lack of information on Node itself can be easily solved using tags. It will be easy enough to add a tag containing size and some reference to the connected mesh.

2.5 Target user audience

As has already been described in sections about the goals of our project even though our primary motivation is to solve a significant issue that affects people with visual impairments (VI) and low vision (LV): the lack of available indoor information, which is a critical resource for navigation and self-preparation for trips, our approach is to solve a related issue: the lack of tools that offer visualisation and editing capabilities for indoor geographic data.

Given this context, our target user audience is, first and foremost, developers. They need a tool to work with geodata, which will be convenient and allow quick editing of data.

We expect that users will be familiar with similar software (meaning software with any editing capabilities). We don't expect programming skills from users, so even calling them developers is an overstatement. They don't need to be familiar with OSM data format, so the application does not require knowledge of the model.

In conclusion, the analysis chapter has provided an exploration of the needs of visually impaired people. We explored related works in the field and how other researchers try to solve existing problems. We analysed existing data representation, justified why we chose the OpenStreetMap format for our work and fully described it. In the end, we define our target user audience, define their needs and expected abilities.

Chapter 3
Project specifications

In this chapter, we will outline the project requirements and describe the stack of technologies used in the implementation of the project.

3.1 Requirements

At its core, the application serves as a visualizer of the collected indoor geodata in OSM format. In other words, the application takes a dataset and transforms it into a digital map of a building.

However, the application also needs to provide the ability to easily modify datasets, which allows for fixing dataset errors or adding additional information to it to adapt it to the developer's needs.

From this point, we can specify the functional and non-functional requirements of the application

3.1.1 Functional requirements

1. **Provide visualisation of geodata**

   Visualisation is a key advantage of our project, it generally makes the dataset understandable for a human being.

2. **Allows read OSM/XML data files**

3. **Provide separation data between different objects: nodes, specific groups of nodes and ways between them**

   It is important to provide separation between different structures in geo-data: building and room need to be visually distinct

4. **Allow reading of tags. Allow adding/deleting tags.**

   Tags are the main source of additional information about the objects in the OSM model, so it is crucial to let users edit this.

5. **Allow view adjustment**

   Raw geo-data may be placed inconveniently for reading, so it will be reasonable to add an option for view adjustments

3.1.2 Non-functional requirements

1. **Use OpenStreetMaps with the corresponding library**

   In our project, we will use an OSMSharp library for proceeding OSM files

2. **Use an OSM model of data**

3. **Simple to understand without special knowledge to use**

   For the understanding, the visualisation user does not need knowledge of the principles of the OSM model

4. **OSM data model provides opportunities for compatibility with other projects**

   Mainly with OpenStreetMaps itself which makes this information more accessible to people who need it

3.1.3 Technology Stack

As a programming language was selected C# with the usage of Windows Presentation Foundation (WPF). To handle OpenStreetMap data, the project utilized the OSMSharp library.

Fair to mention that the project was not planned as a final product but rather as a fully functional prototype. There will be a lot of 'good to implement' objectives which will be mentioned in the Evaluation and the Implementation chapters, but the goal is to fulfil defined functional requirements.

Chapter 4
Design

In this chapter we will discuss planned design and used design solutions in application. We take a look at prototype design evolution and justify some of our solutions.

In our work, we decided to stick with User-Centred Design [8], which will affect our designs. Since we planned that the application would be easy to use without any additional knowledge we need to ensure that the user interface is intuitive and easy to navigate. In the design we must not miss possible user misrepresentation during use, so the addition of possible warnings and error notifications must be considered.

4.1 Data Visualization

The main focus of the user's attention will be on data visualisation. The user will be working with the data for the most amount of time and the main functions of the app will revolve around it. Given the importance of this element, it is necessary to design the interface in such a way that the work is as convenient as possible.

As was mentioned, the results our application will produce are supposed to be used to develop projects for people with VI and LV. As a result, we consider that information that is relevant to their navigation is the most important. Based on user surveys and analysis [11, 15] of other research we can identify the interior of the building, stairs and elevators, doors and windows, objects of interest or obstacles. Other important data is the division of the purpose of the premises. So our work concentrates on those elements of visualisation.

4.2 User Interface

We begin our discussion of design from a sketchy version of what we want to achieve. Figure 4.1 presents a rough sketch of the interface device. Different colours highlight different important areas of interest. As we discussed in the previous subsection our main point of user interest is the visualisation itself. So a clickable canvas with elements takes up most of the screen (in Figure 4.1 inside the first red area).

Inside visualisation we planned to do a visual separation of elements depending on their properties: different types of elements have different colours, even if they have the same OSM type but have different logical types like room and building silhouette, inside lines are thinner than outside lines, elements have different selection colours, etc.

Other main important parts of a layout taken by floor selector (in Figure 4.1 inside the second blue area) and tags overview (in Figure 4.1 inside the third green area). Floors are an important part when we are talking about buildings because they have different layouts, so users need to clearly understand which ones are active. Not less important part of the OSM model are tags which basically have all useful information about objects. That being said, the user needs to have an easy way to affect them, adding new or deleting existing ones.

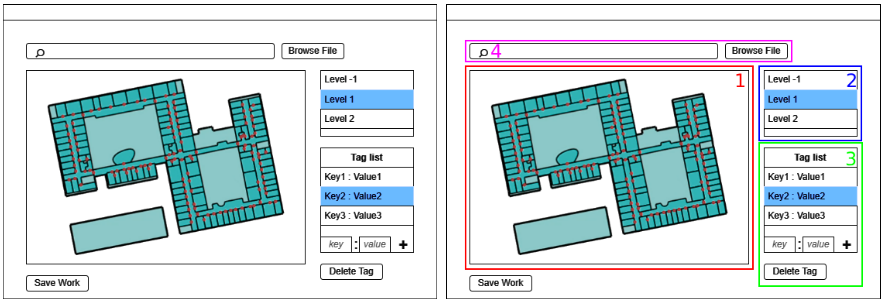

Figure 4.1: UI sketch

4.3 OSM format reading and storing

We used the OSMSharp library to work with OSM format, so we could easily separate OSM files into three collections: Nodes, Ways and Relations. If we create a diagram of how the application works (Figure 4.2) it becomes easier to understand: information from the file is separated into three main collections of main OSM types. After that, all collections are parsed through tags: we find buildings and determine the number of existing floors. Then we see all the elements related to the floors because unfortunately there is no direct connection between the building elements in the data.

Theoretically, this problem can be solved more easily at creation, by connecting building elements via Relations or specific tags. But since existing datasets do not have this for universality we found elements manually.

After elements are found we create different types of objects: NodeObject, OpenedWayObject and ClosedWayObject to store any information about all objects inside visualisation. As a pair to them, we create their shape collection so that individual elements will be clickable on canvas.

After the user finishes work, objects are recompiled again into Nodes, Ways and Relations collections which will be written into a new file.

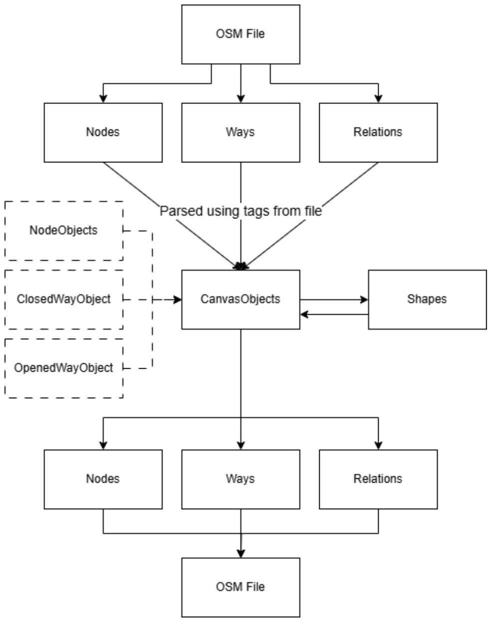

Figure 4.2: Application Architecture diagram

4.4 First prototype

The first working application prototype (Figure 4.3) was quite crude and did not have all of the planned functionality at the time. In many respects, it repeats the interface sketch (Figure 4.1). There were significant flaws in its design like confusing terms or like an awkward tag list that took up more space than necessary. Also, during the first testing process, which will be described in Chapter 6.1, problems related to feedback on user actions have been identified. The more embedded features and tools within the app became, the more it became necessary to rethink its design.

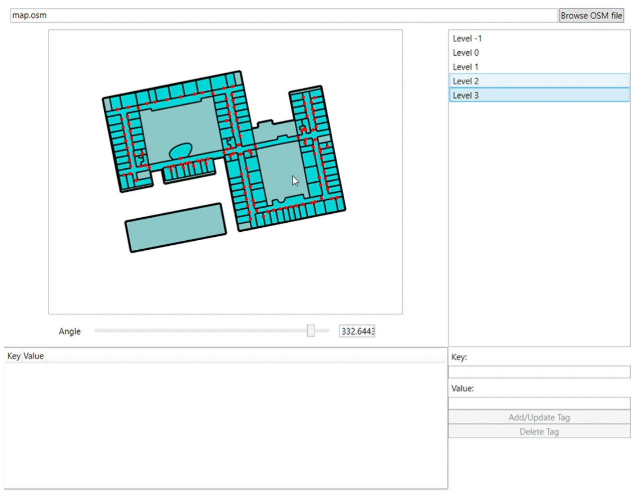

Figure 4.3: First prototype screen

4.5 Second prototype

The second prototype (Figure 4.4) became much more complex and advanced. The emergence of new features forced the creation of a top toolbar toggle. In this design, some more helpers and elements make the application more user-friendly. As a result of prototype testing (described in Chapter 6.1), we got rid of confusing labels, trying to address the issue of ambiguous naming. Tips were added on the left side of the screen. It describes every mode of application, so it will be easy to understand their meaning. The tag list was reworked to make it more compact.

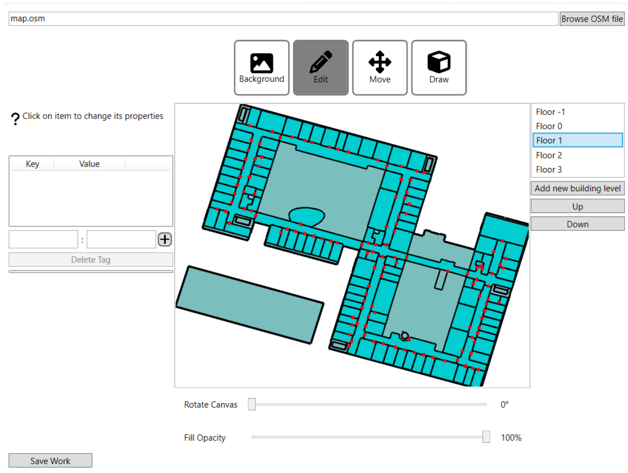

Figure 4.4: Second prototype screen

Overall last application prototype shows visible progress compared to the first one, from the perspective of both functionality and implementation of the application design. The work was done with the use of the results of a cognitive walkthrough testing (described in Chapter 6.1). The result is an application that implements all important functional requirements.

Chapter 5

Implementation

In this chapter, we will discuss an implementation process, which challenges we met during it and how it was solved. We will have a look at application structures and talk about implementation details.

5.1 Code structure

Our code consists of multiple nested structures. Simple ones are used for UI and rendering and more complex classes are used to store and process more complex data.

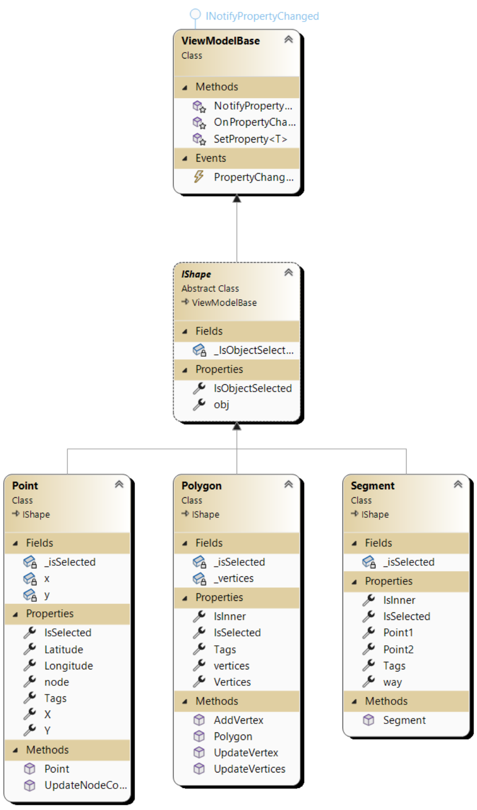

Figure 5.1: Base structures

The most basic class is `IShape`. Classes labelled in Figure 5.1 `Point`, `Polygon` and `Segment` extend this class and are used to render data on a canvas.

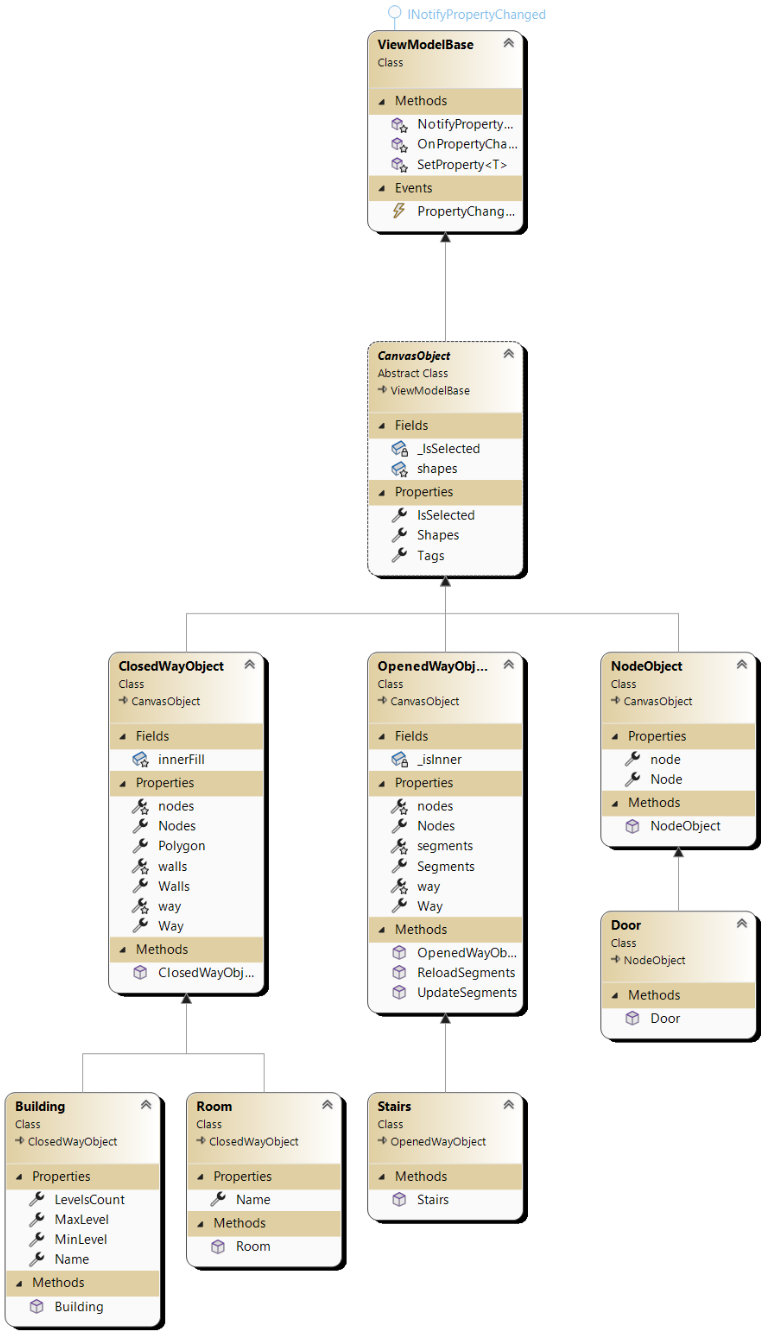

Figure 5.2: High-level structures

High-level structures labelled in Figure 5.2 used to describe complex entities, such as `Building`, `Room`, `Stairs` and `Door` extend `NodeObject`, `OpenWayObject` or `ClosedWayObject` depending on item shape. These object classes extend the general `CanvasObject` class. These classes utilise base structures.

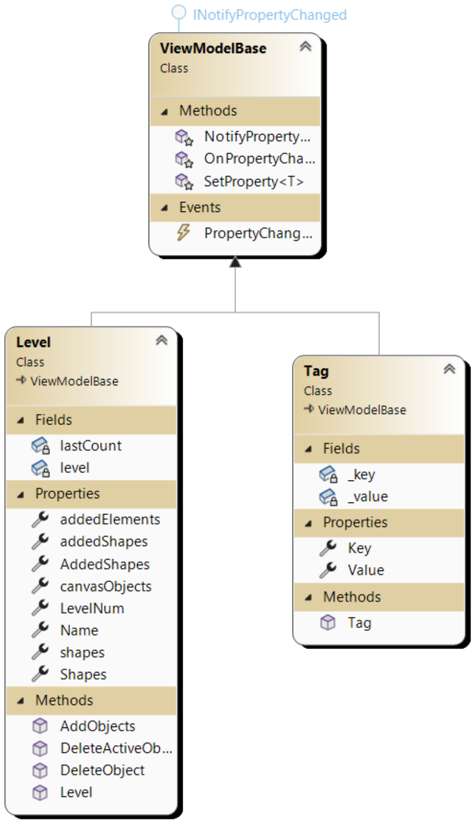

Figure 5.3: Level and Tag

`Tag` class is holding a single piece of object description. `Level` class labelled in Figure 5.3 is a wrapper for all the high-level structures.

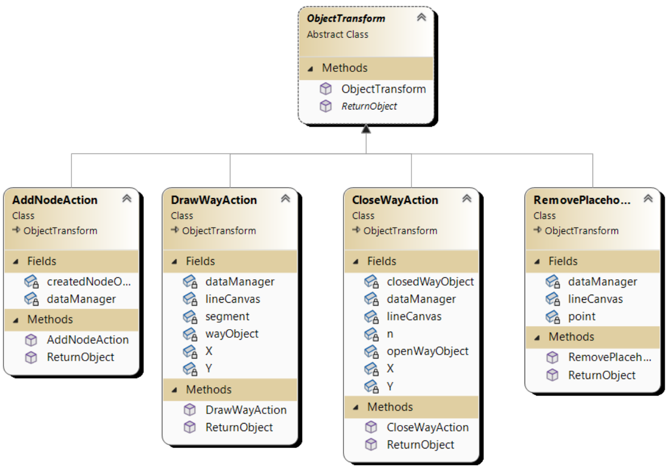

Figure 5.4: Actions

Tools in our app are implemented with action classes labelled in Figure 5.4 which have methods to perform respective operations.

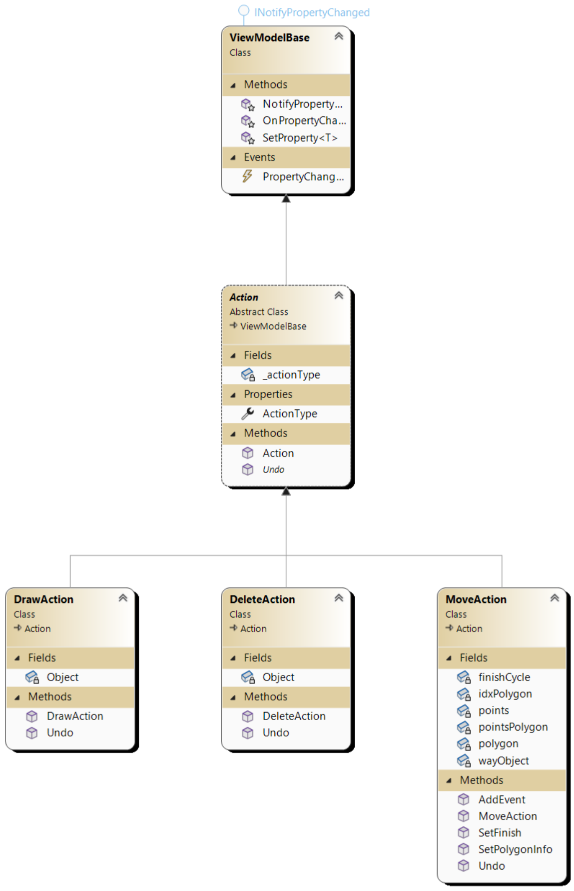

Figure 5.5: Undo Actions

Similar to Actions labelled in Figure 5.4 there are classes to undo (Figure 5.5) these actions. Basically, it is action classes doing reverse operations.

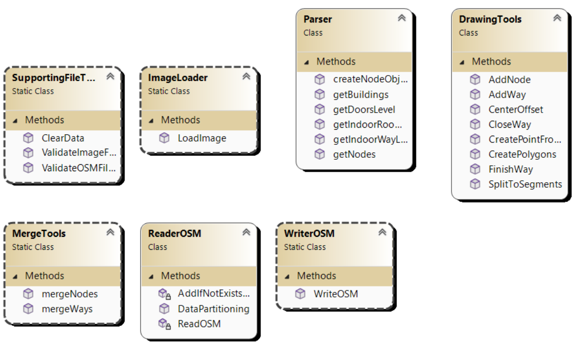

Figure 5.6: Utilities

There are a few utility classes labelled in Figure 5.6 involved into loading, reading, parsing, rendering, collecting and writing data.

5.2 The coordinates problem

One of the biggest challenges in implementation was coordinates. All elements in OSM format have their coordinates, but it is recorded in WGS84 format as a pair of longitude and latitude. Translating these coordinates onto a flat 2D canvas format without significant loss in accuracy and doing the reverse translation was one of the tasks that we solved in the process of working on the project.

We tried several potential solutions, but the most successful and simple was to use the Mercator projection, a common method for projecting the spherical Earth onto a 2D map while preserving angles locally and after it to map the 2D Cartesian coordinates in meters onto a 2D canvas depending on the canvas size. It also worked fine in the reverse direction of the coordinate translation.

5.3 The tags problem

As we have already discussed, a major problem with the OSM format is the lack of direct communication between the actual related elements. For example, if there is a building and a room in a dataset, it is impossible to understand from the file content whether they are connected or not, it will be possible to understand only on visualization because of overlapping.

This creates some difficulties for further use of OSM data for example for 3D printing, because if the file is complex and contains more than one building, it is impossible to separate their content.

We have considered a possible solution to this problem and came to the conclusion that the simplest solution is to make a unique tag for a building and use it to select objects.

Tags, in general, are quite a universal tool. As a potential use-case, they allow us to attach information about the 3D model of the object or its specific parameters such as dimensions. Tags have a very big potential and they will be given more attention in future work on the project.

In conclusion, this chapter has provided an overview of the implementation process and detailed the structure of the code. We discussed the difficulties encountered: the problem with coordinates and the nuances of the OSM format. After that, we discussed the chosen solutions.

Chapter 6

Evaluation

In this chapter, we will discuss the evaluation process of the application. The evaluation was conducted in two phases: cognitive walkthrough without users and and with the participation of users.

6.1 Evaluation by cognitive walkthrough

Before testing the app with users, we conduct a cognitive walkthrough test [12]. Although we interviewed the person with VI to find out what information would be most relevant to them and scheduled tests with users, it was decided to conduct a cognitive walkthrough test first to troubleshoot potential obvious problems.

A cognitive walkthrough is designed to simulate the cognitive activities of the user, the simulation concentrates on the dialogue between the human and computer in each phase. First of all, we define task-definition question

- **Q0: What does the user want to achieve?**

  The user wants to get OSM data in a readable format and easily read and edit them.

To achieve the goal, the user needs to go through several steps:

1. **Open file.**
2. **Get visualisation.**
3. **Upload an image of the building plan.**
4. **Adjust an image.**
5. **Select any object to edit.**
6. **Edit objects.**
7. **Save work.**

For each step, we need to go through several questions:

- **Q1: Will the correct actions be evident to the user?**
- **Q2: Will the user connect the label of action with their goals?**
- **Q3: Will the user receive sensible feedback?**

Right now we will go through each step and answer these questions:

1. **Open file.**
   a. **Q1: Will the correct actions be evident to the user?**
      Yes. If the user opens a correct OSM file it will be loaded.
   b. **Q2: Will the user connect the label of action with their goals?**
      Yes. Loading is realized through common browsing of files.
   c. **Q3: Will the user receive sensible feedback?**
      Yes, if the user chooses an unsupported file type, the user will get a warning message.
2. **Get visualisation.**
   a. **Q1: Will the correct actions be evident to the user?**
      Yes. visualisation will appear after loading the file on a previously empty canvas.
   b. **Q2: Will the user connect the label of action with their goals?**
      Yes, from the building schema, the user can understand if he loaded the correct dataset.
   c. **Q3: Will the user receive sensible feedback?**
      Specifically no. So far, the user only receives a visualised image of the building.
3. **Upload an image of the building plan.**
   a. **Q1: Will the correct actions be evident to the user?**
      Yes. The image will appear after loading the file under the visualisation.
   b. **Q2: Will the user connect the label of action with their goals?**
      Yes, as far as we can evaluate labels of instructions are clear.
   c. **Q3: Will the user receive sensible feedback?**
      Yes. In case of only one possible error, an unsupported file type, the user will get a warning message.
4. **Adjust an image.**
   a. **Q1: Will the correct actions be evident to the user?**
      Yes. The image will move, scale or rotate according to the used command.

   b. **Q2: Will the user connect the label of action with their goals?**
   Under our assumptions, explicit instructions on the screen on how to use the commands should be sufficient to accomplish the task.
   c. **Q3: Will the user receive sensible feedback?**
   Other than actual changes in image placement, no. There will be no other sensible feedback. That will be the first found issue: *lack of feedback during work with image.*

5. **Select any object to edit.**
   a. **Q1: Will the correct actions be evident to the user?**
   Yes. After selection list of tags of the selected object will appear.
   b. **Q2: Will the user connect the label of action with their goals?**
   Yes, the user will distinguish objects by using different selection colours.
   c. **Q3: Will the user receive sensible feedback?**
   Yes, colours and selection will guide the user in their actions.

6. **Edit objects.**
   a. **Q1: Will the correct actions be evident to the user?**
   Yes. Possible actions will affect tags or objects.
   b. **Q2: Will the user connect the label of action with their goals?**
   Yes, all possible actions in the project are obviously signed.
   c. **Q3: Will the user receive sensible feedback?**
   Yes, after changing the list of tags or objects will be updated.

7. **Save work.**
   a. **Q1: Will the correct actions be evident to the user?**
   Yes. The user will get a notification.
   b. **Q2: Will the user connect the label of action with their goals?**
   Specifically no, but the button description should be fairly obvious to the user. That will be the second found issue: *we expect something to be obvious for the user, but we cannot guarantee that.*
   c. **Q3: Will the user receive sensible feedback?**
   Success or errors will be displayed in notifications.

The main issue found during the cognitive walkthrough is a lack of sensitive feedback for user action. Another possible issue is that we assume that something will be obvious for the user, but, obviously, without actual user testing.

As a result of such testing, the application was slightly redesigned by the time of testing, in large part on the interface side, more unambiguous labels and instructions for various tools within the application were prescribed. From this evaluation of the last version, we can conclude that the app should do well in front of users.

6.2 Evaluation with the participation of users

After the prototype was adjusted based on the results of the cognitive walkthrough we moved to the evaluation process with users. During the evaluation, 5 participants (will hereinafter be referred to as P1-5) were tasked with recreating part of the 3rd floor of a CTU building on Charles Square according to the building plan.

Participants were required to use the think-aloud protocol technique during accomplishment tasks similar to tasks at our cognitive walkthrough evaluation. Upon fulfilment, they fill out a System Usability Scale (SUS) form [23].

Before starting the evaluation process participants were interviewed on several questions, which we will discuss further below, and were briefly introduced to an OSM data model. As we expect that the application can be used without additional knowledge, participants have not explained all the details of the model or the nuances of the application, only the essence of the other three model types: Node, Way and Relation.

6.2.1 Testing procedure

Test participants one by one performed the task of completing the existing OSM file with data following the provided floor plan image. During the task, participants performed the think-aloud protocol technique [26, 23] which is wildly used in UI testing [6]. Such a technique involves participants verbalizing their thoughts, feelings, and actions while performing a set of specified tasks. This technique provides observers with insights into the participant's cognitive processes, making thought processes explicit during task performance. It helps to analyze user behaviour while performing tasks and identify bad design decisions in the user interface.

The execution process was videotaped and manually documented in parallel. Consent for recording and data processing was obtained from the participants.

At the end of the test, the data from notes and in video format were analyzed and the identified problems were corrected in the final version of the program.

6.2.2 Participants overview

As was mentioned, participants were interviewed on several questions:

- **Q1: What is your educational background? Is it connected with software?**

- **Q2: Do you have previous experience with similar applications(for example any map editor)?**
- **Q3: What is your English level?**

All participants answered the first question positively.

Majority of the participants(P1, P2, P4) responded negatively to the second question. P3 mentioned that has some previous experience with map editors and P5 answered the second question negatively but said was more familiar with the OSM data model.

For the last question, most of the participants(P1, P2, P4, P5) answered that they had B2 English level and only P3 had level B1.

6.2.3 Task overview

As was said scenario of tasks was recreating part of the building according to the building plan, i.e. adding missing interior parts to an existing building outline. Participants were provided with an OSM file from OpenStreetMap [18] service and a 3rd-floor fire escape plan of the building.

The main task was separated into a smaller 4 tasks:

- **First Task:** The first task was to upload both, OSM and image, files into the application

  The user was expected:

  - **Browse an OSM file and open it.**
  - **Switch to work with background.**
  - **Browse and upload an image file.**

- **Second Task:** The second task was to adjust the image according to the size of the OSM representation, match position and angle.

  The user was expected:

  - **Switch to work with background.**
  - **Optionally for convenience adjust representation opacity.**
  - **Adjust the image using guidelines for existing shortcuts.**

- **Third Task:** The third task was to create the interior of the building using available tools. Users had to place the new rooms on the correct floor. Since the tagging system is key in the OSM model we also tested the users' understanding of their use and asked them to add tags to new objects.

  The user was expected:

  - **Change active building floor.**
  - **Switch to draw mod of application.**
  - **Add all needed line objects to the representation.**

  - **Switch to edit mod of application.**
  - **Add corresponding tags to new object.**

- **Fourth Task:** The fourth task was similar to the first but tested the understanding of the node elements. It was necessary to add elements to the plan and tags to them accordingly.

  The user was expected:

  - **Switch to draw mod of application.**
  - **Add all needed point objects to the representation.**
  - **Switch to edit mod of application.**
  - **Add corresponding tags to new object.**

an additional task was to fill out a basic SUS form by ranking each question from 1 to 5 based on how much they agreed with the statement they were reading. 5 means they agree completely, 1 means they disagree vehemently:

- **Q1: I think that I would like to use this system frequently.**
- **Q2: I found the system unnecessarily complex.**
- **Q3: I thought the system was easy to use.**
- **Q4: I think that I would need the support of a technical person to be able to use this system.**
- **Q5: I found the various functions in this system were well integrated.**
- **Q6: I thought there was too much inconsistency in this system.**
- **Q7: I would imagine that most people would learn to use this system very quickly.**
- **Q8: I found the system very cumbersome to use.**
- **Q9: I felt very confident using the system.**
- **Q10: I needed to learn a lot of things before I could get going with this system.**

6.2.4 Evaluation results

Now we will review the results of the user evaluation.

The first task was easily completed by all participants. Only P3 had a little trouble at runtime, not immediately recognizing that the image and geodata were loaded in different paths.

The second assignment raised considerably more questions. Participants P2, P3, P4 and P5 did not immediately see the image transformation instructions already open on the screen and had difficulty locating them. Participants P1, P2 and P4 mentioned that after some time they got used to the control and could recognize it as quite easy to use. P4 noted nothing unambiguous and P3 expressed maximum difficulty in using it.

The third and fourth tasks were similar and for the most part the participants handled them well. Issues were mostly in visual feedback for users. Participants P1, P3, P4, P5 were confused if they are selected object or not. Also, participants P2 and P3 didn't properly understand how line objects work.

Outside of tasks participant P4 said that a tutorial is needed when using the application for the first time. Participants P2 and P3 also made mistakes during execution and said that undoing the actions is necessary that need to be added.

To sum up repeat all found issues in a structured list:

1. Confusing position of instructions for applications mode.
2. Unclear feedback for users' actions.
3. Missing undo function.
4. Not intuitive enough tools which require an explicit tutorial.

The results of the SUS form are summarised in Table 6.1. The table reflects the SUS score per participant for every question, which is calculated [23] based on participants' answers.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
P1	3	4	3	4	4	4	3	4	3	1
P2	2	4	1	3	1	2	4	2	1	4
P3	2	3	2	3	2	3	3	4	2	4
P4	1	4	2	1	3	1	4	3	3	4
P5	1	4	3	0	4	3	3	4	3	4

Table 6.1: Participant SUS score per question

If we calculate the average value according to the SUS Score calculation rules [23], then we get the next score per participant reflected in Table 6.2.

Participant	SUS Score
P1	82.5
P2	60
P3	70
P4	65
P5	72.5

Table 6.2: SUS score per participants

That gives an average result of **70**, which is above the average SUS score of 68. Such results indicate that an application has a decent level of usability.

If we calculate a standard deviation we will get a approximate deviation of 7,58.

As a result of user testing and evaluation, the app has been redesigned. Even though the evaluation showed a decent result, several problems that need attention were found. Some functions, such as highlighting, became more visible on the screen. Additional functions such as undo operations were implemented.

Chapter 7

Conclusions

In this chapter, we will discuss our results and our next plans after this project and make a goal summarization.

7.1 Discussion of results

During our work, we have achieved some results. For the final summaries, let us recall what our goals were at the beginning.

1. Study the problem. Determine what tasks the application will perform and how it will be used.
2. Explore options for solving the problem. Choose a suitable one and justify why we have implemented it.
3. Prepare design specifications for the chosen solution.
4. Identify available services, which we can use in our solution. Decide on the technology stack. Create tools for editing and managing geodata files. Develop a prototype with this functionality.
5. Evaluate created prototype. Test our solution in the available way and rework the prototype based on the evaluation.

During the preparation phase (Goal 1), we conduct an analysis and describe our motivation behind the project. We reviewed possible solutions and chose the OSM format for our work (Goal 2). For processing this data format we decide to use the helping library: OSMSharp (Goal 4). We discussed that we are interested in creating a tool for geodata processing. The tool should be easy to use and allow wide editing of datasets (Goal 3).

We want to create a usable tool for working with geodata, to make that dataset readable and understandable for developers who will work with them. This is a rather large task that we have not fully realized, but we have made significant progress in this direction. The current project is already capable of processing OSM files and allows editing datasets in different ways (Goal 4). We complete our goals of implementing the functionality of reader and writer of OpenStreetMap format and tools functionality for complete editing of OpenStreetMap format elements. At this stage application allows drawing custom objects, editing by moving or deleting and of course editing tags.

We tested our app with users (Goal 5), which helped us identify problem areas in the prototype and also provided us with recommendations of potentially useful features that could be implemented on the job.

After the evaluation was accomplished we managed to add some important features in our application (Goal 5). Worth mentioning that we also make progress in implementing user-friendliness elements of redactors such as undo functions, tags recommendations and image transformation for convenient usage of reference images.

7.2 Future work

In future work, it is planned to finalize the project to a full-fledged application and use it in practice in related projects. During user testing, we find some interesting ideas which can be useful inside the application, for example, first-startup tutorial or integration of OSM learning materials. It will be great to work on a practical usage of the project and possibly adapt it for use as a tool to create haptic maps.

The idea and the prototype definitely has potential and usage, especially if as a result of future work it will be finalized and debugged to the state of a full-fledged application.

Appendix A
Contents of the attachment

To this work attached a zip file with the following content:

```
Submission ..................... the main folder containing all the files
├── Digital Twin ............. the folder with binary files and test files
│   ├── Binary ............................. the folder with binary files
│   │   └── Digital Twin.exe .................... runnable application
│   └── OSM files ........................... the folder with test files
│       ├── CTU test file.osm ........... test .osm file of CTU building
│       └── Fireplan CTU.png ..................... image of floor plan
├── Source Code ........................... source code of the project
├── thesis.pdf ...................... text of the thesis in PDF format
└── LaTeX Source Code ...... source form of the thesis in LaTeX format
```

Appendix B
AI Assistants

The use of these AI tools aligns with the guidelines and permitted extent outlined in the "Framework Rules for the Use of Artificial Intelligence at CTU for Study and Teaching Purposes in Bachelor and Follow-up Master Studies" document (issued on 29th January 2024).

Microsoft Copilot (formerly known as Bing Chat) has been used for self-study, literature search and rephrasing.

Grammarly AI Writing Assistant was used to improve the correctness of academic writing.

Appendix C

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