Universidad Politécnica
de Madrid

Escuela Técnica Superior de
Ingenieros Informáticos

Master in Digital Innovation

Master Thesis

User-centred Design for the Interface of an Artificial Intelligence Buildability Tool

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July, 2021

This Master Thesis has been deposited in ETSI Informáticos de la Universidad Politécnica de Madrid.

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Abstract

By 2050, the population of the world will increase by more than 2 billion. This growth will especially influence urban areas and will determine an urgent need to build more housing and develop the infrastructure. The architecture, engineering, and construction (AEC) industry will be challenged. Professionals will have more opportunities for designing and building, but they will also face new limitations as the resources of the planet are already stressed enough.

To this, the recent investments in the Build-to-Rent (BTR) sector add up. With house prices only rising, it is becoming harder for young people to afford a house. Moreover, due to the pandemics, the high levels of unemployment and wage cuts will make it impossible for many people to sustain or even increase their savings. Thus, it is estimated that in the near future, more houses will be used for rent, which will determine a transition from home ownership.

Within this context, Lurtis is developing a buildability estimator, which will enable developers and architects to maximize the potential of a plot and of an investment. This tool reduces the time of pre-design and can create dozens of design solutions based on user preferences and governmental regulations. Users can easily compare which project is more profitable, without the need to build anything, saving resources and time.

The objective of this Master Thesis is to design the user experience for the buildability tool, to facilitate its adoption. The paper discusses the recent trends in the real-estate industry and explains the concept of buildability. It explores the strongest competitors in the industry focusing on their design strengths and weaknesses. It then analyzes the needs of potential users and provides different design solutions for the tool. The evaluation of these solutions is presented, culminating with details about the technical implementation of the buildability estimator. The paper concludes with a reflection on the entire design process and with future ideas to be tackled.

Table of Contents

1 Introduction

The United Nations estimate that by 2050, the number of people living on Earth will increase from about 7.6 billion today to nearly 10 billion [1]. Moreover, this growth will focus on urban areas which will contain 68% of the entire population [1]. The rapid urban development will impact our infrastructure, energy systems and even employment opportunities. Due to increased housing demand, the construction industry will need to build an average of 13,000 buildings every day through 2050 [1] (Figure 1.1).

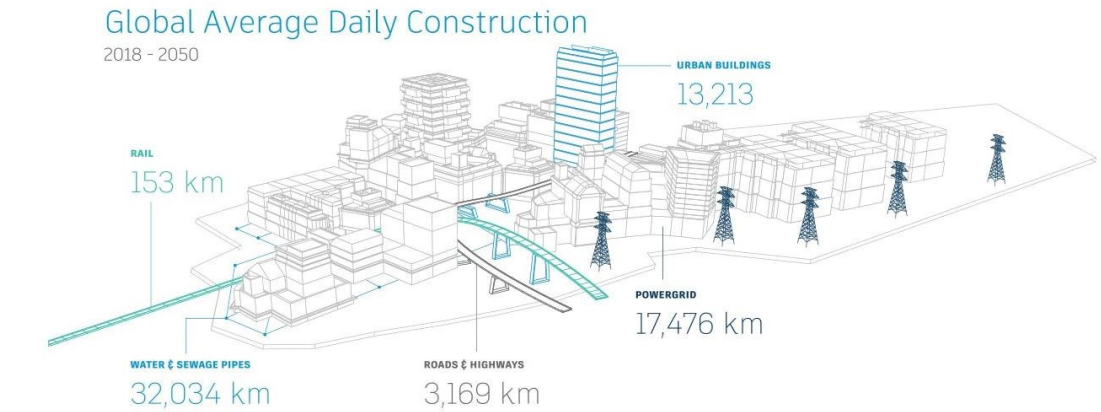


Figure 1.1 Global Average Construction within 2018-2050 [1]

These trends will impose considerable challenges on the real estate industry. Maximizing efficiency while reducing costs will become a mandatory demand. Moreover, regulation standards which become more rigorous each year will force companies to adopt new technologies and invest more in the R&D departments. The AEC (architecture, engineering, and construction) industry will need to rethink how they design and operate building environments [1].

Within this context, Lurtis aims at providing an AI-based buildability estimator that will assist architects, designers, constructors, and investors by automating the design process. Lurtis Rules is a company founded in 2015, with more than 20 years of experience. It offers digital solutions based on Artificial Intelligence in the fields of architecture, engineering, finance and health. The company is based both in Madrid and London, and the entire team consists of 22 members. The collaboration with the company started in the Innovation & Entrepreneurship course, in which a business case was tackled. The business case was to analyze the market potential of the buildability estimator.

The collaboration continued within the Master Thesis project and it involved designing the user experience for the previously investigated tool in order to facilitate its market adoption. Some of the key features of this software will be: providing users with an early estimate of a land's potential, assessing which project is more profitable, specifying the building typology and how the distribution of living units must be to obtain maximum profitability. As inputs, users have to select a land, customize its setback, specify a set of regulations and their preferences. As outputs, the tool generates optimized designs with detailed information about the building price, orientation, buildability and other metrics.

During the project, Lorena Cruz Pino (Business Development Lead at Lurtis) was the main supervisor. All of the tasks were decided together with her, and

the progress was discussed in weekly meetings. Nicolás Tapia Sanz (Junior Programmer at Lurtis) also participated in the meetings as his work involves technically implementing the tool. Another company participating in the study was Morph Estudio. As Lurtis works in close collaboration with them, Morph's members agreed to participate in the user research phase. Regarding the UX development process, I was the only designer.

The process of designing the user experience for the buildability tool involved researching existing similar products on the market, understanding potential users in order to create technical features mapping their needs and experimenting with different design solutions. An initial objective was to implement the resulting UI in Unity. Due to time constraints and the scope of the project being so large, the UI was not technically implemented, but the mechanics of the real-time development platform Unity were tackled.

The paper firstly discusses the recent trends that influence the real-estate industry with a focus on the outspread of the COVID-19 virus and on the developments of the BTR sector (Chapter 2). It then explains the concept of buildability and the initial features established by Lurtis to be included in the first version of the tool (Chapter 2). In Chapter 3 the most powerful competitors are analyzed, focusing on their design strengths, weaknesses, price points and customer segments. For a clearer comparison, the competitors are assessed against a set of core features. Following, the paper delves into the user research part (Chapter 4). It presents a stakeholders mapping and a prioritization matrix in order to identify all the people influenced by the project and the connections between them. Then, it discusses the findings of the interview performed with architects as well as the refined persona and customer journey. Chapter 5 explains the process of designing the prototype expanding on the changes needed to transition from low-fidelity to high-fidelity. In Chapter 6 the findings of the testing sessions and the design improvements are presented. Lastly, Chapter 7 tackles the main aspects of the technical implementation using Unity.

2 Market research

When starting the project, the first objectives were to learn about the product and the domain. Thus, the trends that currently dominate the real estate industry were analyzed. Then, a closer look was taken at Lurtis value proposition, focusing on understanding the minimum buildability requirements.

2.1 COVID-19 impact on real estate

The outbreak of the Coronavirus disease has impacted the real estate market on each one of its sectors. As governments all over the world imposed a strict lockdown, workplaces transitioned to home offices, shopping moved almost entirely online, and restaurants were forced to shut down [2]. Although these measures were mandatory for slowing down the spread of the virus, they also imposed overwhelming challenges on the economy and implicitly on the real estate sector.

Analyzing the effects of the Coronavirus outbreak on the real estate industry is difficult as its impact spreads across multiple sectors and depends on larger macroeconomic factors. Moreover, due to the rarity of the event, data availability is limited which makes it harder to predict future scenarios. However, the following sections will try to expand on the COVID-19 effects, particularly on the commercial and residential markets.

The commercial real estate sector, with a focus on the hotelier industry and retail properties, was directly hit by the pandemics. In the United States, hotel industry revenue per available room fell 11.6% at the beginning of March 2020, whilst in China the occupancy rate fell 89% by the end of January 2020 [3]. Moreover, some of the largest hotelier chains such as Marriott International or Hilton Worldwide either placed tens of thousands of workers on furlough or borrowed substantial loans as response to the unprecedented fall in demand [4, 5]. The European market was also affected, as in March 2020 hotel occupancy in Germany decreased by over 36% compared to the previous year, and Italian cities such as Rome recorded an occupancy rate of approximately 6% [6]. London remained the most stable with an occupancy rate of approximately 47% [6].

In offices, the shift to remote working and telecommunication is expected to have started a long-term change. Due to this, it is forecasted that some offices will get smaller, while others could investigate increasing the square footage per person to minimize the risks of infection. The decline in office real estate is expected to be comparable to the economic crises of 2002 and 2008 [7] (Figure 2.1). Insolvency is likely to rise and “companies will give priority to restoring their business” rather than investing in real estate projects [7]. It is estimated that the Paris prime office market could lose even 10% of its values, whilst the biggest cities in Germany and Italy could record a drop of 20% [7].

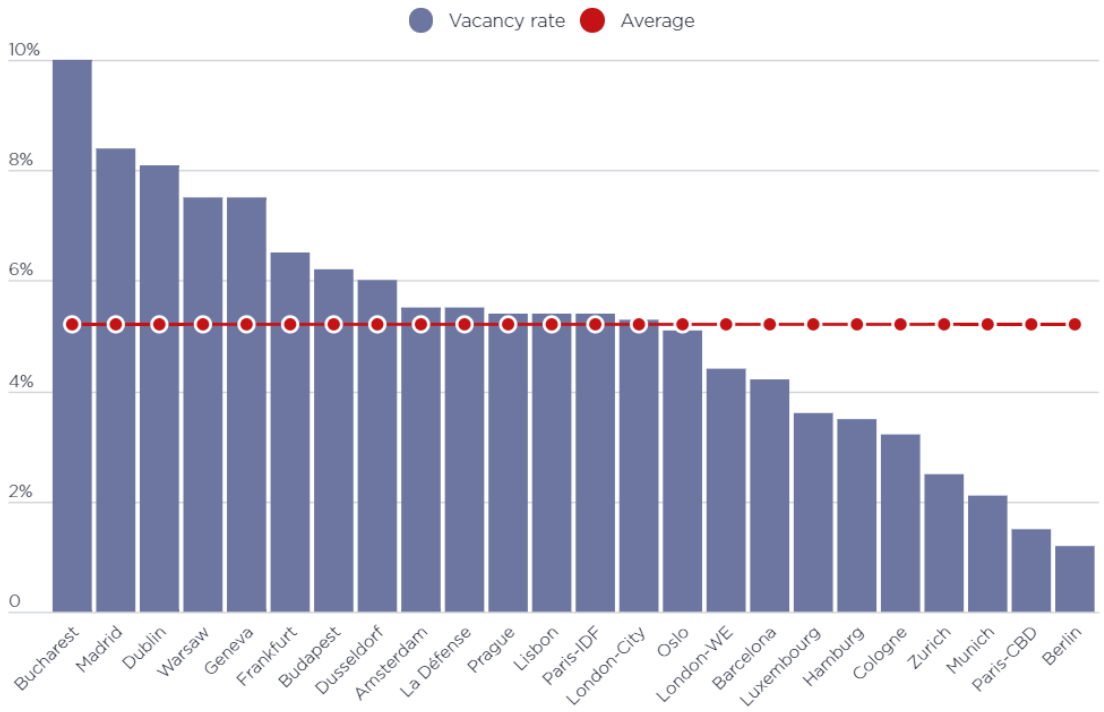


Figure 2.1 European office vacancy rates (Q1 2020) [8]

The residential real estate market was also affected by the pandemic, but it is forecasted that the impact will be less severe compared to the other real estate sectors [7]. However, health concerns, wage cuts, unemployment and the potential economic recession led to fewer buyers looking for a new home. Moreover, due to the high infection rates, sellers were more reluctant listing their properties or allowing strangers to visit their homes. Thus, in the US the number of home sales dropped in April and May 2020 to their lowest levels since the financial crisis in 2007 [9] (Figure 2.2). The number of new property listings in April 2020 was 40% lower than the previous year [9]. There was also a decrease in the home-buying activity as home showings per listing in the US were down over 40% in April compared with the same period last year [9].

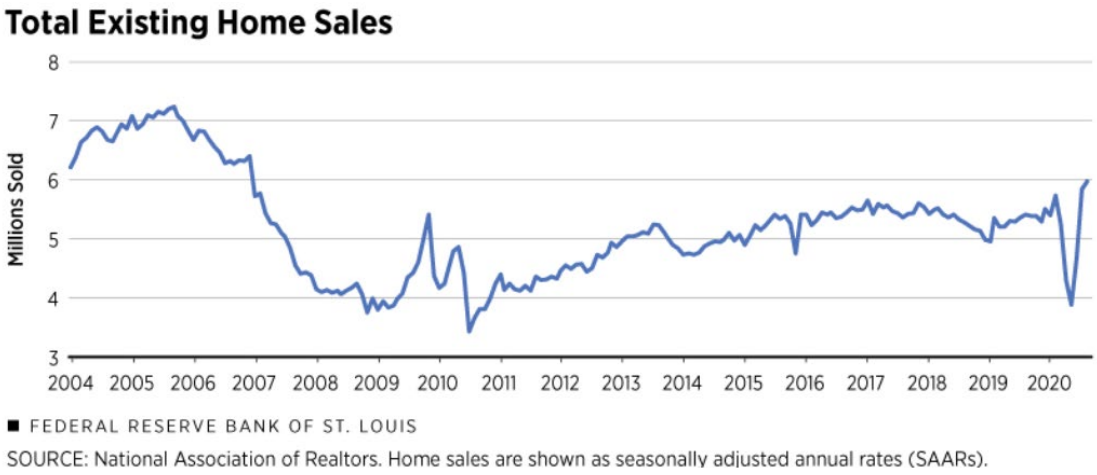


Figure 2.2 Total home sales in the US

The exact effects of the pandemic on the residential sector depend on the local conditions. Despite the large decrease in home sales, real estate activity began to improve in the last months. Monetary and fiscal policies are expected to lead to a slow recovery of the sector in the second half of 2021. Furthermore, brokers started to apply innovative methods to avoid any infection risks such as offering house tours via Skype and FaceTime [3].

Besides the aforementioned effects, another trend to be taken into consideration is the increase in digitalization. Multiple organizations started shifting to remote working, relying on digital collaboration tools. Engineers reinvent their working routine by including 4D and 5D simulations for planning projects. Moreover, contractors are looking at online channels to order construction materials or even to monitor their employees' well-being [10]. Thus, further investments in technology and digitalization are expected to happen as a result of the pandemic.

There is still much uncertainty about how the pandemic will reshape the nature of work and home environments. It is not clear yet if the previously discussed trends will be permanent or will reverse. However, the industry will definitely look differently from its current state. It is the perfect time for companies to find opportunities in order to build a more productive and resilient industry.

2.2 Build-to-Rent Market

Built-to-Rent (BTR) refers to the development of properties that are designed with the sole intention of appealing to the rental market, as opposed to long-term home ownership [11]. As Lurtis targets the BTR industry in Europe, the following analysis will focus on these two markets.

In the first quarter of 2020, BTR occupied 18% of Europe's entire commercial market, after it received in 2018 an investment of more than £15 billion [12]. In 2019, BTR gained higher investments than the office sector, which made it the preferred property investment segment.

In Europe, BTR has been a long-established rental model, while the US is still capitalizing on the trend. In 2019, Germany, Ireland, Poland, and Sweden attracted the strongest investor interest, closely followed by the UK [13]. In Sweden, BTR investment volumes increased by more than 40%, while in Germany they reached €20 billion [13]. In the UK, Brexit and the pandemic slowed down the growth, but investments still outperformed expectations and grew to €5.9 billion [13].

The UK BTR market is divided between local developers (28%), UK housebuilders (27%), major UK developers (17%), contractors (14%), registered providers (9%) and major international developers (3%) [14]. According to the latest numbers, there are 167,853 BTR units [14] (Table 2.1).

Obviously, large cities are more under investment. The distribution of BTR units is spread unequally throughout UK (Figure 2.3), but the main hotspots for BTR are in London, Manchester, Leeds, Birmingham, Brighton.

Status	Q2 2020 Totals	Q2 2019 Totals	Increase
Complete	47,754	34,858	37%
Under Construction	34,132	35,826	-5%
In Planning	80,730	63,552	27%
Totals	167,853	137,714	22%

Table 2.1 BTR units in the UK

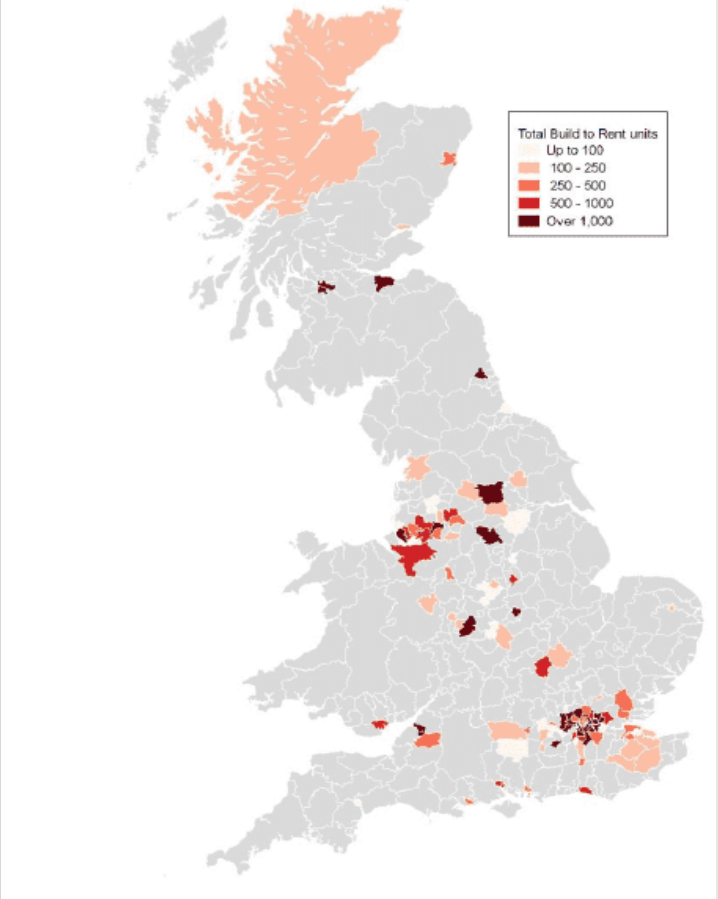


Figure 2.3 BTR units by local authority in UK (Q1 2019) [15]

Although relatively new in Spain, the BTR market received over €2.3 billion of investment in 2020 [15], which makes its growth evident. The main reasons for this trend are the rising house prices, which place an entry barrier especially for young people. Moreover, in cities such as Madrid, Barcelona or Seville, the people's desire to live near their jobs denies them the option to buy their own place.

Despite the COVID-19 slowing down construction activity, it is expected that shift to renting will intensify due to the pandemic [17]. Rising unemployment and wage cuts will make it harder for people to afford buying a house, especially for first-time buyers [17]. Moreover, as blocks in central areas are becoming less desirable, people might look to less densely populated areas which could lead to new opportunities of development for BTR in peripheral locations or satellite cities [17].

2.3 Buildability requirements

The term 'Buildability' refers to the extent to which the design of a building facilitates the ease of construction [18]. A Buildability Estimators enables developers and architects to maximize the potential of a plot and of an investment. Taking into consideration user preferences and governmental regulations, the estimator can create dozens of design solutions by dividing the plot into volumes and simulating different distributions of living units.

Lurtis established a set of minimum buildability requirements to be included in the first version of the tool to achieve their value proposition. A first step in designing the user experience was understanding these requirements.

The minimum buildability requirements were divided into the following four phases: defining a plot, regulations, user preferences and generating designs.

In the defining a plot phase, users can either create a customized shape or select on the map one of the available lands. After setting up the plot, they have to define one or more entrances, and the back segment.

In the second phase, users have to input a set of regulations which change the final volumes and their distribution. The first one is the setback per side (the distance between each land side and the building structure), which can be adjusted by interacting with the map. Following, the maximum height (m), buildability (m^2), plot occupation (%), number of floors, attic setback (m), computability of zones (%) and building length (m) have to be specified.

The third phase involves deciding the user preferences. Users have a set of default configurations to choose from (studio, 1-bedroom, 2-bedrooms, 3-bedrooms). They can customize the percentage of each configuration to be included in their design. They can also create their own type by choosing the number of bedrooms, bathrooms, kitchens, and the façade length. After choosing the percentage of each unit type, they have to define the final set of parameters: corridor width (m), building bay (m), width of portal façade (m), width of vertical communication façade (m), floor height (m), facade thickness (m), thickness of party wall (m), distance to ventilate the vertical communication core (m) and the number of stairs.

The next and final stage implies generating the designs based on all the previously inputted parameters. Users have the possibility to sort or filter the solutions based on characteristics such as price, building area, orientation, and number of living units. They can also compare their favorite designs which will allow them to see a more detailed analysis of the selected options. Finally, if users are not satisfied with the generated designs, they can choose to create their own customized building by dragging and dropping the distribution of living units in the land previously defined.

Lastly, once decided upon the final design, users can choose to export a PDF or a FBX model and preview it in 2D or 3D. In the main dashboard, users have the possibility to review all the projects they have been working on.

3 Competitive analysis

After familiarizing with the market and with the minimum buildability requirements, the next step was to conduct a competitive analysis. The competitors were already identified as Lurtis previously conducted market research. Thus, five companies were taken into consideration as the most important players in the industry: Archistar, Testfit, Spacemaker, Kreo and Matterlab. Initially, each company was individually analyzed in terms of four main criteria: design strengths, design weaknesses, customer base and price. Then, each competitor was assessed against a set of core features for a clearer comparison.

3.1.1 Archistar

Archistar Property Platform [19] is a digital tool powered by Artificial Intelligence which allows property professionals to find, design and assess detailed building sites. With the use of generative design, it can easily create dozens of 3D building options that comply with government planning regulations. Archistar also offers environmental factors simulations such as sunlight or cross-ventilation and accurate feasibility assessments.

Archistar targets a broad base of customers such as property developers, real estate agents, architects, builders, town planners, property investors and even universities. For each of these segments, they pinpoint transparently on their website the benefits of using their tool [20]. Moreover, they highlight the most important features for each customer category and offer the possibility to request a demo.

In terms of pricing, three types of schemes are available: Starter, Professional and Elite. The prices range from $295 per month (Starter plan) to $2495 per month (Elite plan) [21]. The Professional plan ($895) is the one recommended for average companies.

As design strengths, Archistar provides **numerous map visualization layers** easily accessible (Figure 3.1). Users can choose to toggle between satellite imagery, flood zones, bushfire areas, heritage listings and many more. **Advanced filtering options** can display properties by zoning, building type, floor space ratio or maximum building height. Moreover, **extensive information** is available for each site such as planning details, property attributes, sales history, rental history, or value estimate. Lastly, Archistar **makes it easy to create multiple designs, filter or export them, and choose a favorite.**

Overall, Archistar offers a comprehensive solution for designing and assessing building sites. The only drawback is that the tool provides at **times too many customizations and site information** which might hinder the navigation for a novice user.

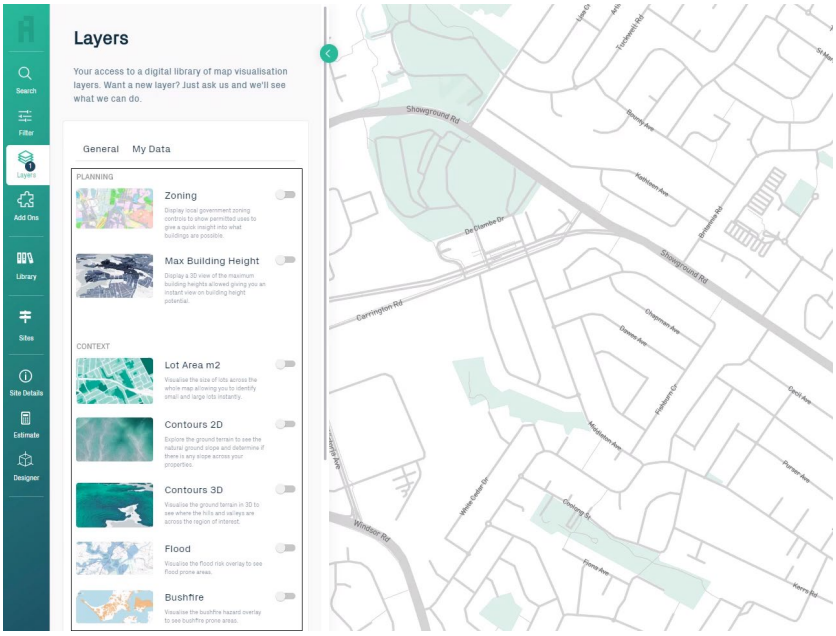


Figure 3.1 Archistar 'Layers' panel

3.1.2 Testfit

Testfit [22] is a building configurator meant to help developers, architects and urban planners easily design site plans for hotels, parking spaces or multifamily buildings. It generates structures with geolocation support and provides building typology presets. Other benefits include detailed feasibility studies, generative parking facilities and custom zoning profiles.

Testfit was built in Dallas (TX), but its use spreads now in six countries and in more than 150 companies. It mostly targets real estate developers, architects, urban planners, and general contractors. As for the price, individuals can use it for $375/month and companies can purchase it depending on the number of users: 5 users: $500/month and 10 users: $1000/month.

In terms of design strengths, Testfit enables a **high interactivity with the map** (users can draw roads and any type of plot shape) and provides detailed feasibility analysis. With the help of presets, users can easily **swap between different building types**. Moreover, using the editor feature, designers **can customize the dimensions and room distribution of every living unit**.

As weaknesses, the interface is rather hard to use as it contains a **large amount of information** (Figure 3.2) which leads to a high cognitive workload. Users are prone to encounter confusions or even problems at the first contact with the tool. Thus, Testfit is mostly designed for specialized use.

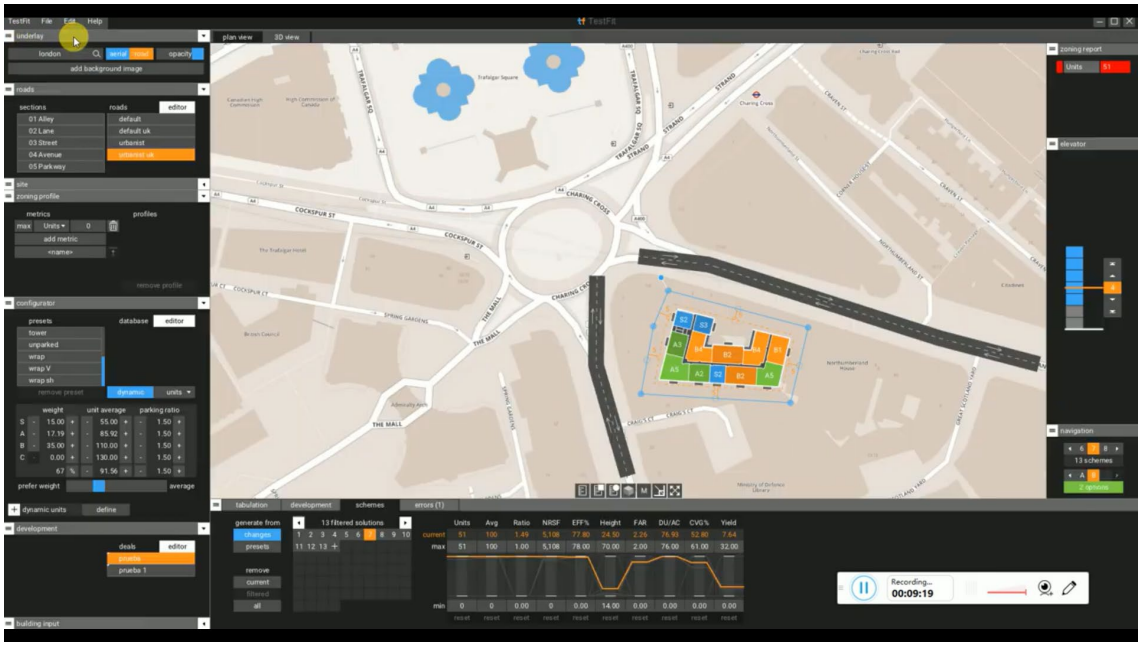


Figure 3.2 Interface of Testfit

3.1.3 Spacemaker

Spacemaker [23] is a cloud-based AI software that allows developers, architects, and other stakeholders in the architecture, engineering and construction (AEC) industry to design and analyze real estate sites. Using generative design, the tool can create multiple design options and assess the living quality of any site.

The company was born in Norway, but now spans over seven countries across Europe and USA. Spacemaker mostly targets real estate developers and architects. Moreover, the company's clients and partners are displayed on their website along with different use cases. The pricing scheme is not available for the public.

In terms of design strengths Spacemaker **quickly generates multiple design options**. Users can easily customize the outputs using different layout types and refine them until they are satisfied with the results. Moreover, the tool offers **advanced visualizations** (Figure 3.3) for sunlight, noise, or wind simulation. Lastly, in Spacemaker, users can filter **designs** and **compare their favorites** based on numerous criteria such as geometry, view, daylight and many more.

Spacemaker is a comprehensive solution that achieves an easy and intuitive use. In terms of design weaknesses, none have been identified.

Figure 3.3 Advanced sunlight visualizations

3.1.4 Kreo

Kreo Modular [24] is an AI-powered software which uses generative design for modular building concepts. It provides immediate cost assessment on design iterations, reducing the cost of feasibility studies. Moreover, the designs created in Kreo are BIM compatible by default which prevents any information to be lost between feasibility stage and technical implementation. As Kreo enables instant access to relevant data for every stakeholder, it encourages transparent communication across all teams during the development of a project.

Kreo targets developers, manufacturers, contractors, and consultants. For each of these customer segments, Kreo identifies pain points and offers solutions which are clearly displayed on their website. Moreover, the company provides illustrative videos explaining individual functions and best practices. As for the price, three main options are available: BASIC at £100 per month for cost consultants or architects, PRO at £1000 per month for architects or developers and ENTERPRISE for developers or manufacturers [24]. They also have a FREE plan that supports a lower number of projects and limited features.

In terms of design strengths, Kreo enables an **easy project kick-off** with the help of default options. After selecting the building frame type, building type, floor height and number of floors, users can immediately start building their desired design. The tool allows an intuitive **interaction** with the map as polygons, rectangles and squares (Figure 3.4) can be easily manipulated and placed to create any building shape. At every step, the **interface is simplistic** and only contains the essential features clearly symbolized with relevant icons.

Lastly, with Kreo, users can customize the floor plan (Figure 3.5) and apartment layout by selecting default variants or by creating their own alternative design.

As design weaknesses, **Kreo might not be appropriate for architects or for a more specialized use**. When starting a new design in Kreo, users only have to choose the frame type, building type, floor height and number of floors from a set of predetermined values. However, in most of the projects, architects have a larger list of specifications they need to take into consideration when starting to design a site. Thus, the choices provided by Kreo might be too limited and might not fit with real-life scenarios. Moreover, Kreo does not create multiple designs and thus, users do not have the possibility to compare different options and choose the best one.

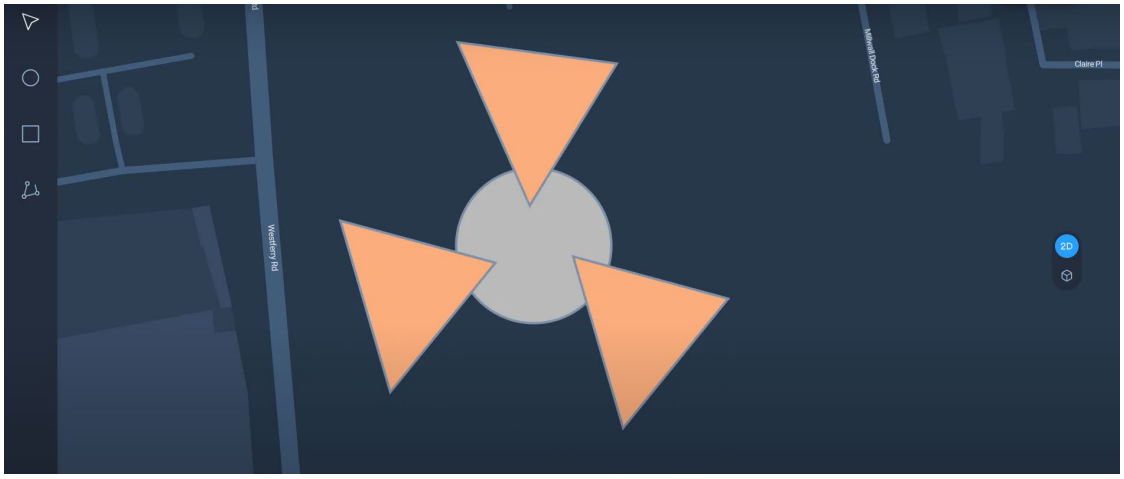


Figure 3.4 Designing the building shape in Kreo

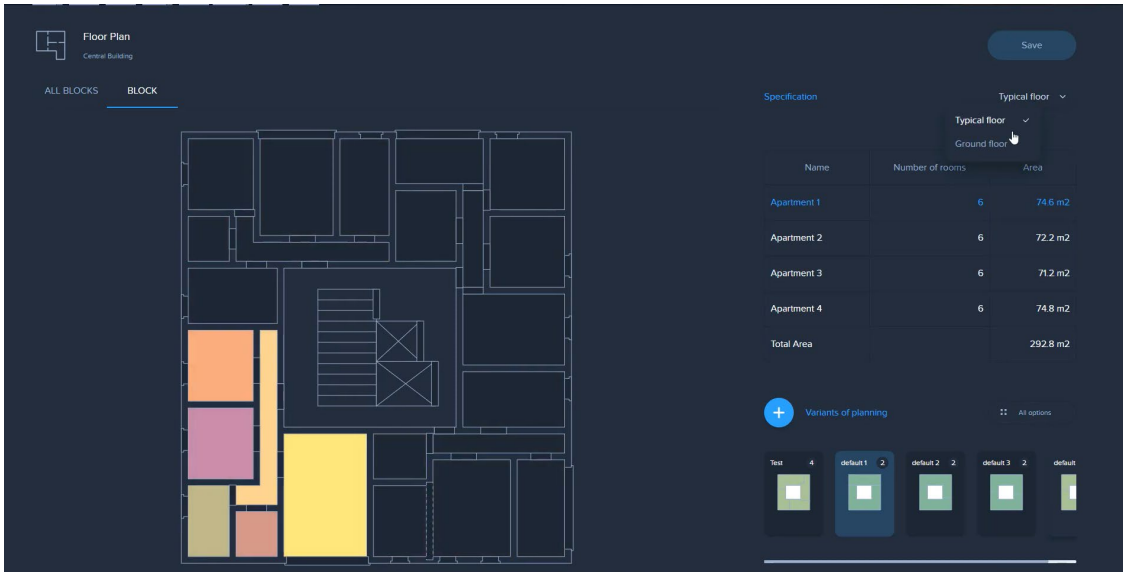


Figure 3.5 Customizing the floor layout in Kreo

3.1.5 Unitize

Unitize [25] is a Revit plugin, designed by Matterlab, which enables designers to build residential layouts. Unitize provides generic model families for quick plan studies, but it also offers the possibility to use custom elements. The units are highly customizable as users can change their width and depth to fit within their project requirements. Furthermore, Unitize automatically generates accurate assessment metrics such as Height (m), Mass Efficiency (%) or Number of Floors.

Unitize is mostly addressed to designers involved in residential projects. Their pricing scheme is not available to the wide public, but they offer a 15-day free trial. The company behind Unitize, Matterlab, provides a wide range of products and services from BIM and management to housing sector projects or even custom software development. They are strongly rooted in the AEC industry.

As design strengths, Unitize has **an easy and intuitive interface** (Figure 3.6). Users can adjust the unit mix percentages and observe in real time **different metrics** based on their inputs. However, compared to the other competitors, **the features offered by Unitize are limited** and only cover one part of the entire building development project.

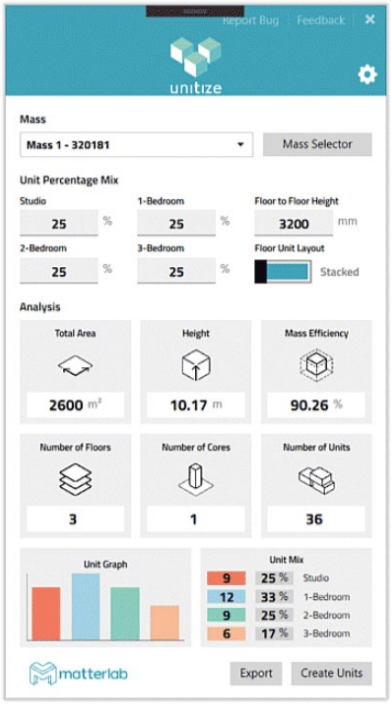


Figure 3.6 Interface of Unitize

3.1.6 Comparison

The previous analysis offered valuable insights into each one of the competitors. However, the strengths identified regard different features, which hinders making a clear comparison between the five companies. Thus, the next step was to assess each competitor against a set of nine core aspects. These aspects correspond to the features Lurtis plans to include in the first version of the buildability estimator. The results are summarized in Table 3.1 for a clear visualization. A more detailed comparison can be seen in Annex 1.

Core features	Archistar	Testfit	Spacemaker	Kreo	Unitize
Interactive selection on map	✔	✔	✔	✔	x
Generative design	✔	✔	✔	✔	✔
User preferences	✔	✔	✔	✔	✔
Unit mix	✔	✔	✔	✔	✔
Filter solutions	✔	?	✔	x	x
Compare solutions	✔	?	✔	x	x
Different typologies (Linear, U, L, and closed block)	✔	✔	✔	✔	x
Financial models	✔	✔	x	x	x
Intuitive use	✔	x	✔	✔	✔

Table 3.1 Comparison of the competitors

The usability competitive analysis proved that Archistar and Spacemaker are the most comprehensive solutions from the ones researched. They encompass most of the core features chosen and their interfaces achieve an intuitive use. In the following parts, the focus will be placed on these two applications targeting the interactions and the user flows they accomplish.

4 User Research

To maximize the quality of the user experience, users were involved from the first stages of product's development [26]. After familiarizing with the real-estate sector, buildability requirements and analyzing the competitors, the next step was user experience gathering. Firstly, all the stakeholders were identified with a focus on the most important and powerful ones. Then, a session of interviewing was performed to gain an understanding of what users really want and need, how they currently work, and their mental representations of their domain [26].

4.1 Stakeholders mapping

Conducting stakeholders mapping offered a clear visualization of all the people influenced by the project and of the connections between them.

The first step was brainstorming about potential people or organizations affected by the product, those who have an influence in its development or a certain interest in its success [27]. In a virtual space, Miro, all the ideas were written on separate sticky notes. External stakeholders were especially targeted.

After the brainstorming phase, similar stakeholders were grouped into categories. Each different category that emerged was named adequately. At the end of the analysis five main categories were identified: Management, Construction, Maintenance, Suppliers and Financial (Figure 4.1).

The following step was to prioritize the key stakeholders to determine their level of interest and power. For this purpose, a matrix (Figure 4.2) where stakeholders are divided into four categories was used:

- High power, highly interested people (Manage Closely)
- High power, less interested people (Keep Satisfied)
- Low power, highly interested people (Keep Informed)
- Low power, less interested people (Monitor)
  [27]

After completing the mapping, architects, designers, and contractors were identified as the most important and powerful stakeholders. On the next level, promotors, project owners, project managers and real estate investors need to be kept satisfied. Although they do not have a high power, field engineers and workers are highly interested in the project and should be kept informed. Lastly, banks, shareholders, maintenance companies, material and service providers only need monitoring.

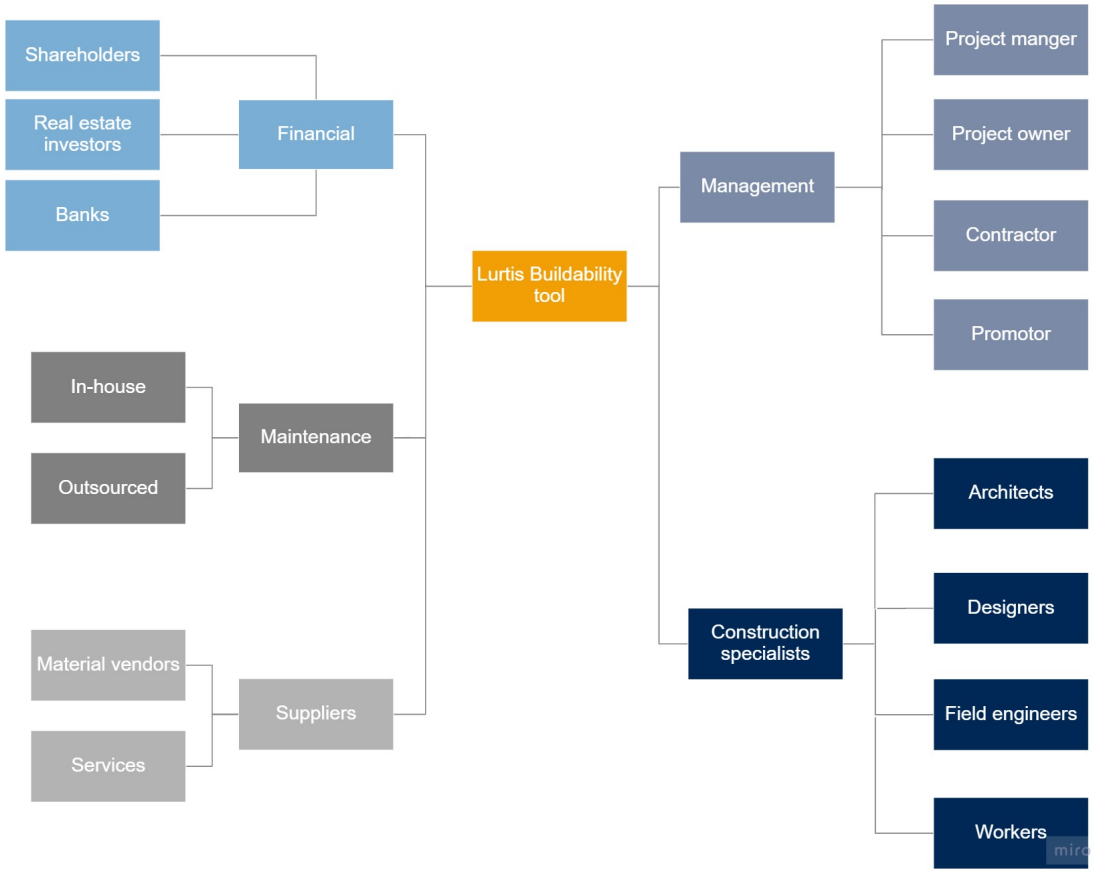


Figure 4.1 Identifying all stakeholders

Figure 4.2 Stakeholders' prioritization

4.2 Existing user research

Lurtis previously conducted market research and thus, has gathered information about potential users. They have identified multiple customer segments: architects, designers, contractors, and developers. As architects and promotors are the most involved in the building process, Lurtis chose to focus on these roles. They have created two personas (Figure 4.3, Figure 4.4) to analyze in more detail the goals and frustrations of these stakeholders.

Personas have numerous benefits in the designing process as they help the team feel more connected to users. Moreover, they bring everyone on the same page as each member thinks about the same persona, instead of each individual working toward his or her own vision of who the end user is [28].

However, Lurtis mostly collected data from online research and not from applying appropriate user research methods. Moreover, the personas created were missing plenty of information such as the background, motivations, and expectations. Thus, the next step was to perform an interviewing session with an architectural studio Lurtis partnered up with to validate the existing information and to refine the personas.

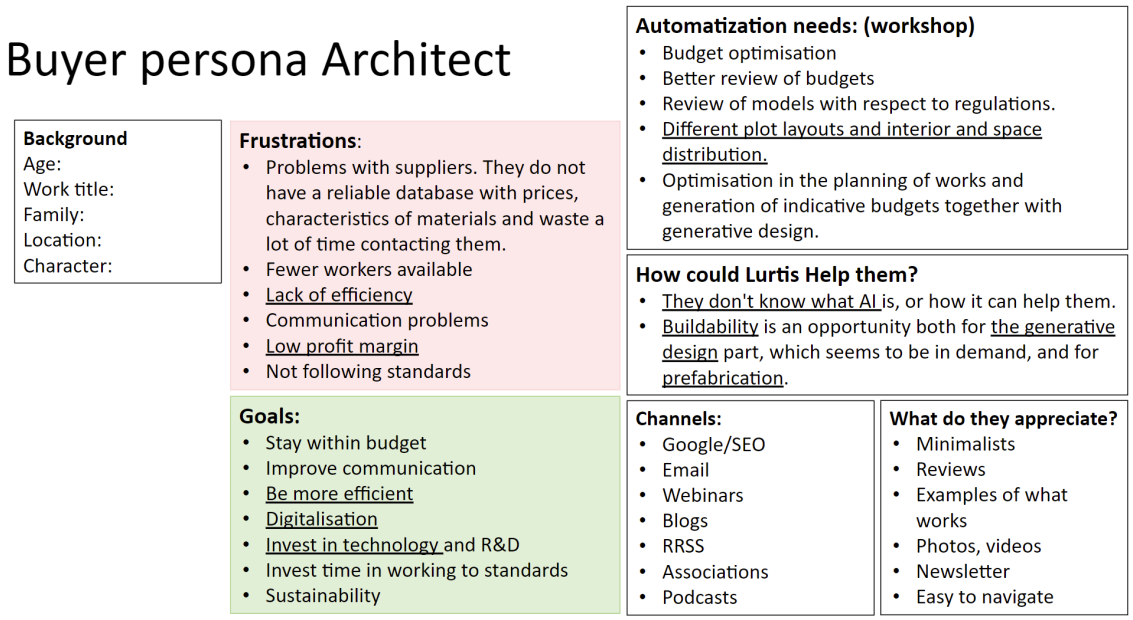


Figure 4.3 Architect persona

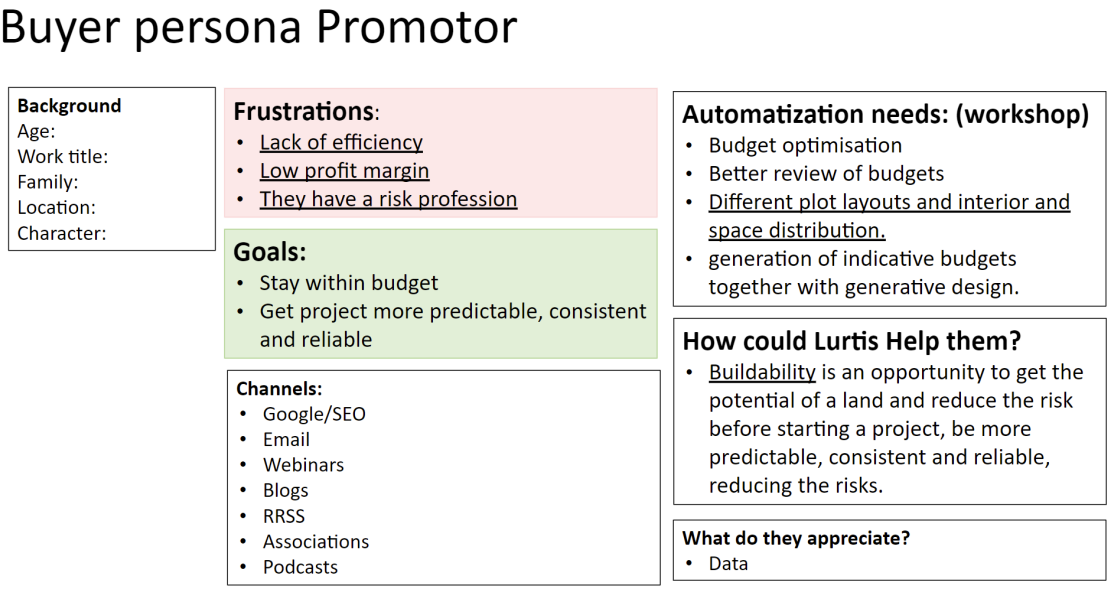


Figure 4.4 Promotor persona

4.3 Interviews

As already mentioned, one goal of the interview was to complete the architect persona to create a detailed image of the potential users. At the same time, the interview aimed at identifying pain points and frustrations regarding the use of the applications currently integrated in the interviewees' work routine.

An unstructured interview, with an approximate duration of one hour, performed on Zoom, proved to be the most adequate approach. This decision was made both to offer the participants flexibility and to collect rich, qualitative data [29].

4.3.1 Participants

There were three participants, all part of Morph Estudio [30], a company based in Madrid that Lurtis has partnered up with. The interviewees are all architects with extensive experience in the development of residential buildings. They are specialized in BIM technology and use daily Autodesk products such as AutoCAD and Revit.

4.3.2 Materials used

- List of questions for interview displayed as a Google Slides presentation (Annex 2)
- Method of notetaking (laptop)
- Communication channel (Zoom)
- Consent forms (Annex 3)

4.3.3 Description of method

The interview was organized in three main parts: general questions, integration aspects and features review. The general and integration sections contained a set of predetermined questions, leading the interview to a more structured path, while the feature review allowed for an open discussion. In the feature review part, the interactions, and the user flows that the most powerful competitors (Archistar and Spacemaker) achieve were discussed.

The content of the interview suffered three alterations. As Morph's availability was limited to one session, Lurtis only agreed with including the essential questions. For each question, follow up questions were prepared to make sure the most important points are touched.

	General questions
Q1	Which tools are you using to make the first sketches?
	How long does this phase usually take?
	How could it be sped up?
Q2	What applications do you usually use in your work routine?
	How easy was it to learn to use them?
	What do you think hindered this process?
	How could it be sped up?
Q3	What do you like most about these in terms of interaction and design?
	What do you think is the main benefit of using them in your work?
	Do you remember a situation where the use of these applications hindered your work?
	Integration questions
Q4	Regarding our product, would it be easier to use it as a Revit plugin or a standalone application in web or desktop format?
Q5	In terms of outcomes, what would be easier to integrate with Revit, a downloaded file or a model in BIM 360?
	Features review

Table 4.1 Interview body of session structure

4.3.4 Timeline

Approximate duration	Procedure
3-5 minutes	Introduction (welcome participants and give instructions)
2 minutes	Warm-up (non-threatening questions)
10-15 minutes	Body of the session (detailed questions)
3 minutes	Summarize interview
2 minutes	Wrap-up

Table 4.2 Interview timeline

4.3.5 Methods to analyze the results

Lurtis did not agree with recording the interview, thus only detailed notes were taken. As methods to analyze the results, two main approaches were chosen: categorizing and counting, and affinity diagram.

The first method involves identifying potential categories in the text as a whole. Then, the number of each instance is counted to identify the most frequent responses.

Affinity diagram is a quick method for analyzing qualitative data. The method involves taking out key points from the participants' responses and writing them separately on sticky notes [31]. The cards are shuffled to avoid any pre-existing order, and similar responses are physically grouped together on a whiteboard. Each category created during the process is then named. This method enables identifying themes in the data and understanding the relationship between different responses.

4.3.6 Findings

After applying the categorizing and counting method, three main groups emerged:

Parameters - 5 times

- "For some of the parameters we have predetermined values so there's no benefit of having sliders or default options."

Integration - 3 times

- "Usually, it is frustrating when we have to integrate work."

Precision - 3 times

- "It is easier and more precise to write numbers in boxes than having sliders."

The categorizing and counting method revealed that aspects related to inputting parameters, work integration and precision are highly important to architects.

To understand further the relationship between these different categories, the affinity diagram method was applied. The outcomes can be seen in Figure 4.5.

The affinity diagram revealed what are the features most beneficial for architects. Thus, they take advantage of filtering between different solutions based on parameters such as built surface and comparing solutions in detail. Moreover, the feasibility analysis helps them estimate which solution has the most potential. In terms of key characteristics, they appreciate the intuitiveness, precision, and easiness to make changes. As work practices, architects divide work across one project and each team member only has to learn one part of the digital designing tool. The affinity diagram also helped to identify a few pain points. The interviewees encountered frustrations when they had to integrate work within the team and when prolonged program loading delayed their work.

Figure 4.5 Affinity diagram for analyzing interview results

4.4 Outcomes

To summarize the insights of the interview, all the relevant observations and paint points, together with appropriate recommendations were compiled into Table 4.3. This choice provides a clear overview of all the important aspects to be considered in the prototyping phase.

Insights	Recommendations
Architects divide effort and work in a modular way	Provide a comprehensive tool that allows multi-user mode and integration of work
Architects want to make changes easily and intuitively	Enable a high level of customization
With inputting regulations, it is easier and more precise to write numbers in boxes than having predetermined options	Allow inputting regulations and preferences both interactively and by writing in text boxes
Architects need advanced options when choosing the unit mix	Provide multiple configurations in the unit mix step
It is useful to compare solutions in terms of 2D models and a set of basic information	Provide the possibility to compare solutions based on a set of parameters
Filtering solutions is beneficial, but the filtering options depend on the experience/profession of the user	Provide a filtering mechanism and define the filtering criteria
A feasibility analysis is useful, but a lot of the parameters are hard to estimate	Define and provide relevant feasibility metrics

Table 4.3 Summary of the interview

All the findings from the interview were used to refine the architect persona (Figure 4.6) and to define the customer journey (Figure 4.7). Creating a customer journey helps understanding the actions users go through with Lurtis' tool. It also helps mapping user's needs and goals to actual features in the application. To create the customer journey, first a relevant scenario was chosen. Then, a series of actions that allow users to complete their goal were compiled into a timeline [32]. Finally, the timeline was enhanced with users' thoughts and emotions to build up a narrative.

Name: Isabela Pérez

Demographics

Gender: Female

Age: 34 years

Based in: Spain

Job: Architect

Background

- MSc Architecture, Building and Planning
- Uses Autodesk products (Revit, AutoCAD) daily
- Communicates frequently with clients
- Team worker

Goals

Provide functional, but also good looking solutions

Following standards

Meet the prefixed project timeline and stay within budget

Improve communication and collaboration

Motivations

Ease in sketching ideas

Fast computations

Realistic rendering

Frustrations

• Problems in integrating work with other colleagues

• Program takes a lot of time to load

• Lack of efficiency

• Not following standars

Expectations

Clients knowing what they want

Figure 4.6 Architect refined persona

Isabela Pérez

Scenario: Isabela is starting a new project with her team. As they want to transition to digitalisation, she recommended them to use an AI based buildability tool with good reviews.

Expectations

• Fast computations
• Easily input parameters and make changes
• Generate multiple designs
• Have a good integration of work

Kickoff

1. Review project's specification

2. Allign the approach across the whole team

Define

3. Draw inital sketches

4. Decide design preferences and parameters

"Can't input all specifications and sketches in one place"

Implement

5. Generate multiple designs

6. Check for compliance with regulations

"I can easily generate lots of different designs"

"I have to check manually for compliance with regulations"

Integrate

7. Integrate work with other colleagues

8. Give and receive feedback

9. Make additional changes

"I have to update multiple files for the same changes"

Deliver

10. Generate reports

11. Communicate with the client

Figure 4.7 Architect customer journey

5 Prototype

The process of developing the prototype started with creating a navigation map to clearly visualize all the features and the relationship between them. The following step was to design the wireframes as they give a realistic feel of how the entire application will flow. Moreover, they are a relevant artifact for design discussion and bring everyone on the same page. Lastly, the low-fi prototype was developed and tested, followed by the high-fidelity prototype.

The prototype was designed based on the Material Design System components, using Figma. A Design System is a collection of reusable components, guided by clear standards [33], that can be used together to build various types of applications. The use of a Design System supports consistency, clarity, and quality in the design process [34]. Moreover, the components used are in compliance with Material Design standards and best practices.

5.1 Navigation map

The navigation map (Figure 5.1) built on the scenario explored in the customer journey. Each of the actions that had been previously identified became features allowing users to accomplish a goal. The resulting screens were then ordered to create an application flow. This process helped identify the hierarchy and the layout of the entire interface.

Thus, it was decided that users will first encounter the 'Main' screen containing all the previous projects. From here, they can choose to start a new project which will lead them into a process made up of four steps. Each step contains unique features that help users create their desired design.

In Step 1, they have to search for a location, load the cadastral data, select a land, and define the borders of the plot chosen. Then, in Step 2, users define the setback of the plot and input a set of regulations (5.4.2.4). They can also go back to re-selecting the land if they have changed their mind in the meantime. In Step 3, users can customize the unit mix and a set of preferences (5.4.2.5, 5.4.2.6). Again, they can return to either Step 1 or Step 2.

Finally, in the last step, based on generative design, the tool creates multiple solutions taking into consideration all the parameters previously selected. Users can choose to filter, sort, or compare these solutions to identify the best one. They can also create their own customized solution if they are not satisfied with the generated designs.

As a last action, they can preview the solutions and export their favorites. Step 4 also allows users to return to any other previous step at any point.

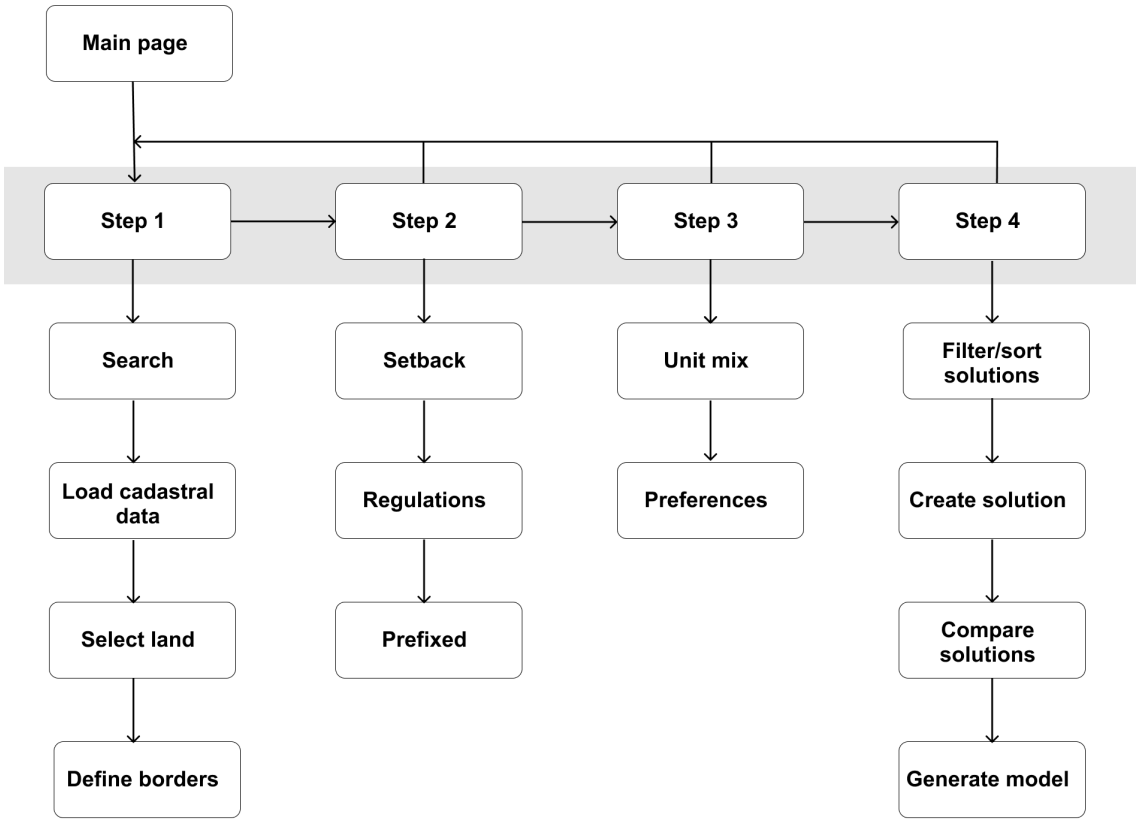
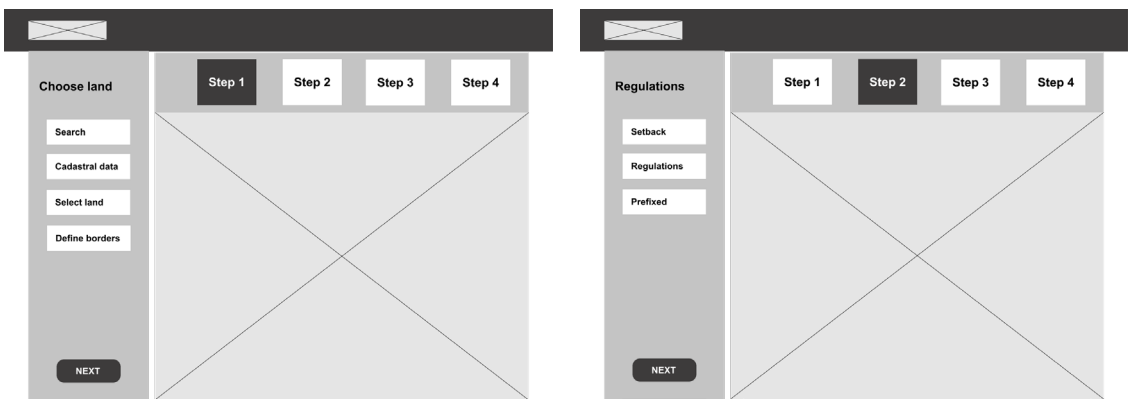


Figure 5.1 Navigation map

5.2 Wireframing

The wireframes started from the structure defined in the navigation map. Only the main screens were created to easily establish a layout that everyone in the team would agree with. The wireframes (Figure 5.2) provided a stimulating artifact for discussion and gave everyone an idea of how the interface could look like. When creating the screens, actual images and text were not used, nor did any type of color scheme. This choice allowed the design to undergo large changes in a short amount of time. For this part of the process, everything was created using Figma.



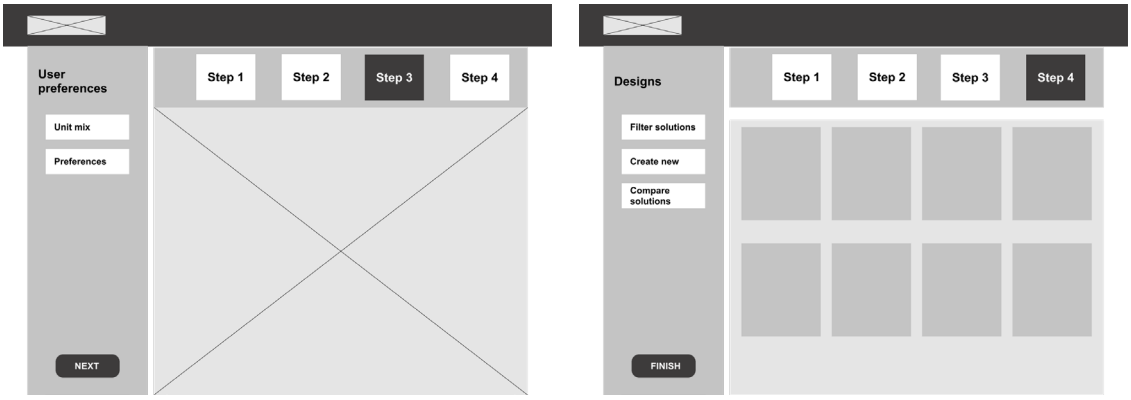


Figure 5.2 Wireframes

5.3 Low Fidelity Mockups

With the wireframes completed, the low fidelity mockups (Figure 5.3) could be created. For this purpose, Figma was used as it is intuitive, it enables a fast-prototyping ability, and it is also supported by extensive resources.

The mockups were designed with accessibility in mind as the information displayed was carefully selected to not overload the user, maintaining a low level of cognitive complexity.

In terms of interaction, the mockups use basic elements such as buttons or cards to increase the ease of use and to facilitate learnability. Complex elements (such as accordions, drop down menus) were used with scarcity as they might decrease accessibility if they are not implemented properly. Each element contains relevant text and icons that give users an idea of the corresponding functions before actually activating them.

Besides using color to convey information, the priority of the information was signalized throughout the prototype by different weights and sizes of the font. Regarding the device, the solution was designed for a desktop environment as it fits more to the architect's work routine.

The low fidelity mockups were evaluated within the team and after multiple design discussions and iterations, they underwent multiple changes.

Figure 5.3 Low-fidelity mockups

5.4 High Fidelity Prototype

Creating the high-fidelity prototype was the longest part of the project. With the scope of the project being so large, this step took more time than expected.

For this part, all the insight obtained during the interviewing session together with the ideas discussed in the design meetings, were taken into consideration.

The prototype underwent a large number of changes in its transition from low-fidelity to high-fidelity. Firstly, the size of the UI elements corresponding to the steps was decreased as the layout of the screens was unbalanced. Moreover, for each step, numbers were added, to enable a better localization across the process (Figure 5.4). For interacting with the map, three options were introduced: zooming in and out, 2D or 3D view and the possibility to change between different layers. For setting up the parameters, sliders and text boxes were combined (Figure 5.5). This choice enables both to input precise numbers, but also to see how different options would work out.

Figure 5.4 The new layout of the steps

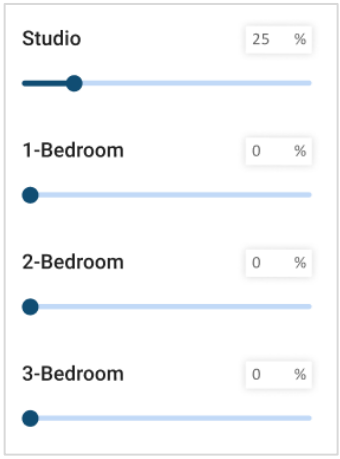


Figure 5.5 Sliders and text boxes to change the unit mix

The color scheme was changed to a more simplistic one, using black and white for the buttons and menus to increase readability. The font remained 'Roboto' as it complies with Material System principles. Different weights and sizes of the font were used to signalize the priority of the information. The minimum font size remained 12 px.

As interaction elements, buttons and cards were preponderantly used, but dropdown menus were included to test if they can speed up the designing process (Figure 5.7 Right). Cards were used (Figure 5.7 Center) for displaying both the available projects and the solutions generated. Two types of buttons were designed, each one with two different states: active/inactive, pressed/not pressed (Figure 5.6). Buttons contain both text and icons to give users an idea of the corresponding functions before actually activating them. All the

interactions deployed are intuitive as they imply clicking, dragging, or dropping and dragging actions. The buttons and cards used are part of the Material Design System, thus they follow Material Design standards.

Figure 5.6 The two types of buttons with their corresponding states active/inactive and pressed/not pressed

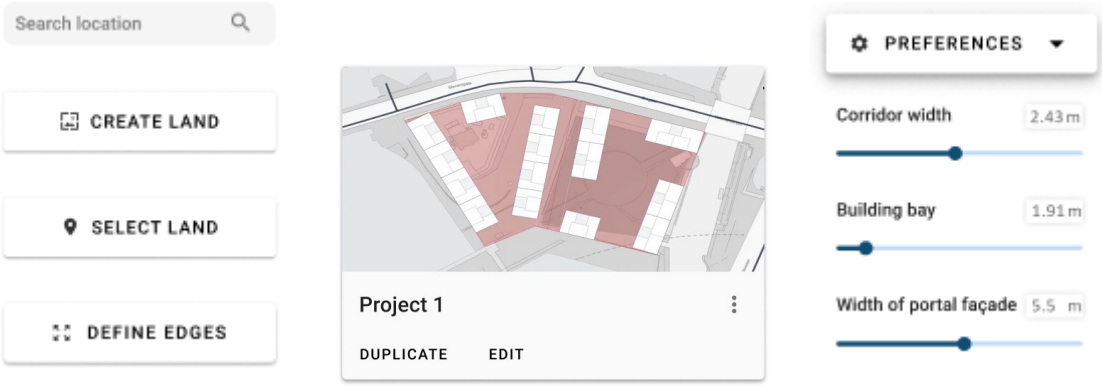


Figure 5.7 Left: search bar; Center: card; Right: drop-down menu

To ensure a high predictability and an intuitive use of the application, the prototype offers visual feedback whenever an important action has been taken (Figure 5.8 Left). Moreover, an informative text (Figure 5.8 Right) is displayed for every action that implies a significant effect.

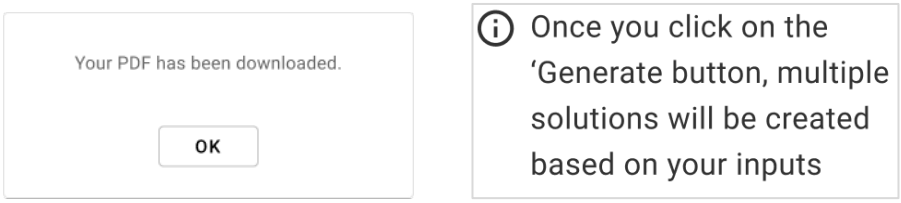


Figure 5.8 Left: feedback pop-up; Right: informative message

5.4.1 Accessibility

In terms of accessibility, the primary color was chosen to ensure a high contrast. The achieved contrast and the compliance of text with accessibility guidelines was checked using the tool 'Able – Friction free accessibility' (Figure 5.9).

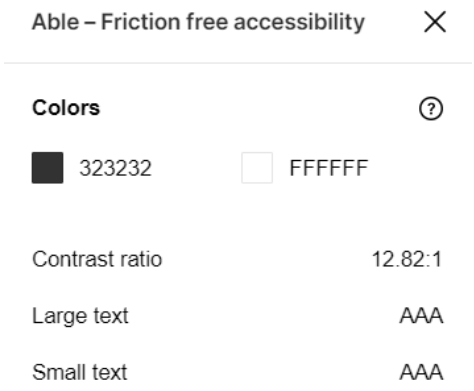


Figure 5.9 Output of the contrast checker tool Able: the contrast between the primary color and background is 12.28.

Moreover, the prototype has been checked against multiple types of visual impairments to ensure that all users can benefit from the solution. The 'Color Blind' tool was used to generate views for emulated color visions such as Tritanopia, Achromatopsia or Deuteranomaly (Figure 5.10). Although some of these visual impairments are quite rare, the results of the control showed the need of changing some colors to be more saturated to be better seen from people with Achromatopsia, the complete lack of color vision.

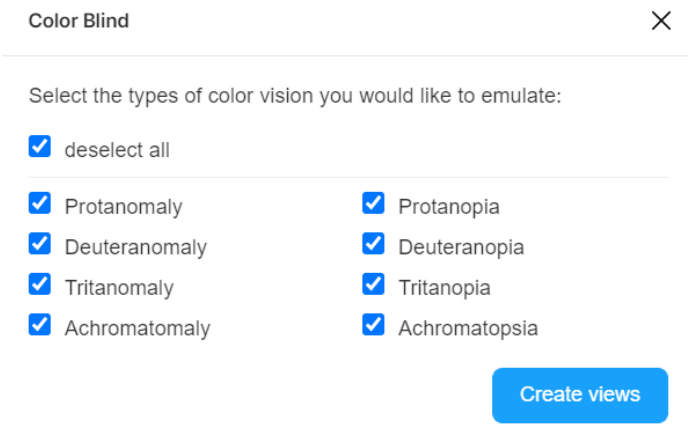


Figure 5.10 Output of Color Blind tool

5.4.2 Userflows

With the high-fidelity prototype, user flows were designed to have a clear understanding of the path users take to achieve their goals with the application. Following, these user flows will be presented, divided based on the main tasks to be achieved with the buildability estimator.

5.4.2.1 Select a land

Selecting a land (Figure 5.11) is the first action users have to complete to build a design. Firstly, they have to start a new project and search for a particular location on the map which can be a country or a city. Then, the map loads with the corresponding cadastral data. The next step is to click on the 'Select Land' option which makes all the available lands highlightable while hovered. When decided upon a parcel, users can select it, thus choosing the contour for future building.

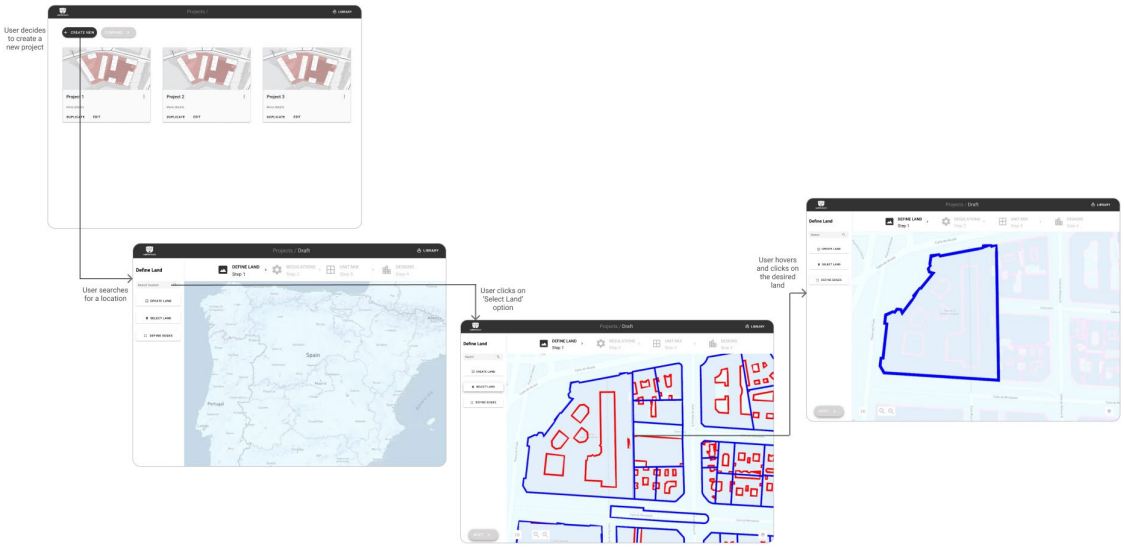


Figure 5.11 Select a land path

5.4.2.2 Define the edges

Once they have selected a land, users have to define its entrances along with the back side of the building (Figure 5.12). Thus, they first have to input the number of entrances and are then prompted to select the main entrance. After they click on the edge corresponding to the main entrance, users are asked to select the back segment using the same mechanism. Once they finish this process, users can advance to the next step.

Figure 5.12 Define the edges path

5.4.2.3 Define the setback

The next action is to define the setback (Figure 5.13). To do so, users have to first click the 'Setback' button. The setback contour and the current value will then appear on the map. By dragging the edges of the contour or by modifying the value in the text box, users can choose the preferred setback.

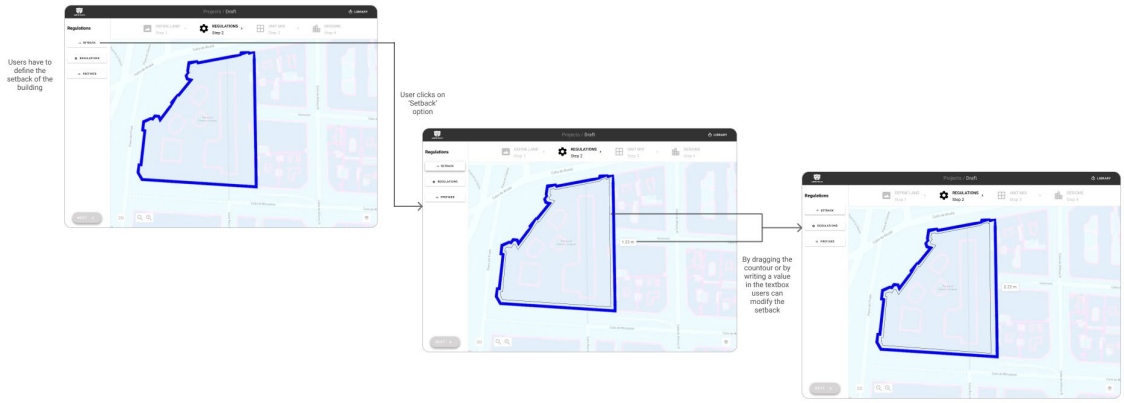


Figure 5.13 define the setback path

5.4.2.4 Input regulations

When inputting building regulations (Figure 5.14), users have to first click on the 'Regulations' button and they will transition to a new screen where all of the available parameters are displayed. After they have edited all of the text boxes according to their preferences, users can return to the main screen using the 'Back' button.

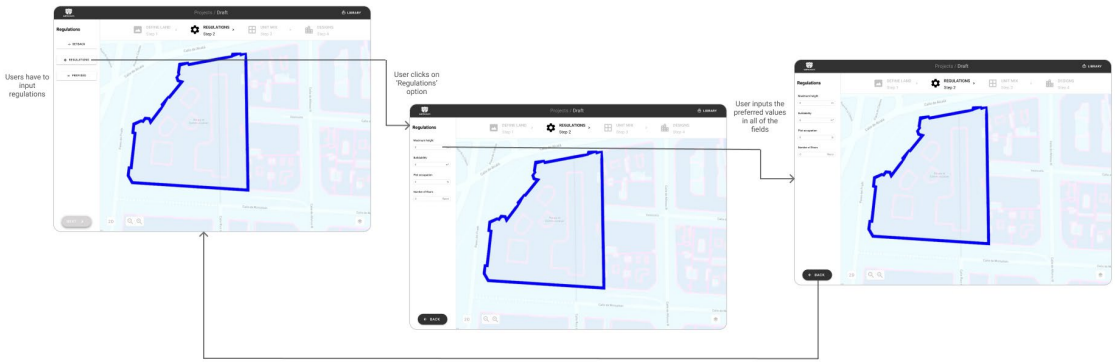


Figure 5.14 Input regulations path

5.4.2.5 Customize unit mix and configurations

In Step 3, the first action is to customize the unit mix. There are four default configurations: Studio, 1-Bedroom, 2-Bedrooms, and 3-Bedrooms. Users can modify the percentage of each type by dragging the handle of the sliders or by writing in the corresponding text boxes (Figure 5.15).

They can also choose to add a new configuration, by clicking the 'Edit configuration' option, choosing a name, the number of bedrooms, bathrooms, kitchens, façade length, and then clicking on the 'ADD' button (Figure 5.16*)*. The process of editing an existing configuration is similar; in this case each type (Studio, 1-Bedroom, etc.) has default values for each of the aforementioned fields (name, number of bedrooms, etc.). Users can change these defaults and save their customized configuration.

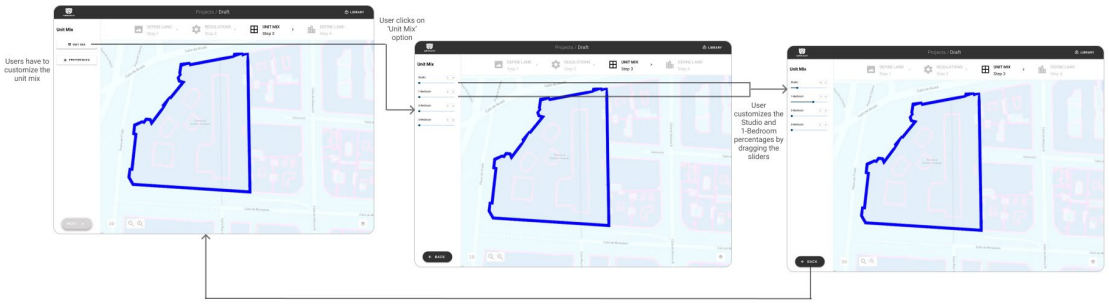


Figure 5.15 Customize the unit mix path

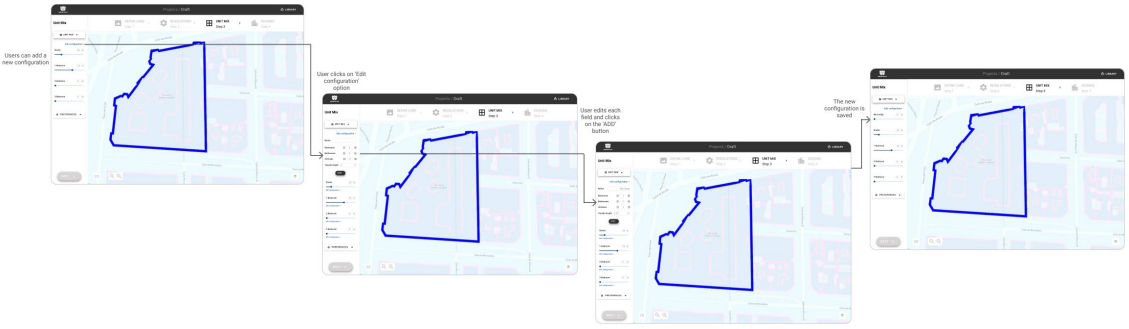


Figure 5.16 Add a new configuration path

5.4.2.6 Input user preferences

When inputting user preferences (Figure 5.17), users have to first click on the 'Preferences' button and they will transition to a new screen where all of the available settings are displayed. After they have edited all of the values by dragging the sliders or by writing in the corresponding text boxes, users can return to the main screen using the 'Back' button.

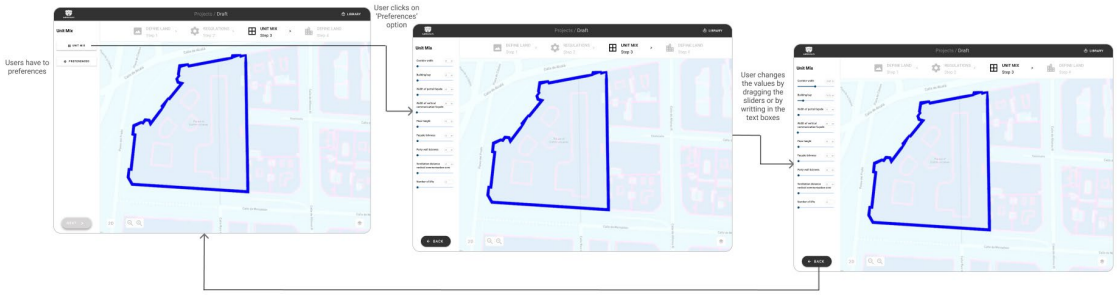


Figure 5.17 Input user preferences path

5.4.2.7 Generate designs

Once all of the previous steps have been concluded, users can generate the designs (Figure 5.18). Firstly, they are informed that all of their inputs will be used for creating the solutions. Then, users can opt if they want to include the feasibility analysis or not, and finally the different designs will be displayed.

Figure 5.18 Generate designs path

5.4.2.8 Filter designs

Users can filter designs by price, building area, orientation or number of living units (Figure 5.19). For example, by dragging the handle of the filter slider, users can choose a price range, and the designs that fit the range will be displayed. The filter can be reset.

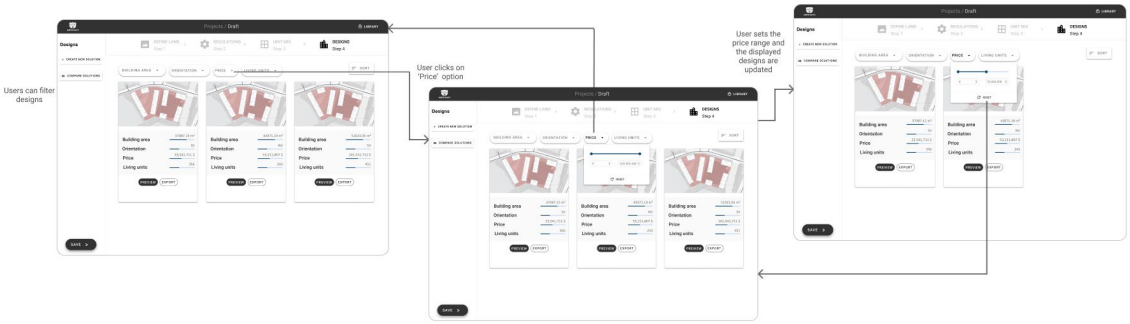


Figure 5.19 Filter designs path

5.4.2.9 Create new design

If users are not satisfied with the generated designs, they can also create their own customized building by dragging and dropping the distribution of living units in the land previously defined (Figure 5.20). Users have the option to export the newly created design.

Figure 5.20 Create new design path

5.4.2.10 Compare designs

Finally, users have the possibility to compare two or more of the available solutions. Once they select two or more designs by hovering and clicking on the corresponding cards, the 'Compare' button becomes active. Clicking the 'Compare' button leads to a new screen where a detailed comparison of the selected solutions is displayed (Figure 5.21).

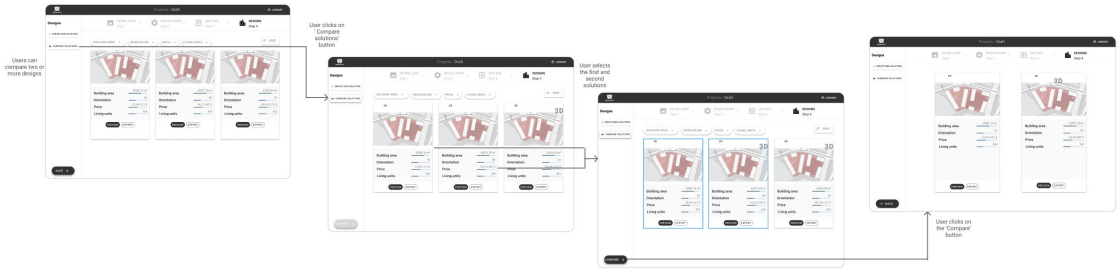


Figure 5.21 Compare solutions path

6 Evaluation Methods

The high-fidelity prototype underwent multiple rounds of testing. Firstly, it was evaluated through a cognitive walkthrough, and then through multiple sessions of usability testing. These methods offered practical insights of what can be modified to make the application easier and more intuitive to use.

At the end of the evaluation phase, all of the insights obtained were integrated into the final version of the high-fidelity prototype.

6.1 Cognitive Walkthroughs

A cognitive walkthrough was conducted to provide immediate feedback and suggestions on how the application can be improved to facilitate users to navigate through it and accomplish their goals. Cognitive walkthroughs are a formative usability inspection method [35, 36, 37] that is task specific. The benefit of performing a cognitive walkthrough is that it is a cost-effective and fast to carry out evaluation method.

6.1.1 Participants

The participants in the cognitive walkthrough were the same members of Morph Estudio. As they are architects, daily using Autodesk products, with extensive experience in designing building sites, they represent the target users.

6.1.2 Materials used

- Functional prototype in Figma
- Method of notetaking (laptop)
- Web cameras, microphones
- Consent forms (Annex 4)

6.1.3 Description of method

First, a relevant scenario was chosen. The scenario consists of the most important actions to be performed with the tool:

Step 1:

- Create a new project
- Search for location (Madrid)
- Select a land
- Define its borders

Step 2:

- Define the setback
- Input regulations and prefixed

Step 3:

- Customize unit mix (25% Studio, 75% 1-Bedrooms)
- Customize Studio configuration (to 2 kitchens instead of 1)
- Add a new configuration
- Input preferences

Step 4:

- Generate designs
- Filter design by price and then reset filters
- Create a new design by dragging and dropping the distribution of living units
- Compare solutions (first and second designs generated)
- Preview chosen solution
- Save project

The session was performed remotely, using Zoom. When conducting the walkthrough, the scenario was presented to Morph's members, showing them each screen at a time in Figma. At each new transition, the participants were asked to reflect and share their thoughts to four questions:

1. Is this what you expected to see?
2. Are you making progress toward your goal?
3. What would your next action be?
4. What do you expect to see next?

A separate notetaker observed the discussion, writing down any areas where expectations were violated, and other usability issues identified.

6.1.4 Suggestions for improvements

The cognitive walkthrough provided rich insights on how the application could be modified to facilitate users to reach their goals.

In the first step, the 'Create land' and 'Select land' options need to be separated as users have to perform only one of them. Moreover, the mechanism of defining the edges is not intuitive enough. In terms of wording, 'land' should be changed for 'plot'.

Regarding the second step, architects preferred using dropdown menus for all of the settings. In this way it is easier to view/hide and change different parameters than transitioning to a new screen. Moreover, the shape of the setback needs to be simplified and once defined, it should be available on every map further in the process.

Regarding the unit mix step, 'Edit configuration' should be changed for 'Edit types'. While adding a new configuration, architects did not find it intuitive pressing the 'ADD' button.

In the 'Create new solution' process, some shapes should not be available depending on the plot previously defined. Moreover, when placing a shape that exceeds the contour of the setback, users should be warned this action is not possible.

The solutions generated should be displayed using smaller cards to allow users to easily scroll between various designs. Lastly, architects found it useful to export a solution both in PDF or FBX format and to have a detailed preview of a design before saving it.

All of the recommendations were written in Table 6.1 for a clear overview.

	Recommendations
Step 1	'Create land' and 'Select land' should be separated
	Redesign the mechanism of defining the edges
	Change 'land' for 'plot'
Step 2	Use dropdown menus for all of the parameters to be changed
	Simplify the shape of the setback, taking into consideration only the main edges
	After defining the setback display it throughout the whole process
Step 3	Change 'Edit configuration' for 'Edit types'
	Change the 'ADD' button in the add a new configuration process
Step 4	Change the available shapes depending on the plot defined
	Provide warnings in the 'Create new solution' process, whenever an action is not possible
	Make solutions smaller and add a scrollbar
	Add the possibility to export both PDF and FBX
	Add the possibility to see a detailed preview of a design before saving it

Table 6.1 Recommendation for the next iteration of the prototype

6.1.5 Design changes

All of the suggestions architects provided were taken into consideration and translated into design changes to create a more usable high fidelity prototype. The 'Define edges' functionality was moved into the second step to simplify the flow. In the 'Select plot' and 'Create plot' processes, informative messages were added (Figure 6.1) to help users understand they only have to complete just one of the two actions available.

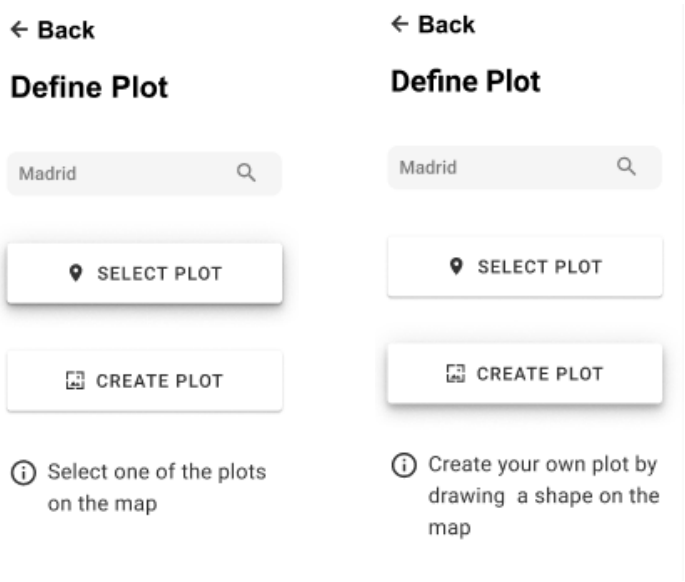


Figure 6.1 'Select plot' and 'Create plot' features with informative messages

The 'Define edges' mechanism was incorporated into the setback feature. In the second step, users are prompted to define both the entrances and the setback by dragging the edges of the blue contour (Figure 6.3) or by using the text boxes.

The space allocated for the setback has been divided into a text box with a default value and a drop-down menu (Figure 6.2). There are three options available in the drop-down menu: Side Entrance, Main Entrance and Back Entrance. Once users choose one of these three options, the corresponding segment on the map changes its color. A legend is also present explaining the meaning of each color (Figure 6.3). Each segment is labelled as "S" + the corresponding number. The same labelling is used both for the text boxes and for the map to achieve a clear identification.

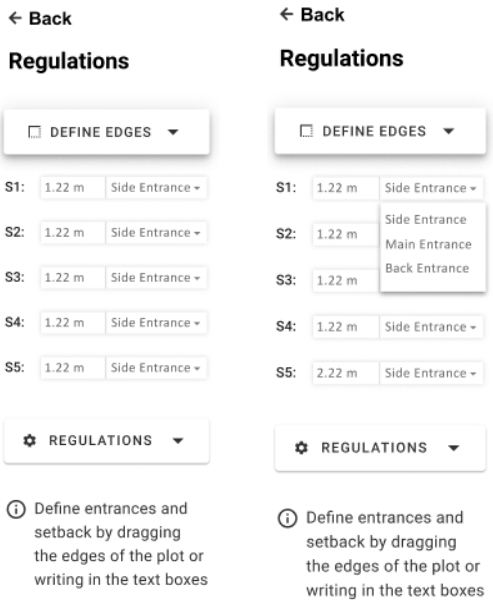


Figure 6.2 'Define edges' mechanism incorporated into the second step

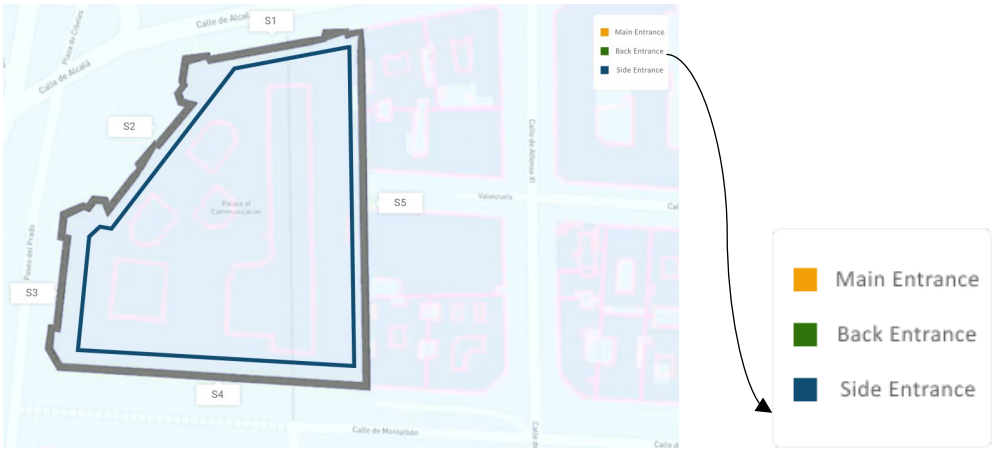


Figure 6.3 Segment labels and legend explaining the meaning of each color

For the regulations, a drop-down menu was included to easily view and hide all of the available settings (Figure 6.4). Architects stated that they prefer this option instead of transitioning to a new screen as it can speed up the design process.

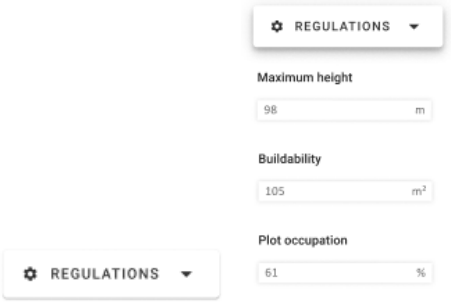


Figure 6.4 Drop-down menu for regulations

In the third step the 'Edit configuration' was changed for 'Edit types'. Moreover, the font size was increased to make the options more visible. The 'ADD' button was also adjusted as architects did not find it intuitive enough. The style of the button remained the same, but the text was changed to 'ADD TYPE' to make the option more explicit and predictable (Figure 6.5).

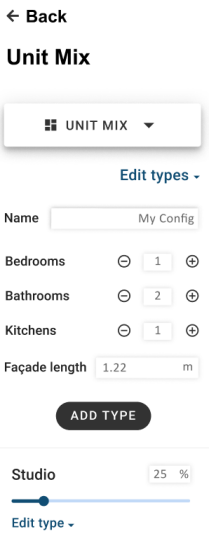


Figure 6.5 Add a new configuration panel with the implemented changes for 'Edit types' and the 'ADD' button

In the fourth step, multiple changes were implemented. Firstly, the size of the cards representing the generated solutions was decreased and a scrollbar was added for users to easily navigate through all of the designs (Figure 6.9).

Moreover, users can now choose to export a solution both in PDF or FBX format (Figure 6.7) and preview it in detail in 2D or 3D. For the 2D view, the option to navigate through different floors was also added (Figure 6.10).

Finally, in the 'Create new solution' process, different distributions of units are now available depending on the shape of the plot. For example, in the plot defined in Figure 6.6 the 'C' shape and the last one should not be available. Thus, the new prototype was adjusted accordingly, and warning messages were added for every illegal action (Figure 6.8). The previous 'EXPORT' button was changed for 'GENERATE' button to keep a consistency with the mechanism the other solutions are generated.

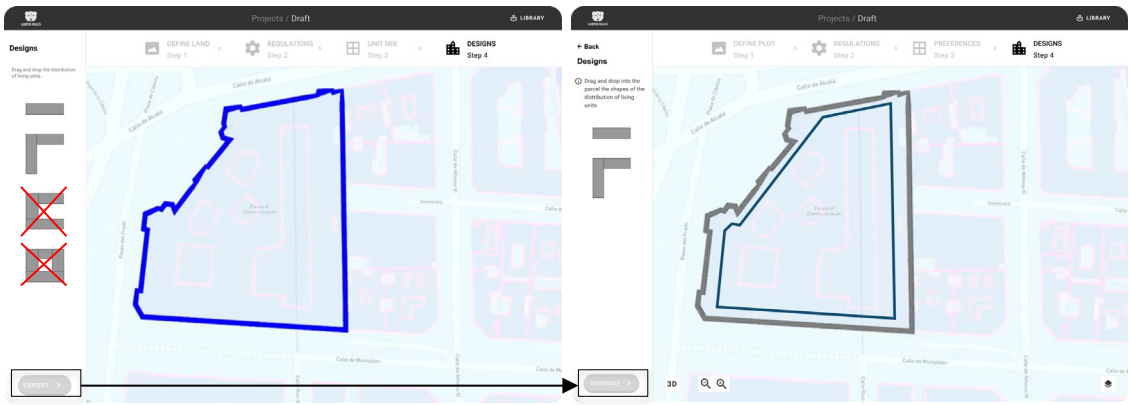


Figure 6.6 Changes applied for 'Create new solution' functionality

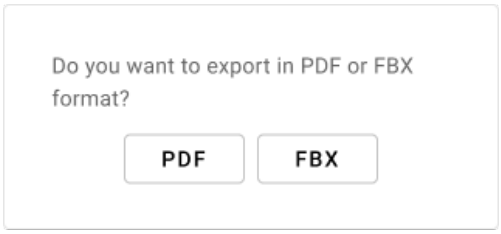


Figure 6.7 PDF or FBX export

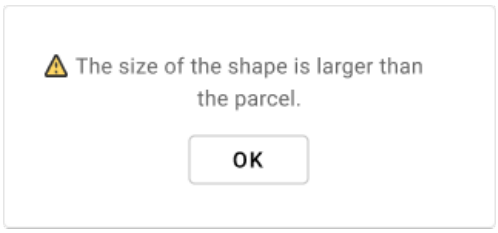


Figure 6.8 Warning pop-up

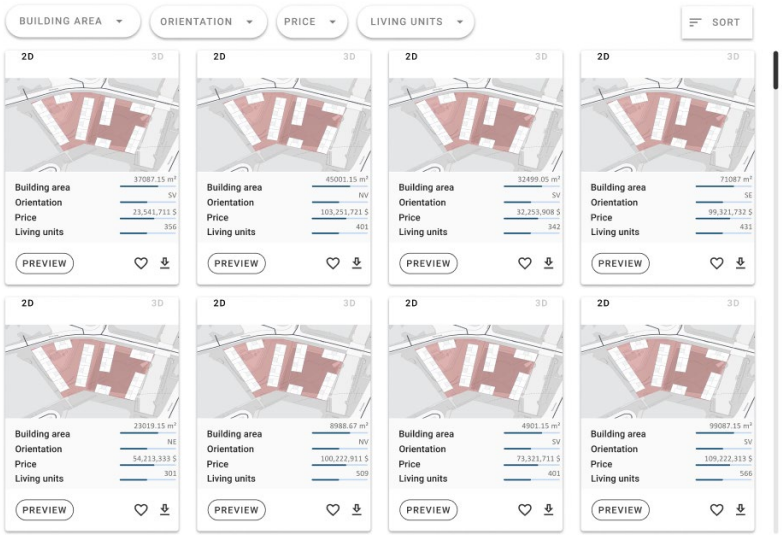


Figure 6.9 New layout of the generated solutions

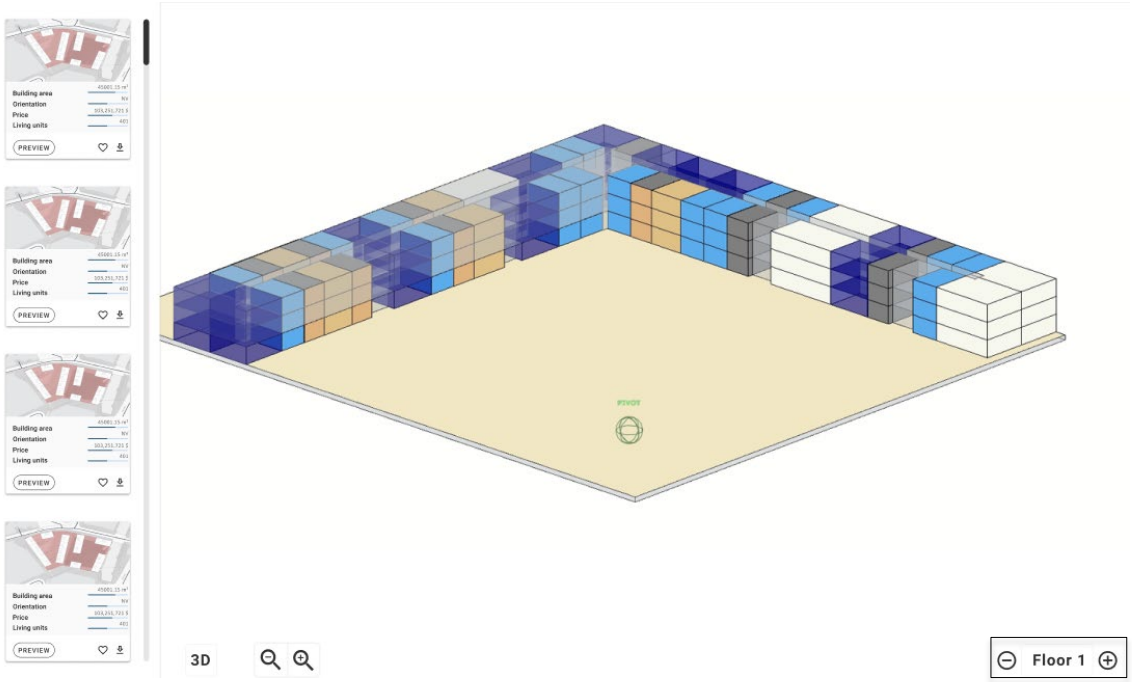


Figure 6.10 'Preview solution' feature

Lastly, in order to save the project, users have to choose a favorite solution (Figure 6.12). A text message prompts them to do so and informs them how can they accomplish this task (Figure 6.11).

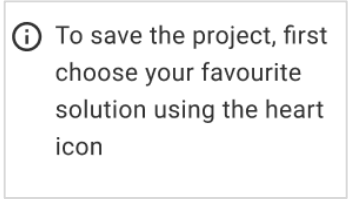


Figure 6.11 Informative text message

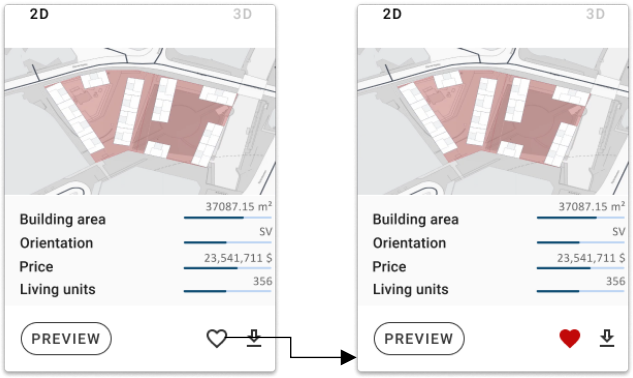


Figure 6.12 The mechanism for selecting a favorite solution

6.2 Usability testing

The next method to evaluate the prototype was usability testing. In usability testing, end users attempt to complete one or more tasks with the product based on representative scenarios [38]. In individual sessions, participants interact with the product while they think aloud. During the interaction, several metrics are recorded such as task success, time on task, and conversion rate. The goal is to identify as many usability problems as possible.

6.2.1 Participants

There is a widespread debate about how many participants should be included in the usability testing. According to Nielsen and Landauer [39] conducting multiple rounds of usability testing with only three to five participants per round generates the best results.

The current usability testing included three participants. Due to time constraints, only one round of testing was conducted. However, taking into consideration the prototype has been previously evaluated through a cognitive walkthrough, a large number of usability problems have already been identified.

As architects could not be reached for this part of the project, participants were chosen based on a convenience sampling. They are all digitally driven individuals, with ages between 25-25 years old, with experience in using technology and desktop-based applications.

6.2.2 Materials used

- Laptop with functional prototype in Figma
- Method of notetaking (laptop)
- List of tasks
- Consent forms (Annex 5)

6.2.3 Process

The process of conducting the usability testing consisted of three main steps:

1. Say the "welcome text" (6.2.4) to the participant.
2. Do the usability testing of the prototype. Ask the participant to perform the chosen tasks (6.2.5), record the objective metrics (6.2.6) and other observations.
3. After using the prototype, ask the participant to fill in the user satisfaction questionnaire (6.2.7.1), the user experience questionnaire (6.2.7.2) and ask for general impressions (6.2.7.3).

6.2.4 Welcome text

"You have been selected to participate in a research study for the development of an artificial intelligence buildability tool for the construction and real estate sectors.

The tool aims at helping stakeholders in the architecture, engineering and construction industry improve their performance and reduce their costs. Architects, designers, developers or contractors can use the tool to estimate a land's potential, input design preferences, customize the unit mix, and evaluate which project is more profitable. Using generative design and traditional machine learning approaches for classification and prediction, the tool can create dozens of different solutions that meet the chosen constraints.

The goal of the research is to develop the interface of this tool using a user-centred design approach. By pursuing this goal, the high-fidelity prototype has been developed. This prototype allows users to go through all of the steps of creating a building site.

With this high-fidelity prototype, I would like to perform a test with you, to understand and evaluate whether the designed application is intuitive and easy to use. In this interview process, I will provide you with a laptop where you can access the prototype and you will be requested to complete a series of tasks while thinking aloud. Meanwhile, I will take some notes to better understand your interaction with the prototype. Finally, I will ask you a few general questions to evaluate your overall experience with the tool.

You are free to stop whenever you want. I will only check the operation of the application, no test will be performed on you."

6.2.5 Tasks to be performed

The scenario chosen consists of the most important tasks to be performed with the tool:

Task 1: Start a new project

- Create a new project

Task 2: Select a plot

- Search for location (Madrid)
- Select a plot
- Advance to the next step

Task 3: Define the setback, entrance, and regulations

- Define the setback for S5 by interacting with the map (to 2.22 m)
- Set S1 as main entrance and S4 as back entrance
- Adjust regulations
- Advance to the next step

Task 4: Customize unit mix and choose preferences

- Customize unit mix (25% Studio, 75% 1-Bedrooms)
- Add a new configuration (name: My Config, 1 bedroom, 2 bathrooms, 1 kitchen, façade length of 1.22 m)
- Adjust corridor width by using the slider
- Adjust the other preferences by using the text boxes
- Advance to the next step

Task 5: Create the desired design

- Generate designs
- Include feasibility analysis
- Filter design by price and then reset filters
- Create a new design by dragging and dropping the first distribution of living units outside the shape and then inside
- Compare solutions (first and second designs generated)
- Choose the first design displayed as favorite and export it as PDF
- Preview the favorite design and switch between 2D and 3D
- Save the project

6.2.6 Objective metrics

While participants go through all of the proposed tasks, the time, number of actions, number of mistakes and success are recorded. At the end, the values obtained are compared with the optimal values to identify potential usability problems.

Measurement	**Description**
Time	Time required to complete one task
Actions	Number of elemental actions performed (click, tap, …) to complete one task.
Mistakes	Number of mistakes made during one task.
Success	Yes/no (whether the participant succeeds at completing the task).

Table 6.2 Objective metrics to be recorded

Task	**Time**	**Actions**
Task 1	5”	1
Task 2	15”	5
Task 3	30”	9
Task 4	40”	18
Task 5	1’	25

Table 6.3 Optimal time and number of actions for each task

6.2.7 Subjective metrics

Besides the objective metrics, the participants' experience with the prototype is also assessed using three methods: the SUS questionnaire, the UEQ questionnaire and general impressions questions. The goal is to assess the participants' overall impression of the prototype in terms of attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty [40].

6.2.7.1 User satisfaction: SUS questionnaire

Participants have to reply with their degree of agreement or disagreement to the following ten sentences, where 1 means "I totally disagree with the sentence" and 5 means "I totally agree with the sentence" [41].

	1	2	3	4	5
I think that I would like to use this system frequently.					
I found the system unnecessarily complex.					
I thought the system was easy to use.					
I think that I would need the support of a technical person to be able to use this system.					
I found the various functions in this system were well integrated.					
I thought there was too much inconsistency in this system.					
I would imagine that most people would learn to use this system very quickly.					
I found the system very cumbersome to use.					
I felt very confident using the system.					
I needed to learn a lot of things before I could get going with this system.					

Table 6.4 SUS questionnaire

6.2.7.2 User experience: UEQ questionnaire

For the assessment of the product, users have to fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. They can express their agreement with the attributes by ticking the square that most closely reflects their impression. Participants are encouraged to not think too long about their decision to make sure they convey their original impression.

	1	2	3	4	5	6	7		
annoying	□	□	□	□	□	□	□	enjoyable	1
not understandable	□	□	□	□	□	□	□	understandable	2
creative	□	□	□	□	□	□	□	dull	3
easy to learn	□	□	□	□	□	□	□	difficult to learn	4
valuable	□	□	□	□	□	□	□	inferior	5
boring	□	□	□	□	□	□	□	exciting	6
not interesting	□	□	□	□	□	□	□	interesting	7
unpredictable	□	□	□	□	□	□	□	predictable	8
fast	□	□	□	□	□	□	□	slow	9
inventive	□	□	□	□	□	□	□	conventional	10
obstructive	□	□	□	□	□	□	□	supportive	11
good	□	□	□	□	□	□	□	bad	12
complicated	□	□	□	□	□	□	□	easy	13
unlikable	□	□	□	□	□	□	□	pleasing	14
usual	□	□	□	□	□	□	□	leading edge	15
unpleasant	□	□	□	□	□	□	□	pleasant	16
secure	□	□	□	□	□	□	□	not secure	17
motivating	□	□	□	□	□	□	□	demotivating	18
meets expectations	□	□	□	□	□	□	□	does not meet expectations	19
inefficient	□	□	□	□	□	□	□	efficient	20
clear	□	□	□	□	□	□	□	confusing	21
impractical	□	□	□	□	□	□	□	practical	22
organized	□	□	□	□	□	□	□	cluttered	23
attractive	□	□	□	□	□	□	□	unattractive	24
friendly	□	□	□	□	□	□	□	unfriendly	25
conservative	□	□	□	□	□	□	□	innovative	26

Table 6.5 UEQ questionnaire

6.2.7.3 General impressions questions

Finally, participants are asked about their general experience with the prototype. Four main topics are explored:

1. What are the main problems you have found while using this prototype?
2. What is the part of the prototype that has been more difficult to understand? Why?
3. What have you liked most of the prototype? Why?
4. Can you describe your overall experience with this prototype?

6.2.8 Results

Following, the results of the usability testing will be presented both in terms of objective and subjective metrics.

6.2.8.1 Objective metrics

The complete objective metrics and observations for each of the three participants can be seen in Annex 6.

All three participants managed to complete the tasks. In general, the participants did not encounter any problems while trying to accomplish the first task. Thus, the average number of mistakes was 0 and the average time was lower than expected. It took participants more time than expected to complete the second task. This might be due to the novelty of the features proposed. However, after familiarizing with the application, participants navigated more seamlessly through the entire flow. For Task 3, participants managed to complete the proposed actions without any doubts. Task 4 was the one scoring the greatest number of mistakes and the highest time deviation (compared to the optimal value). Most of the participants needed verbal cues to accomplish this task. Lastly, participants found it intuitive to complete Task 5. The average time was above the optimal average, but the average number of mistakes was only 1.

Task	Time (average)	Optimal value
Task 1	3,33”	5”
Task 2	21,67”	15”
Task 3	40”	30”
Task 4	1’6”	40”
Task 5	1’8”	1’

Table 6.6 Time on task

Task	Actions (average)	Optimal value
Task 1	1	1
Task 2	7,66	5
Task 3	10,33	9
Task 4	24,33	18
Task 5	26	25

Table 6.7 Actions per task

Task	Mistakes (average)
Task 1	0
Task 2	2
Task 3	1,33
Task 4	5,33
Task 5	1

Table 6.8 Mistakes per task

6.2.8.2 SUS questionnaire

The total SUS score for all three participants is: 83,3/100. The SUS scores in detail are as follows: Participant 1: 87.5/100, Participant 2: 80/100, Participant 3: 82,5/100.

	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
1	0	0	0	2	1
2	2	1	0	0	0
3	0	0	0	2	1
4	3	0	0	0	0
5	0	0	0	0	3
6	3	0	0	0	0
7	0	0	3	0	0
8	3	0	0	0	0
9	0	0	1	2	0
10	0	1	1	1	0

Table 6.9 Responses to the SUS questionnaire

6.2.8.3 UEQ questionnaire

The complete responses to the UEQ questionnaire for each of the three participants can be seen in Annex 7. Each of the six attributes was rated excellent (Figure 6.13). Only the persipicuity was rated closer to 'Good'.

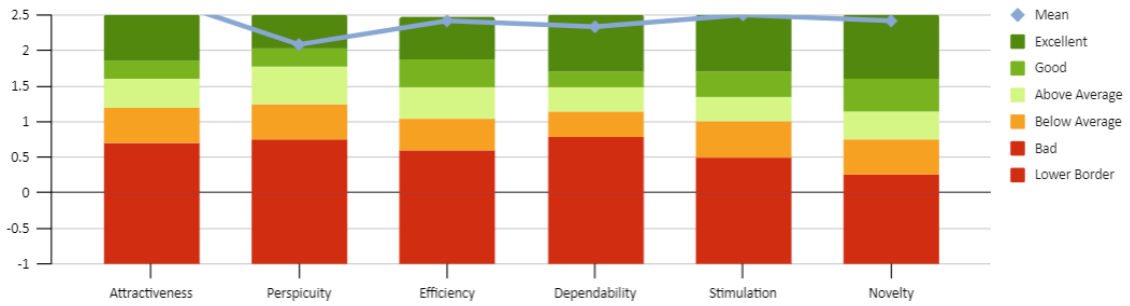


Figure 6.13 UEQ questionnaire results

6.2.8.4 General impressions

Overall, the participants enjoyed interacting with the map and with the generated solutions. Moreover, they appreciated the novelty of the features proposed.

At the first contact with the tool, it took them longer to understand how different mechanisms work. Moreover, in the beginning, they did not observe the informative messages which hindered accomplishing some of the tasks

and generated confusions. However, as they advanced in the process, participants started to grasp the flow and completed faster the given tasks.

In general, participants encountered problems while trying to complete the fourth task. As they did not initially see the 'Edit types' feature, they were confused and started to navigate through the other available controls. Once they were prompted about the existence of the 'Edit types' feature, users accomplished their goal without any other help.

There was also some confusion about the 'Save' button in the last step. Users expected to see a 'Next' button instead of a 'Save' one, as they did throughout the whole application. Thus, when asked in the final task to save the project, participants were confused, but proceeded with the right action after a few seconds. Overall, the participants managed to accomplish all of the tasks proposed.

6.2.9 Usability problems

The usability testing provided rich insights on what problems users could encounter while trying to reach their goals with the application. A summary of all of the usability problems identified can be seen in Table 6.10.

Usability problems	Recommendations
Informative messages were overlooked initially	Make the informative messages more visible
'Edit types' in Step 3 was hard to see	Highlight the 'Edit types' feature
'Save' button in Step 4 was not intuitive	Change the mechanism for saving the project
Some of the controls such as the drop-down menus were too small	Increase the size of the controls

Table 6.10 Usability problems and recommendations

6.2.10 Design improvements

The informative messages helped the users to accomplish the tasks proposed. However, at the first contact with the application, they were overlooked. In the newest version of the prototype, the informative messages were made more visible (Figure 6.14).

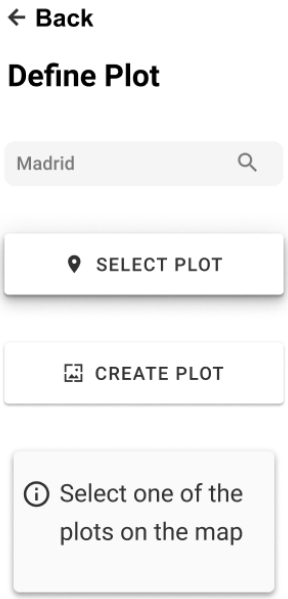


Figure 6.14 New layout for informative messages

As participants encountered problems regarding the size of the controls they had to interact with, the text boxes and the drop-down menus were enlarged. Moreover, the spacing between different fields was increased to make it easier to process the different information displayed (Figure 6.15).

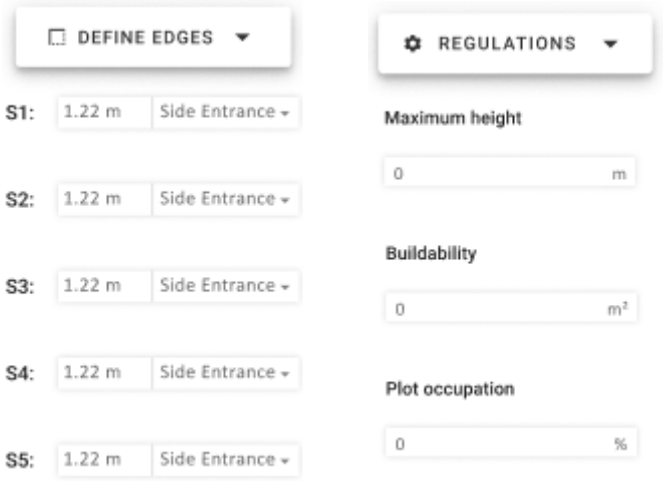


Figure 6.15 Increased size for interactive controls

In general participants had problems in Task 4 because they overlooked the 'Edit types' feature. Thus, in the new prototype this feature was highlighted using a stroke for a clearer differentiation from the background (Figure 6.16).

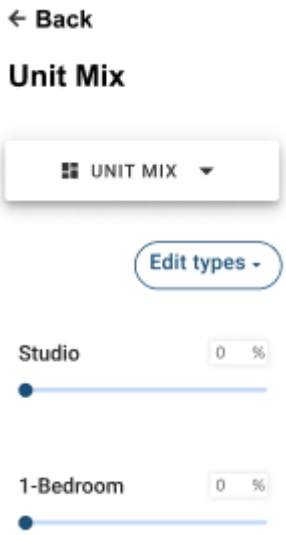


Figure 6.16 New layout with stroke for 'Edit types' feature

For saving the project, the 'SAVE' button was replaced with a next one to achieve a consistency with the rest of the application. A pop-up was added after clicking on the 'NEXT' button to notify the users that the project will be saved, and they will return to the main dashboard (Figure 6.17).

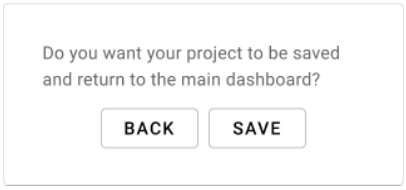


Figure 6.17 Pop-up for saving the project

7 Implementation

A prerequisite of the project was to implement the UI in Unity. As the scope of the project proved to be larger than initially estimated, the user interface was not technically implemented, due to time constraints. However, as Unity is widely used and offers valuable resources for UX designers, the basics of implementing the proposed UI for the buildability tool in Unity will be tackled above.

Unity offers three systems that enable building user interfaces (UIs): UI Toolkit, the Unity UI (uGUI) package, and the Immediate Mode Graphical User Interface (IMGUI) [42].

UI Toolkit is the newest UI system offered by Unity. It contains core features and functionalities required to create user interfaces, UI assets, and resources that support learning. It is the recommended system for building UIs, but it is still missing some essential features found in uGUI and IMGUI.

The Unity User Interface (Unity UI) package is an older, GameObject-based UI system mainly used for creating runtime UIs for games [42]. By arranging the different components and using the game view, the UI can be styled. The Unity UI supports advanced rendering and text features [42].

The Immediate Mode Graphical User Interface (IMGUI) is a code-driven UI Toolkit mostly used for creating custom Inspectors for script components, extensions for the Unity Editor, and in-game debugging displays [42]. As it is not recommended for creating runtime UIs, the IMGUI is outside the scope of the project.

The UI Toolkit offered by Unity is still under development and essential features for building the interface are still in the 'planned' phase. Thus, the implementation using Unity UI package will be further discussed, touching on the most important aspects such as the canvas, visual and interaction components, events, and assets.

7.1 Canvas

The Canvas contains all of the UI elements. It is a Game Object with a Canvas component on it, and all UI elements must be children of it [43]. The Canvas area is shown as a rectangle in the Scene View, which makes it easy to position UI elements inside of it. Within the Canvas, the UI elements are ordered into a hierarchy; the earliest drawn component appears at the top while the latest appears on the bottom. The order can be changed by dragging the components in the hierarchy or by scripting.

In Unity, every UI element is treated as a rectangle and can be modified using the **Rect Tool**. With the Rect Tool, different components can be moved, resized, or rotated. **Rect Transform** enables performing more complex transformations to UI elements such as resizing (while keeping the local scale unchanged), changing the anchors or the pivot. The controls in the Rect Transform panel are similar to the ones in Figma: position on the X or Y axis, width, height, and rotation (Figure 7.1). As Unity is a 3D environment, the position of the elements on the Z axis can also be changed.

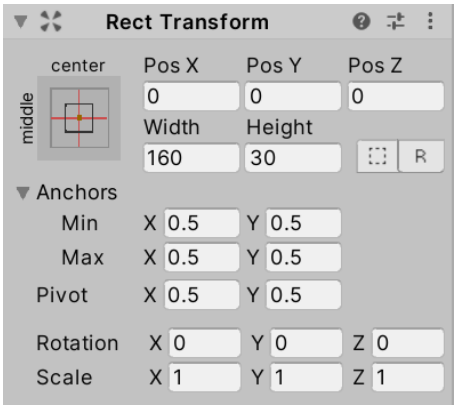


Figure 7.1 Rect Transform panel in Unity

7.2 Visual and interaction components

Unity UI offers a set of components with specific functionalities which facilitate the process of developing user interfaces. Some of the most basic components are text, images, buttons, toggles, dropdown menus, scrollbars and input fields. The implementation details of the components used throughout the prototype will be next discussed.

The text component has a text area where developers can input the text which will be displayed. It is possible to change the font of the text, the font style, size, line spacing or to select if the text has a rich text capability (Figure 7.2). Moreover, Unity UI allows customizing the alignment, the color or even the material. By applying the 'Best Fit' option, text will be resized to fit the available space (Figure 7.2).

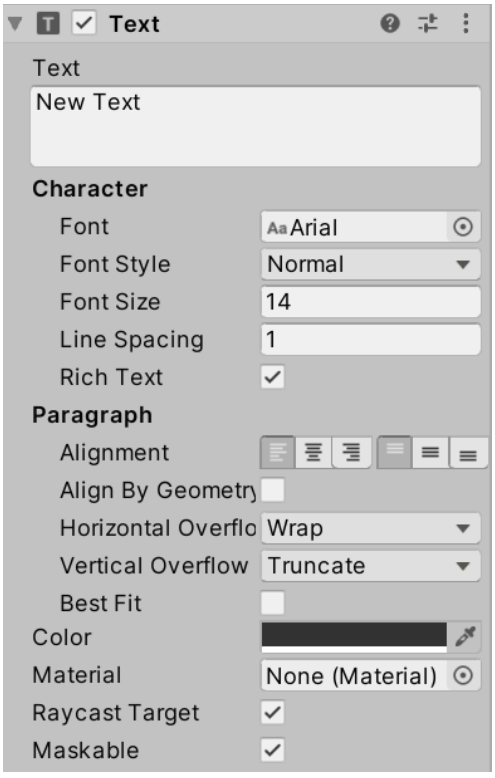


Figure 7.2 Text panel in Unity

For the image component, a Sprite, a material or a color can be applied. The Image Type setting determines how the sprite will appear: simple, sliced, tiled or filled [44]. There is also an option to 'Set Native Size' which resets the image to the original sprite size (Figure 7.3). Any image can be imported as a Sprite by changing its 'Texture Type'.

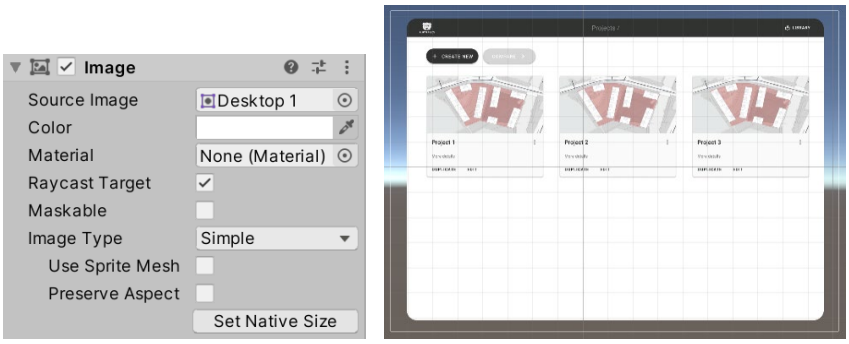


Figure 7.3 The image panel -left; a Sprite applied to the Image component – right

Buttons are one of the most used components in user interfaces. In Unity, a Button has an **OnClick** UnityEvent to define what it will do when clicked [45]. The color of the button when it is pressed, selected or disabled can be changed (Figure 7.4). Moreover, the component comes by default with a text field which determines what will be written on it.

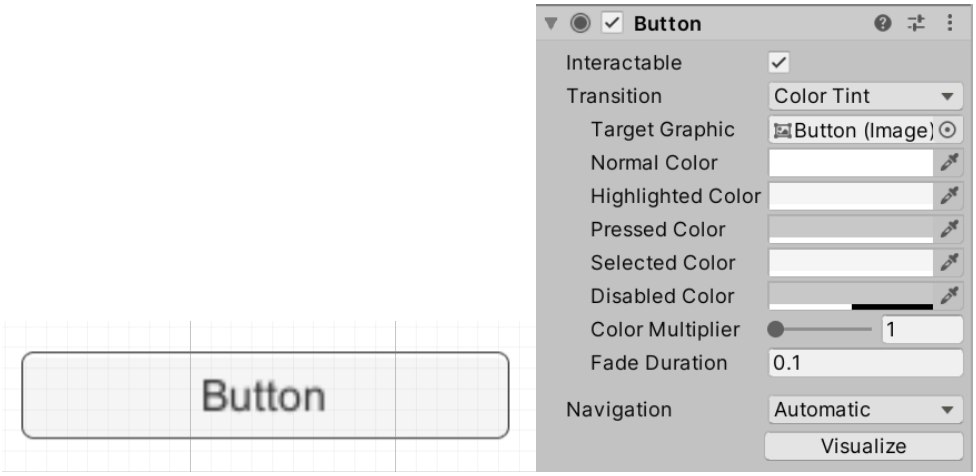


Figure 7.4 Button layout – left; button panel – right

The Slider has a current value parameter which determines its current position. The current value has to be within the Min Value and Max Value limits (Figure 7.5). The default behavior of the Slider is to increase from left to right, but it can be changed by using the 'Direction' property. It can also increase vertically using the same 'Direction' property. When the user drags the handle, the Slider event **On Value Changed** is invoked and passes the current value of the slider as a float type dynamic argument. The Scrollbar is similar to the Slider, but the Scrollbar's handle can change in size to represent the distance of scrolling available.

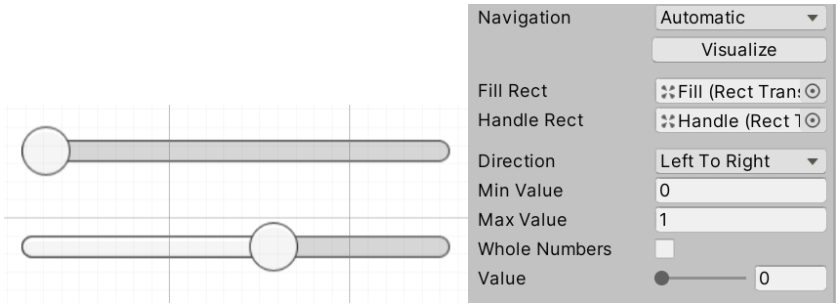


Figure 7.5 Slider layout – left; slider settings – right

Drop down menus are complex elements; in Unity they are designed to have a label, an arrow, and a template. The list of options in the menu can be specified in the Inspector (Figure 7.6) or assigned in the script. Each option can receive both a text and an image. When one of the options in the menu is clicked, an **On Value Changed** event is invoked and passes an integer number value that is the index of the selected option.

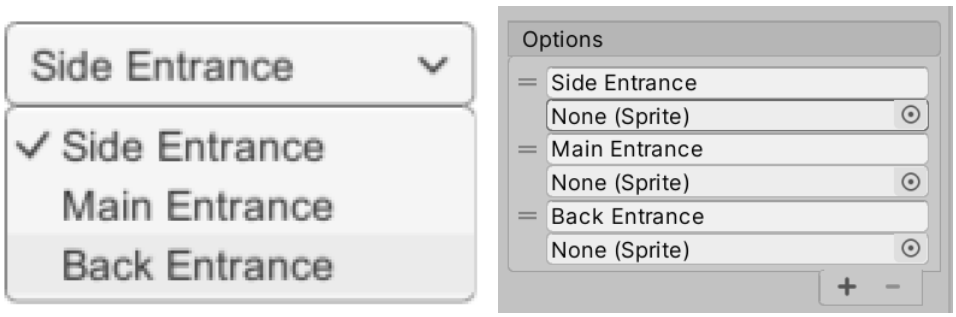


Figure 7.6 Example of drop-down menu – left; specifying the dropdown menu options using the Inspector - right

An Input Field is a text control which is editable (Figure 7.7). It has a placeholder and a text component which changes as the user types in the field. The value can be retrieved from a script after the editing. When the text content of the Input Field changes, an **On Value Changed** event is invoked and can pass send the current text content as a string type dynamic argument. The **End Edit** event is invoked when the user finishes editing and can send the current text content as a string type dynamic argument.

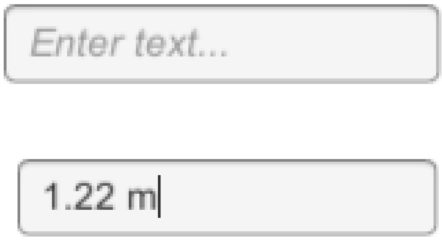


Figure 7.7 Example of using the Input Field

7.3 Events

Events are handled by the Event System. Based on input such as keyboard or mouse, the system sends events to the corresponding objects of the application. The Event System has five main components:

- **Event System Manager**: controls every element in the event handling process such as which Input Module is active, or which GameObject is selected.
- **Raycasters**: used to determine on what element is the pointer over; depending on the UI elements they target, they can be classified as:
  - Graphic Raycasters: UI elements
  - Physics 3D Raycasters: 3D elements
  - Physics 2D Raycasters: 2D elements
- **Input Modules**: sends pointer events to components when inputs are detected such as a mouse is moved, or an Input Field changed; uses Raycasters to calculate which element is currently pointed at.
- **Event Trigger**: receives events from the Event System and calls registered functions for each event.

The Event System supports a number of default events, but they can be further customized.

7.4 Assets

Besides the built-in functionalities and components, Unity offers the Asset Store where a large number of assets, tools, scripts can be downloaded. An asset is an item that can be used in any Unity project. Assets can come from 3D models, audio files, images or any file that has a format Unity supports.

Unity has default behaviors for managing assets; it can automatically import them and process data such as what import settings should be used.

Anything included in the 'Asset' folder is read and converted into project-ready content. Internal representations of the assets are stored in the project's Library folder which is like a cache folder.

Using Assets, Design Systems can be imported in Unity and deployed for building consistent designs. For example, different UI kits are available for free or for purchasing in the Asset Store (Figure 7.8). Besides these, companies can develop in-house Design Systems.

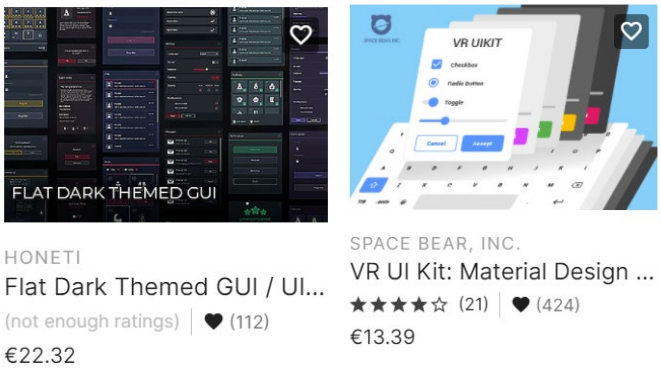


Figure 7.8 Examples of UI kits available in the Asset Store

8 Results and conclusions

This paper presented a user-centred approach for designing the user experience for Lurtis' Buildability Estimator.

The competitive analysis has shown the design strengths and weaknesses of similar products already existing on the market.

Through the user research, some of the previous assumptions about the target users were confirmed, while others were disregarded. The interview provided valuable insights into the work practices of architects and identified pain points regarding the use of the applications currently integrated in the interviewees' work routine. All of the findings were used to refine the architect persona and to define the customer journey. The customer journey helped understanding the actions users go through while trying to accomplish their goals with the tool. Moreover, the customer journey was used as a starting point for the navigation map.

Next, the prototyping phase followed. After defining the navigation map to have a clear image of the entire flow of the application, wireframes and low-fidelity mockups were created. The wireframes and mockups provided a stimulating artifact for discussion and brought everyone on the same page. The high-fidelity prototype was then designed taking into consideration all of the insight obtained and the ideas discussed. After completing the first iteration of the prototype, user flows were also created.

The high-fidelity prototype underwent multiple rounds of testing. Firstly, it was evaluated through a cognitive walkthrough where expert users offered practical suggestions on how the application can be improved to facilitate users to navigate through it and accomplish their goals. After the design changes were implemented, the high-fidelity prototype was evaluated again through usability testing. Non-expert users tried to accomplish a series of tasks with the prototype while thinking aloud. In the beginning users struggled to find certain interface elements, but after familiarizing with the application, the processes were intuitive to follow. However, this can be due to the fact that the participants in the usability testing were not architects and thus were not accustomed with the terms and processes involved in this profession.

Lastly, the paper tackled some of the basic concepts needed for developing user interfaces in Unity. However, there are many other aspects to be taken into account. Designing for multiple resolutions, making complex components such as drop-down menus accessible, or creating seamless screen transitions are just few of the most important things to consider for achieving intuitive interactions and creating easy to use interfaces.

As future plans the visual identity of the Buildability Estimator needs to be further developed. As the time was limited, the research focused on creating a smooth user experience and on achieving a natural integration of all of the proposed features. Moreover, the tool needs to be tested through multiple sessions of usability testing with architects as they represent the targeted customer segment.

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10 Annexes

10.1 Annex 1

Unique features	Archistar	Testfit	Spacemaker	Kreo	Unitize
Design strengths	Different layered view of an area	Different layered view of an area	View of the distribution of types of buildings	Easy to start a project	Simple and easy to use interface
	Highly detailed view of land	Interactive selection of an area on map	Easy specification of design preferences	Easy to interact with the map	Warnings on wrong parameters
	Multiple filtering options	Interactive drawing of roads	Fast creation of multiple sketches	Detailed architectural and structural reports	
	Good integration - possibility to use add-ons such as aerial imagery or sales/listings	High customization of each unit	Precise and well visualized 3D analysis (density, sun, wind)	Easy to adjust floor plan layout	
	Comprehensive description of a site	Generative parking		Easy to adjust apartment layout	
	References to official government documents	Possibility to use presets			
		Financial models			
Design weaknesses	Too many customization options - might be hard to find a particular setting or information	Too technical interface - specialized use only			Too limited
Customer base	property developers, real estate agents,	real estate developers, urban	real estate developers, architects	manufacturers, developers,	designers, architects

	architects, home builders, governments, property investors, universities	planners, architects		contractors, consultants	
Channels	Website, Facebook, Instagram, LinkedIn, YouTube	Website, Facebook, Instagram, LinkedIn, YouTube, Twitter, Online chat	Website, Facebook, Instagram, LinkedIn, YouTube	Website, Facebook, Instagram, LinkedIn, YouTube, Twitter, Online chat	Website, LinkedIn, YouTube, Twitter, Online chat
Core features					
Interactive selection on map	✔	✔	✔	✔	x
Generative design	✔	✔	✔	✔	✔
User preferences	✔	✔	✔	✔	✔
Building mix	✔	✔	✔	✔	✔
Filter solutions	✔	?	✔	x	x
Compare solutions	✔	?	✔	x	x
Different typologies (Linear, U, L and closed block)	✔	✔	✔	✔	x
Environment simulation (sunlight, ventilation)	✔	✔	✔	x	x
Financial models	✔	✔	x	x	x

Table 10.1 Detailed competitive analysis

10.2 Annex 2

Figure 10.1 First slide – Discussion topics

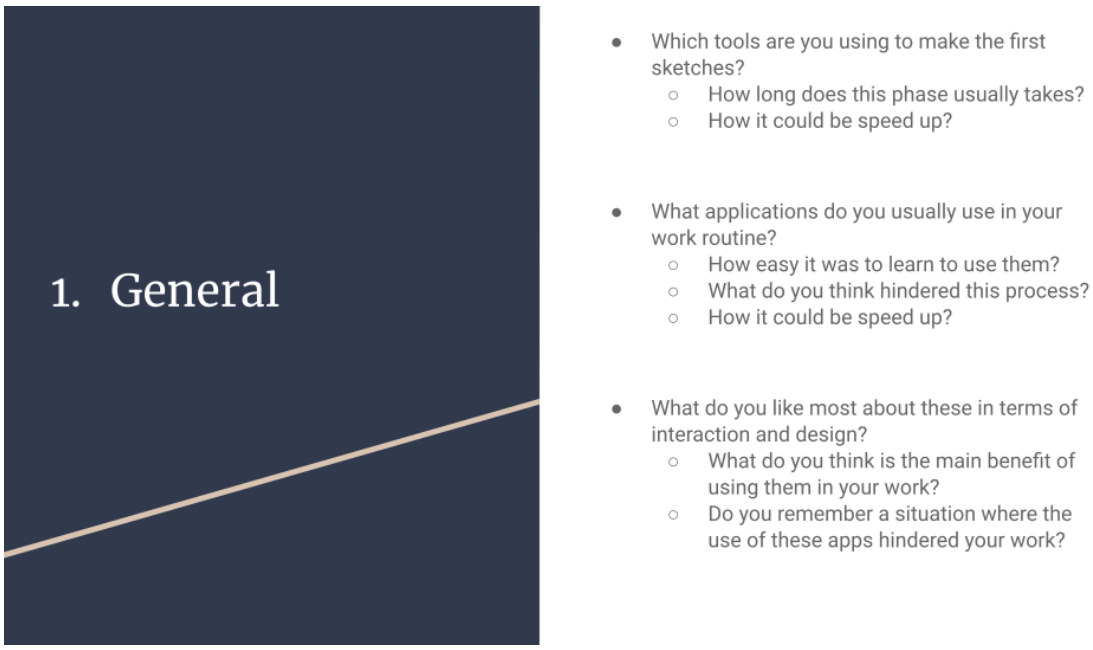

Figure 10.2 Slide 2 - General questions

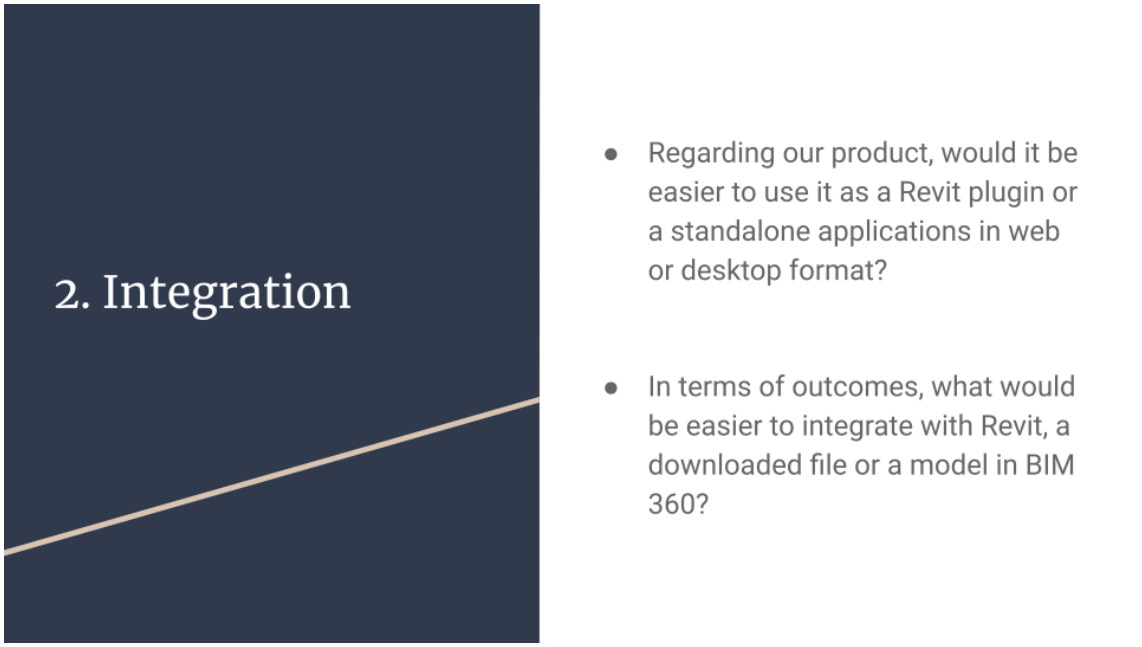

Figure 10.3 Slide 3 – Integration questions

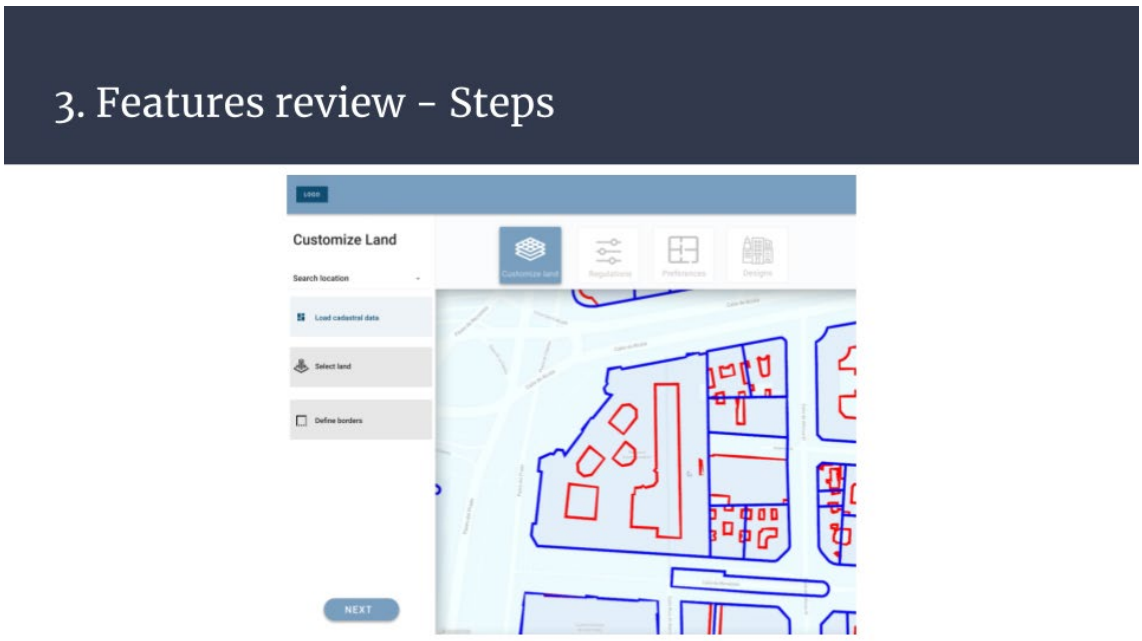

Figure 10.4 Slide 4

3. Features review - Steps

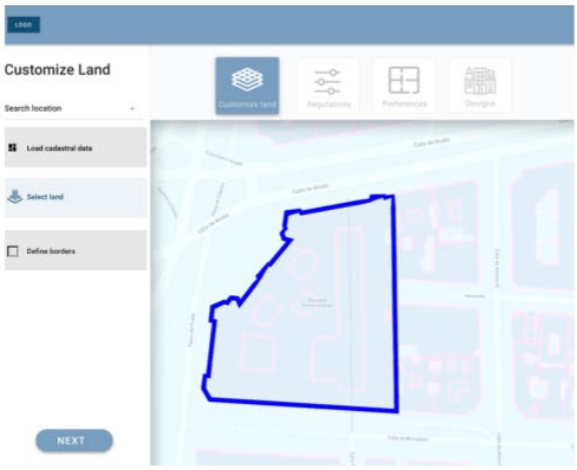

Figure 10.5 Slide 5

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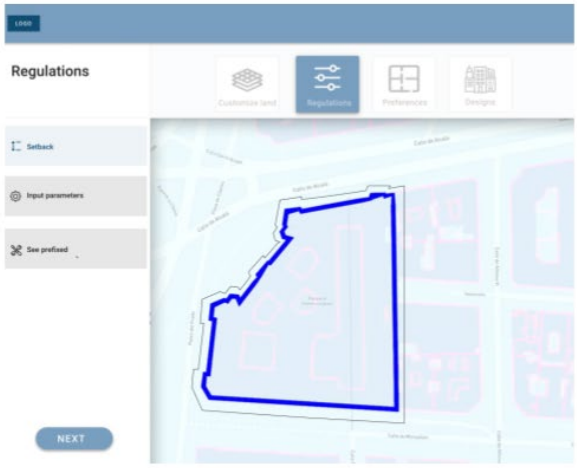

Figure 10.6 Slide 6

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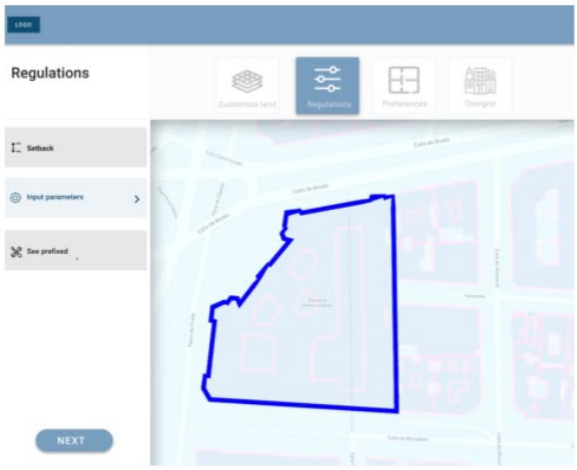

Figure 10.7 Slide 7

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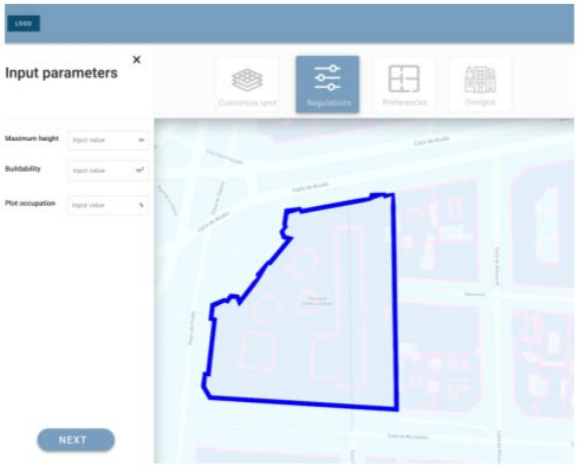

Figure 10.8 Slide 8

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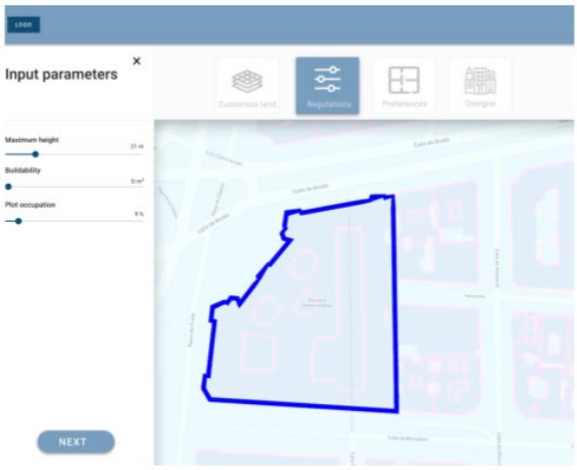
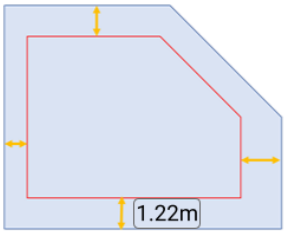


Figure 10.9 Slide 9

3. Features review - Setback



Map interactive

1. Drag margins around
2. Drag arrows around
3. Insert number on map

Figure 10.10 Slide 10

3. Features review - Regulations

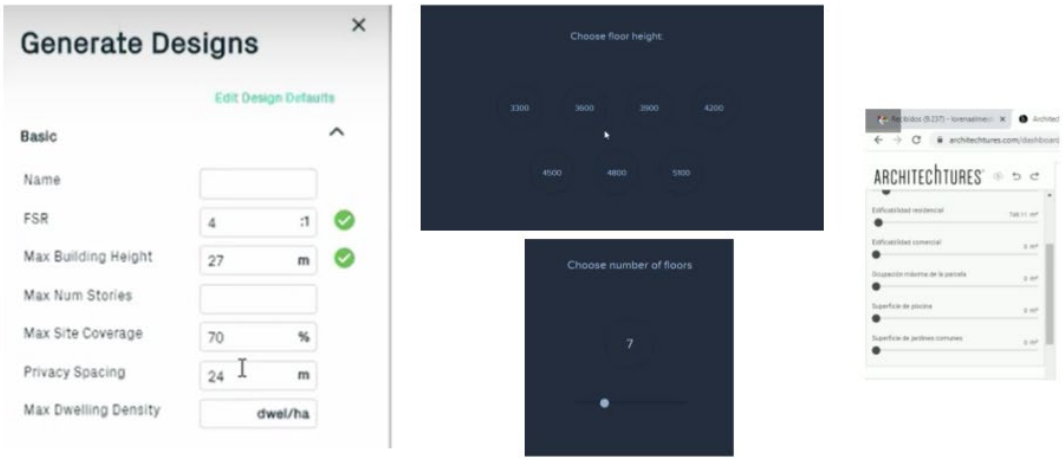


Figure 10.11 Slide 11

3. Features review - Building Unit Mix

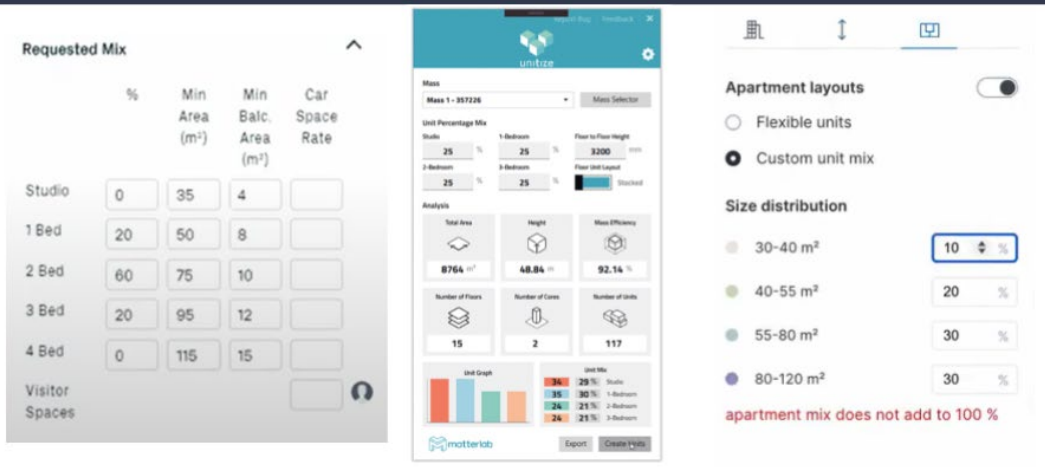


Figure 10.12 Slide 12

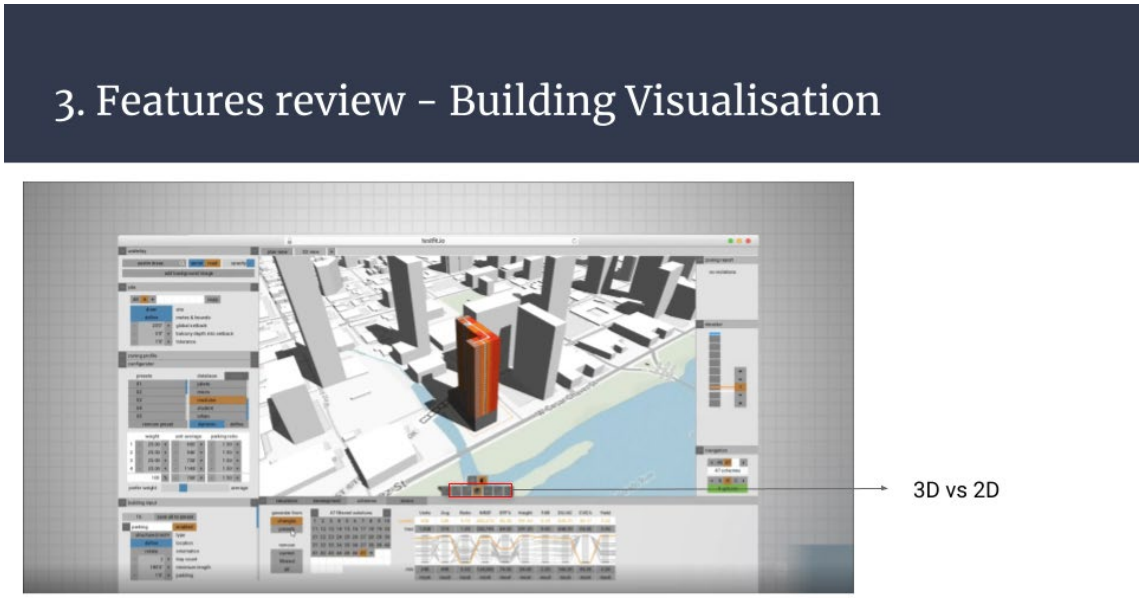


Figure 10.13 Slide 13

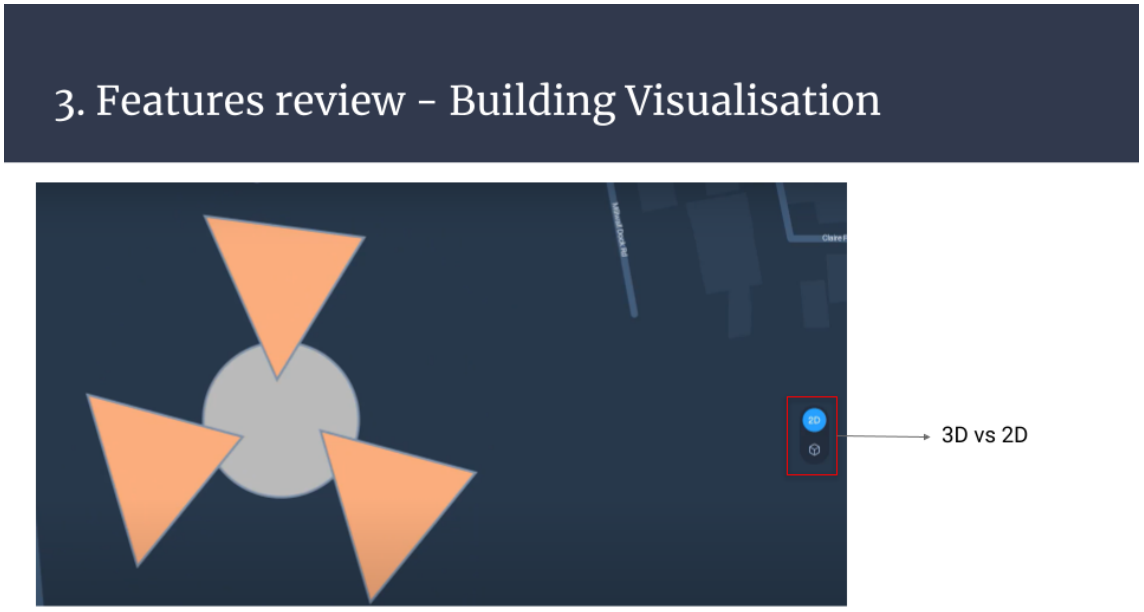


Figure 10.14 Slide 14

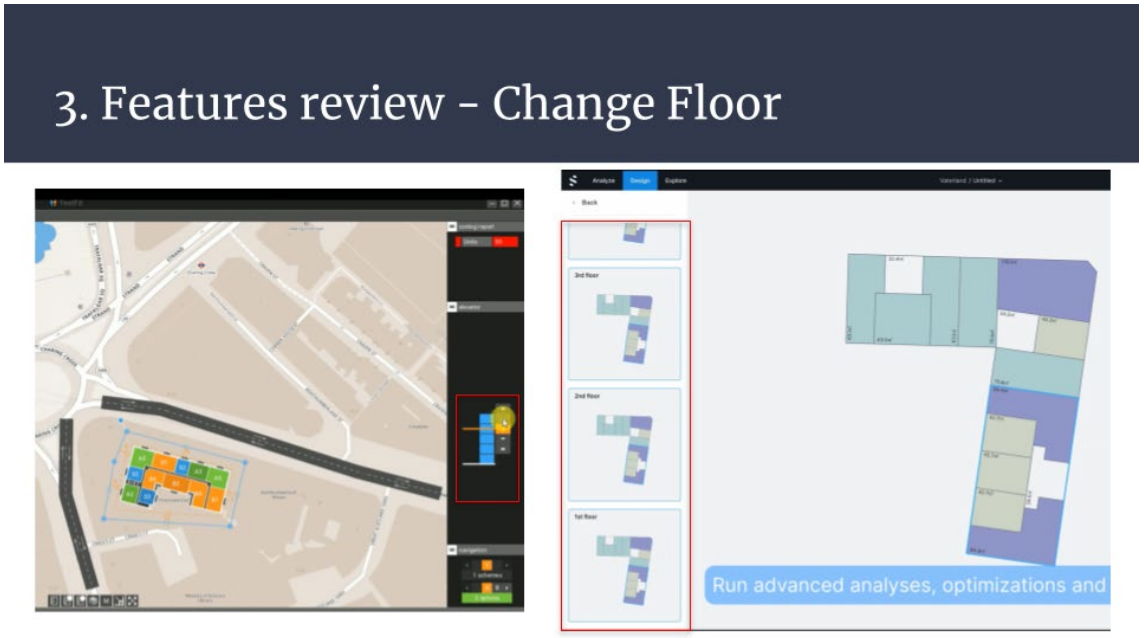


Figure 10.15 Slide 15

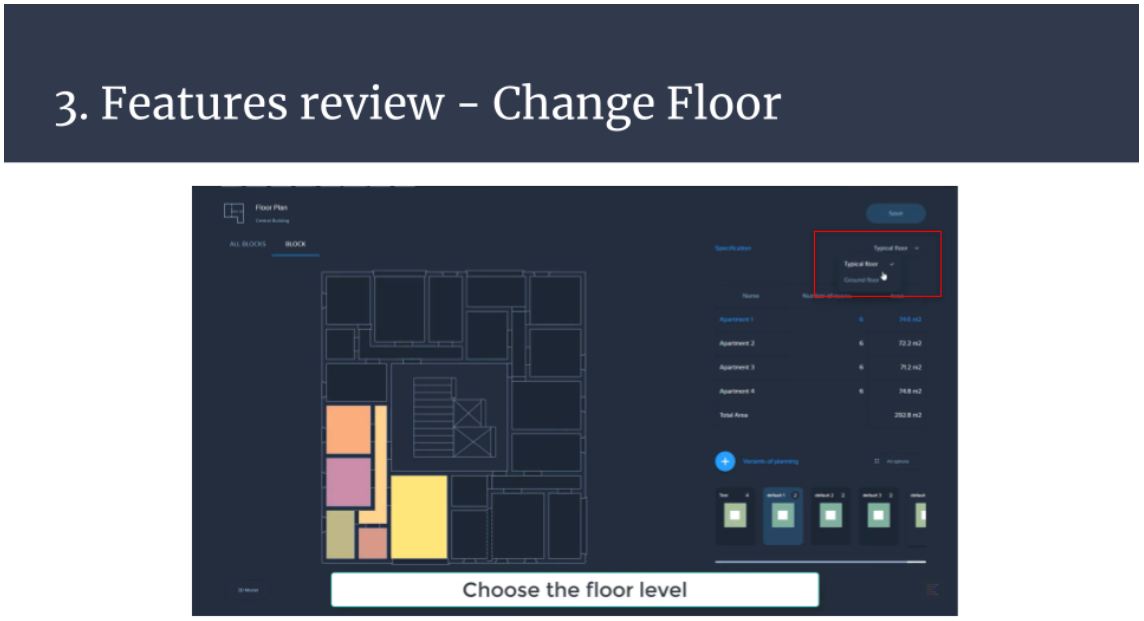


Figure 10.16 Slide 16

Figure 10.17 Slide 17

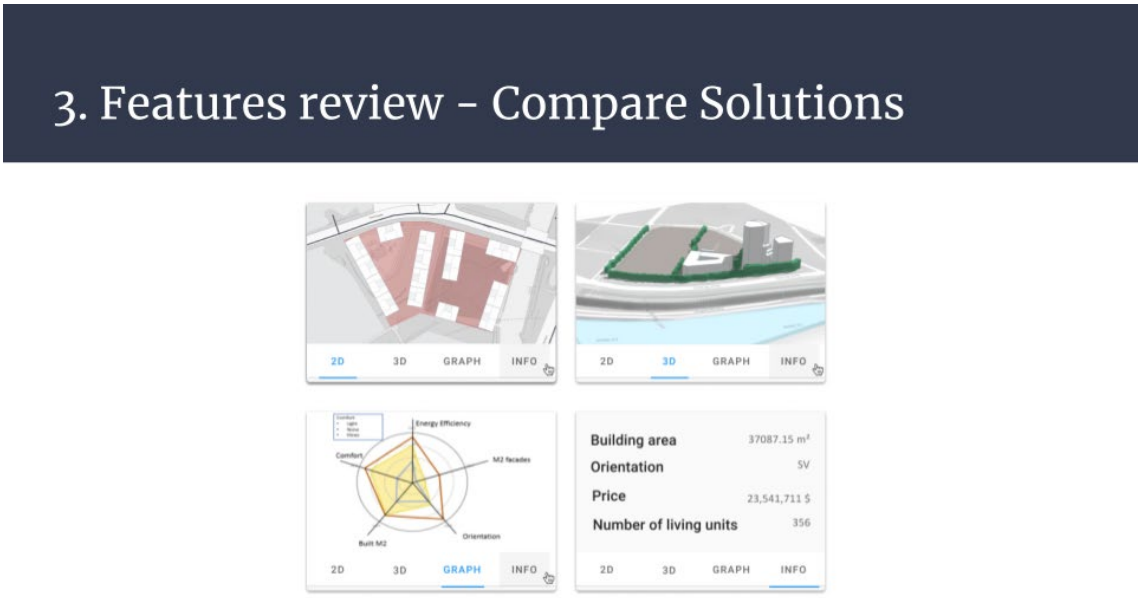


Figure 10.18 Slide 18

3. Features review - Filtering Solutions

Figure 10.19 Slide 19

3. Features review - Feasibility

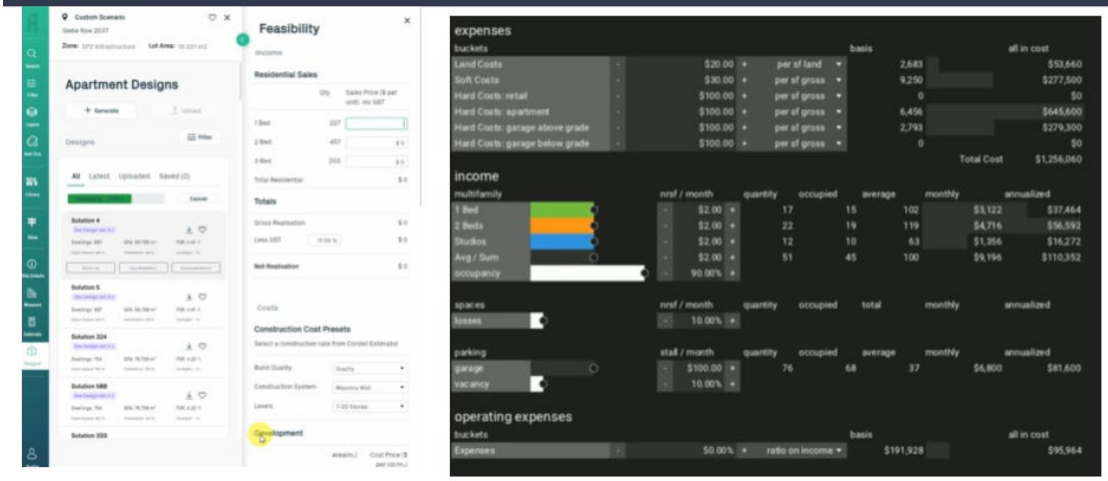


Figure 10.20 Slide 20

Figure 10.21 Slide 21- Final slide

10.3 Annex 3

User-centred Design for the Interface of an Artificial Intelligence Buildability Tool

Information brochure

June 2021

DESCRIPTION: You are invited to participate in an interview for the development of Lurtis' buildability tool. By participating in this activity, you will be asked a series of questions which will help us make the product easy to learn and use. The questions refer to your work routine and to the digital tools you use the most to accomplish your job-related tasks. Some of the questions you can expect are: 'Which tools are you using to make the first sketches? How long does this phase usually take? ' or 'What applications do you usually use in your work routine? How easy was it to learn to use them?'. The activity is meant to help us develop the product; it is not indeed to test your individual performance in any way. During the study, only written notes will be taken, no audio or video recording will be captured.

TIME INVOLVEMENT: Your participation will take approximately 1h.

RISKS AND BENEFITS: There is no discomfort involved in this study, nor any risks. We cannot and do not guarantee or promise that you will receive any benefits from this study.

PARTICIPANT'S RIGHTS: If you have read this form and have decided to participate in this study, please understand your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time without giving any reasons. You have the right to refuse to answer particular questions and/or fulfil requests. The results of this research study may be presented at educational, scientific or professional meetings or published in course papers or scientific articles. Your identity will not be made known in written materials resulting from the study.

- All your data will be made anonymous at the earliest possible stage and will be processed anonymously.
- Research data will be stored using secured cloud-based storage solutions so unauthorized access will be minimized. Only the direct researcher and Lurtis' members will have access to the data.
- The written notes will be destroyed after the research project has been completed.

CONTACT INFORMATION:

Questions: If you have any questions, concerns or complaints about this research, its procedures, risks and benefits, please contact Gabriela Mitrana (gabriela.mitrana@alumnos.upm.es). As the study is part of the Master Thesis for UPM and UT, you can also contact the Ethics Committee of ECMS (ethicscommittee-cis@utwente.nl).

Figure 10.22 Information brochure for interview

User-centred Design for the Interface of an Artificial Intelligence Buildability Tool

Consent form

June 2021

I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research . My questions have been answered to my satisfaction. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Gabriela Mitrana (gabriela.mitrana@alumnos.upm.es) or the Ethics Committee of ECMS (ethicscommittee-cis@utwente.nl).

☐ I give permission for the answers provided to be used for analysis, and possibly presented to the board members of the Master Thesis defense.

☐ I give permission for the answers provided to be quoted in research outputs.

SIGNATURE _____ **DATE** _____

The extra copy of this consent form is for you to keep.

If you have any questions, concerns or complaints about this research, its procedures, risks and benefits, please contact Gabriela Mitrana (gabriela.mitrana@alumnos.upm.es) or the Ethics Committee of ECMS (ethicscommittee-cis@utwente.nl).

Figure 10.23 Consent form for interview

10.4 Annex 4

User-centred Design for the Interface of an Artificial Intelligence Buildability Tool

Consent form

June 2021

I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research . My questions have been answered to my satisfaction. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Gabriela Mitrana (gabriela.mitrana@alumnos.upm.es) or the Ethics Committee of ECMS (ethicscommittee-cis@utwente.nl).

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Figure 10.24 Information brochure for cognitive walkthrough

User-centred Design for the Interface of an Artificial Intelligence Buildability Tool

Information brochure

June 2021

DESCRIPTION: You are invited to participate in a cognitive walkthrough for the development of Lurtis' buildability tool. By participating in this activity, you will be shown a scenario using the high-fidelity prototype. The high-fidelity prototype is a computer-based interactive representation of the application; it resembles the final design in terms of details and functionality. The scenario covers the full functionality of the system; it consists of the main tasks to be performed with the application. The person conducting the walkthrough will present to you the scenario, showing you each screen at a time. At each new screen, you will be asked to share your thoughts regarding different aspects such as possible actions or expectations. Some examples of questions you can expect are: 'Are you making progress toward your goal?' or 'What would your next action be?'. The activity is meant to help us develop the product; it is not indeed to test your individual performance in any way. During the study, only written notes will be taken, no audio or video recording will be captured.

TIME INVOLVEMENT: Your participation will take approximately 1h.

RISKS AND BENEFITS: There is no discomfort involved in this study, nor any risks. We cannot and do not guarantee or promise that you will receive any benefits from this study.

PARTICIPANT'S RIGHTS: If you have read this form and have decided to participate in this study, please understand your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time without giving any reasons. You have the right to refuse to answer particular questions and/or fulfil requests. The results of this research study may be presented at educational, scientific or professional meetings or published in course papers or scientific articles. Your identity will not be made known in written materials resulting from the study.

- All your data will be made anonymous at the earliest possible stage and will be processed anonymously.
- Research data will be stored using secured cloud-based storage solutions so unauthorized access will be minimized. Only the direct researcher and Lurtis' members will have access to the data.
- The written notes will be destroyed after the research project has been completed.

CONTACT INFORMATION:

Questions: If you have any questions, concerns or complaints about this research, its procedures, risks and benefits, please contact Gabriela Mitrana (gabriela.mitrana@alumnos.upm.es). As the study is part of the Master Thesis for UPM and UT, you can also contact the Ethics Committee of ECMS (ethicscommittee-cis@utwente.nl).

Figure 10.25 Consent form for cognitive walkthrough

10.5 Annex 5

User-centred Design for the Interface of an Artificial Intelligence Buildability Tool

Information brochure

June 2021

DESCRIPTION: You are invited to participate in a usability testing session for the development of Lurtis' buildability tool. By participating in this activity, you will be asked to perform a series of tasks with the high-fidelity prototype. The high-fidelity prototype is a computer-based interactive representation of the application; it resembles the final design in terms of details and functionality. Some examples of the tasks you can expect are: 'create a new project', 'search for a location', 'select a land', 'adjust the setback' or 'filter the generated designs by price'. During your interaction, different metrics will be recorded such as the time on task, number of actions or success rate, to help us understand your interaction with the application better. At the end, you will be asked to fill in the user satisfaction questionnaire, the user experience questionnaire and share your general impressions about the experience. The activity is meant to help us develop the product; it is not indeed to test your individual performance in any way. During the study, only written notes will be taken, no audio or video recording will be captured.

TIME INVOLVEMENT: Your participation will take approximately 1h.

RISKS AND BENEFITS: There is no discomfort involved in this study, nor any risks. We cannot and do not guarantee or promise that you will receive any benefits from this study.

PARTICIPANT'S RIGHTS: If you have read this form and have decided to participate in this study, please understand your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time without giving any reasons. You have the right to refuse to answer particular questions and/or fulfil requests. The results of this research study may be presented at educational, scientific or professional meetings or published in course papers or scientific articles. Your identity will not be made known in written materials resulting from the study.

- All your data will be made anonymous at the earliest possible stage and will be processed anonymously.
- Research data will be stored using secured cloud-based storage solutions so unauthorized access will be minimized. Only the direct researcher and Lurtis' members will have access to the data.
- The written notes will be destroyed after the research project has been completed.

CONTACT INFORMATION:

Questions: If you have any questions, concerns or complaints about this research, its procedures, risks and benefits, please contact Gabriela Mitrana (gabriela.mitrana@alumnos.upm.es). As the study is part of the Master Thesis for UPM and UT, you can also contact the Ethics Committee of ECMS (ethicscommittee-cis@utwente.nl).

Figure 10.26 Information brochure for usability testing

User-centred Design for the Interface of an Artificial Intelligence Buildability Tool

Consent form

June 2021

I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research . My questions have been answered to my satisfaction. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Gabriela Mitrana (gabriela.mitrana@alumnos.upm.es) or the Ethics Committee of ECMS (ethicscommittee-cis@utwente.nl).

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Figure 10.27 Consent form for usability testing

10.6 Annex 6

Participant 1					
	Time	**Actions**	**Mistakes**	**Success rate**	**Observations**
Task 1	3”	1	0	100%	The participant had no doubts in accomplishing the task.
Task 2	30”	12	5	100%	Initially, the participant wanted to search for the location by interacting with the map; after he failed, he saw the left panel.
Task 3	30”	9	0	100%	The participant easily identified S5 on the map and understood how to use the drop-down menus. No problems were encountered while changing the regulations.
Task 4	1’30	30	10	100%	The participant successfully customized the unit mix, but encountered confusions when asked to add a new configuration. He did not see the ‘Edit types’ feature and started to navigate through the other controls available. Only when prompted about the existence of the ‘Edit types’ feature, he could complete the task.
Task 5	50”	25	0	100%	The participant found it intuitive to perform the actions in Task 4. The only doubt was when he had to save the project. The participant read the informative text in the ‘Create new solution’ feature and was helped by it. He expected to see a ‘Next’ button instead of a ‘Save’ one, as he did throughout the whole application. However, after a few seconds, he proceeded with the right action.

Table 10.2 Usability testing results for the first participant

Participant 2					
	Time	**Actions**	**Mistakes**	**Success rate**	**Observations**
Task 1	3”	1	0	100%	The participant accomplished the task without any doubts.
Task 2	20”	6	1	100%	The participant completed the task without any issues. However, she did not see the informative message.
Task 3	40”	11	2	100%	The participant easily identified S5 on the map and understood how to use the drop-down menus. However, she felt that the drop-down menus are too small. She did not read the informative message. The participant enjoyed interacting with the map to change the setback.
Task 4	50”	21	2	100%	The actions were intuitive for the participant. However, the participant made a mistake at some point and started to click on the other elements available instead of using the ‘Back’ button. She thought the ‘Back’ button would lead to the previous step (Step 2).
Task 5	1’15”	27	2	100%	The participant found it intuitive to generate designs and filter them. While trying to create a new solution, the participant felt confused; she read the informative message which helped her eliminate some of the doubts. The participant enjoyed interacting with the icons and buttons to preview a solution, export it and set it as favorite. The participant did not find it intuitive to use the ‘Save’ button when asked to save the project.

Table 10.3 Usability testing results for the second participant

Participant 3					
	Time	**Actions**	**Mistakes**	**Success rate**	**Observations**
Task 1	4”	1	0	100%	The participant completed the task without any issues.
Task 2	15”	5	0	100%	The participant found the task intuitive to perform and did not have any doubts during the interaction.
Task 3	50”	11	2	100%	The participant was confused at the beginning of the task. She did not know how to interact with the edges of the contour and did not see the informative message. After she was prompted about its existence, she read it and managed to modify the setback. Then, she also tried to set the main entrance by interacting with the map, but when this did not work, she used the drop-down menu.
Task 4	1’	22	4	100%	The participant modified the Studio and 1-Bedroom configurations using the sliders. While trying to add a new configuration she did not see the ‘Edit types’ feature and started to navigate through the preferences. The participant was given verbal cues to identify the ‘Edit types’ feature. The task went smoothly after this point.
Task 5	1’20”	26	1	100%	The participant generated the solutions and filtered them successfully. She was confused when creating a new feature as she did not understand how to interact with the different unit distributions but completed the task. The participant enjoyed previewing the solution.

Table 10.4 Usability testing results for the third participant

10.7 Annex 7

	1	2	3	4	5	6	7		
annoying	□	□	□	□	□	□	x	enjoyable	1
not understandable	□	□	□	□	□	x	□	understandable	2
creative	x	□	□	□	□	□	□	dull	3
easy to learn	□	x	□	□	□	□	□	difficult to learn	4
valuable	x	□	□	□	□	□	□	inferior	5
boring	□	□	□	□	□	□	x	exciting	6
not interesting	□	□	□	□	□	□	x	interesting	7
unpredictable	□	□	□	□	□	x	□	predictable	8
fast	□	□	□	x	□	□	□	slow	9
inventive	x	□	□	□	□	□	□	conventional	10
obstructive	□	□	□	□	x	□	□	supportive	11
good	x	□	□	□	□	□	□	bad	12
complicated	□	□	□	□	□	x	□	easy	13
unlikable	□	□	□	□	□	□	x	pleasing	14
usual	□	□	□	□	□	□	x	leading edge	15
unpleasant	□	□	□	□	□	□	x	pleasant	16
secure	x	□	□	□	□	□	□	not secure	17
motivating	x	□	□	□	□	□	□	demotivating	18
meets expectations	x	□	□	□	□	□	□	does not meet expectations	19
inefficient	□	□	□	□	□	□	x	efficient	20
clear	□	x	□	□	□	□	□	confusing	21
impractical	□	□	□	□	□	□	x	practical	22
organized	x	□	□	□	□	□	□	cluttered	23
attractive	x	□	□	□	□	□	□	unattractive	24
friendly	□	x	□	□	□	□	□	unfriendly	25
conservative	□	□	□	□	□	□	x	innovative	26

Table 10.5 UEQ responses – first participant

	1	2	3	4	5	6	7		
annoying	□	□	□	□	□	x	□	enjoyable	1
not understandable	□	□	□	□	x	□	□	understandable	2
creative	□	x	□	□	□	□	□	dull	3
easy to learn	□	x	□	□	□	□	□	difficult to learn	4
valuable	x	□	□	□	□	□	□	inferior	5
boring	□	□	□	□	□	x	□	exciting	6
not interesting	□	□	□	□	□	x	□	interesting	7
unpredictable	□	□	□	□	□	x	□	predictable	8
fast	□	□	□	x	□	□	□	slow	9
inventive	□	x	□	□	□	□	□	conventional	10
obstructive	□	□	□	□	□	□	x	supportive	11
good	x	□	□	□	□	□	□	bad	12
complicated	□	□	□	□	□	x	□	easy	13
unlikable	□	□	□	□	□	□	x	pleasing	14
usual	□	□	□	□	□	x	□	leading edge	15
unpleasant	□	□	□	□	□	□	x	pleasant	16
secure	x	□	□	□	□	□	□	not secure	17
motivating	□	□	□	x	□	□	□	demotivating	18
meets expectations	x	□	□	□	□	□	□	does not meet expectations	19
inefficient	□	□	□	□	□	□	x	efficient	20
clear	□	x	□	□	□	□	□	confusing	21
impractical	□	□	□	□	□	□	x	practical	22
organized	x	□	□	□	□	□	□	cluttered	23
attractive	□	x	□	□	□	□	□	unattractive	24
friendly	□	x	□	□	□	□	□	unfriendly	25
conservative	□	□	□	□	□	x	□	innovative	26

Table 10.6 UEQ responses – second participant

	1	2	3	4	5	6	7		
annoying	□	□	□	□	□	□	x	enjoyable	1
not understandable	□	□	□	□	□	□	x	understandable	2
creative	x	□	□	□	□	□	□	dull	3
easy to learn	□	x	□	□	□	□	□	difficult to learn	4
valuable	x	□	□	□	□	□	□	inferior	5
boring	□	□	□	□	□	x	□	exciting	6
not interesting	□	□	□	□	□	□	x	interesting	7
unpredictable	□	□	□	□	□	x	□	predictable	8
fast	□	x	□	□	□	□	□	slow	9
inventive	x	□	□	□	□	□	□	conventional	10
obstructive	□	□	□	x	□	□	□	supportive	11
good	x	□	□	□	□	□	□	bad	12
complicated	□	□	□	□	□	□	x	easy	13
unlikable	□	□	□	□	□	□	x	pleasing	14
usual	□	□	□	□	x	□	□	leading edge	15
unpleasant	□	□	□	□	□	□	x	pleasant	16
secure	x	□	□	□	□	□	□	not secure	17
motivating	x	□	□	□	□	□	□	demotivating	18
meets expectations	x	□	□	□	□	□	□	does not meet expectations	19
inefficient	□	□	□	□	□	□	x	efficient	20
clear	□	x	□	□	□	□	□	confusing	21
impractical	□	□	□	□	□	□	x	practical	22
organized	x	□	□	□	□	□	□	cluttered	23
attractive	x	□	□	□	□	□	□	unattractive	24
friendly	x	□	□	□	□	□	□	unfriendly	25
conservative	□	□	□	□	□	x	□	innovative	26

Table 10.7 UEQ responses – third participant