Exploring the Benefits of Game Visualization Patterns in the Design of Construction Planning Applications.

Master's thesis in Computer science and engineering

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Abstract

The construction domain has in recent years increased its pace of adopting digital solutions to solve complex problems related to productivity and collaboration. Another domain that simulates similar challenges is the strategy & city-builder genres of video games. Since both domains are heavily involved in navigating the spatial and temporal dimensions, it is possible that design patterns from the latter could be beneficial in software applications for construction planning. This potential benefit was explored by first identifying 30 Visual Design Patterns in three games. These patterns were then utilized in the implementation of 12 software features in a preexisting construction planning application, of which 9 were based on specific patterns. The features were evaluated in an prototype evaluation using the several design methods with a focus group. Results from the evaluation largely indicate that the Visual Design Patterns had a positive impact on productivity and collaboration, however, since the participants interacted with the features acting as proxies for the underlying patterns, further research is needed to reinforce these initial findings.

Keywords: Construction, Planning, Construction Planning, Video Games, Strategy Games, City-Builders, Interaction Design, Computer, science, computer science, engineering, project, thesis.

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Introduction

In the wake of the recent pandemic era, which has lead businesses to adopt digital solutions at a significantly accelerated pace, professional sectors across the board are embracing the advantages of software applications to an extraordinary extent. One of these sectors is the construction industry, which in 2022 accounted for 6.2% of GDP growth in Sweden [1]. However, the construction industry in Sweden, like many others, has recently experienced economic decline. Some possible underlying factors are the war in Ukraine, increased borrowing costs as well as reduced economic stability in general that started in 2022 and may persist through 2023.

In these trying times, marked by both economic hardship and human conflict, it is important for companies to focus on increasing productivity and collaboration.

Yolean, a startup company developing a digital and collaborative visual planning tool for construction projects [2], has identified a solution that could potentially improve productivity and collaboration when planning using their current web-based 2D planning experience: adding complementing 4D features. We have been tasked to design, develop, test and evaluate a prototype of their application with such features implemented to determine its potential benefit for their customers.

4D, unlike 2D, combines 3D space with the time dimension, which is of significant temporal importance for planning. While 2D can include flat images of the buildings and architectural schematics, 3D allows for the model to be viewed as in the real world. The time dimension allows for the 3D model or other objects in the scene to change, move, appear or disappear at certain points.

The process of creating a prototype of an application with a set of 4D features from the ground up is both complex and time-consuming and attempting to solve the wicked problem which this design challenge represents prompts us to analyze another domain that also tackles problems related to 3D visualizations and time. Therefore, we have decided to identify and utilize design patterns found in 3D video games, specifically Strategy and City-builder games.

These game genres in which the player is constructing buildings, directing resources and coordinating a workforce, simulate the challenges present in modern construction projects. It might therefore be useful to analyze how these games are designed, particularly regarding 3D and user-interface visualization, and identify key design patterns which could benefit solving the challenges previously stated.

By leveraging reusable design solutions found in games with geometrical and temporal aspects similar to those of construction projects, we wish to enhance the process and outcomes of the development of this prototype. Furthermore, we aim to inspire other designers and problem solvers to explore the potential value that advancements in game design and visualizations could provide to non-game related domains.

1.1 Problem Statement

While the 2D planning features Yolean is currently comprised of can yield positive results, the architectural structures being planned and constructed are complex 3D spaces with numerous rooms, locations, levels and sections that are often built simultaneously or in rapid succession. And to translate that environment to an application which does not feature a 3D visualization of the structure and still manage to provide the information and functionality required to overcome the challenges previously mentioned is a difficult endeavor.

The addition of 4D features might be able to increase productivity and improve collaboration in construction projects. However, designing such features can be a complex and demanding task, which is why discovering and utilizing reusable design patterns might not only be beneficial but necessary to streamline its design and development process.

This project will deal diligently with design patterns, specifically those related to visualization of data and interactive user interface elements. Design patterns are used by designers to solve commonly occurring experience or interface related design problems [3], and visualization design patterns (VDP), see 3.3.1, focus particularly on challenges related to conveying information to users through an interface.

1.2 Research Questions

1. Which Visual Design Patterns can be identified in popular strategy and city-building games?
2. How might these VDPs be modelled and categorized?
3. Which VDPs are useful when designing features for a visual construction planning application?
4. Which VDPs can contribute to increased productivity and improved collaboration in construction projects?

1.3 Objectives

1. Explore and discover VDPs in four relevant games.
2. Model a system for classification and categorization of VDPs.

3. Produce a library of VDPs used in Strategy & City Builder Games applicable in design of visual construction planning applications.
4. Design a Low-fidelity prototype showcasing possible implementations of patterns from the library, such as a digital mock up or paper prototype etc.
5. Develop a High-fidelity web application prototype linked to a planning project on the Yolean platform.
6. Evaluate the high-fidelity prorotype to achieve greater knowledge of VDPs that positively impact productivity and collaboration in Visual Planning User Experiences.
7. Increased awareness of how design patterns in games can be identified and used outside of its inceptive domain.

Throughout the remainder of this thesis, these research questions and objectives will be referred to as RQ1 to RQ4, and O1 to O7, respectively.

1.4 Delimitations

While the project does involve the development of the features and prototype, it is not considered a software development focused project since its main topics of importance are the VDPs, the design process and the evaluation of the features based on the patterns. Therefore, it will only be described to a degree that is relevant and contributes to the main topics.

Furthermore, this thesis will not thoroughly examine construction planning theory or processes, only to a moderate degree. Instead, greater focus will be placed on the wants and needs of involved stakeholders from the industry.

2

Background

The purpose of this section is to provide essential context, introduce the stakeholders of the project as well as their domain and present related work.

2.1 Commercial Application Development

Developing features for an application to be used by many different companies requires long planning and careful research. More specifically, it requires research on the main approach taken when utilizing interaction design for companies. The importance of well designed interfaces in enterprise environments has been highlighted by deeming usability to be one of the main factors for user satisfaction [4]. While usability has been a large part of interaction design for a long time, there are other less explored methods that do show potential. As such, some research points toward a possible connection between gamification of enterprise software through interaction design [5]. This experimental approach of using gamification for something other than entertainment purposes might have potential that warrants further exploration. Two common terms in user interfaces, specifically in games, is diegetic vs non-diegetic elements. Diegetic elements being things characters in the game can see and hear, existing in their world. An example of a non-diegetic element is the heads up display which only the players can see, such as an ammo counter or hit points counter. Furthermore, the use and removal of non-diegetic graphical user interfaces has been examined [6]. This could contribute to the project's final result on diegetic versus non-diegetic interfaces and their effectiveness in an enterprise application.

2.2 Stakeholder - Yolean AB

Yolean AB is a small software startup company based in Gothenburg, Sweden. It was registered in 2014 and currently has 9 employees, most of which are software developers. They have developed a web application for visual planning specifically designed for the construction industry.

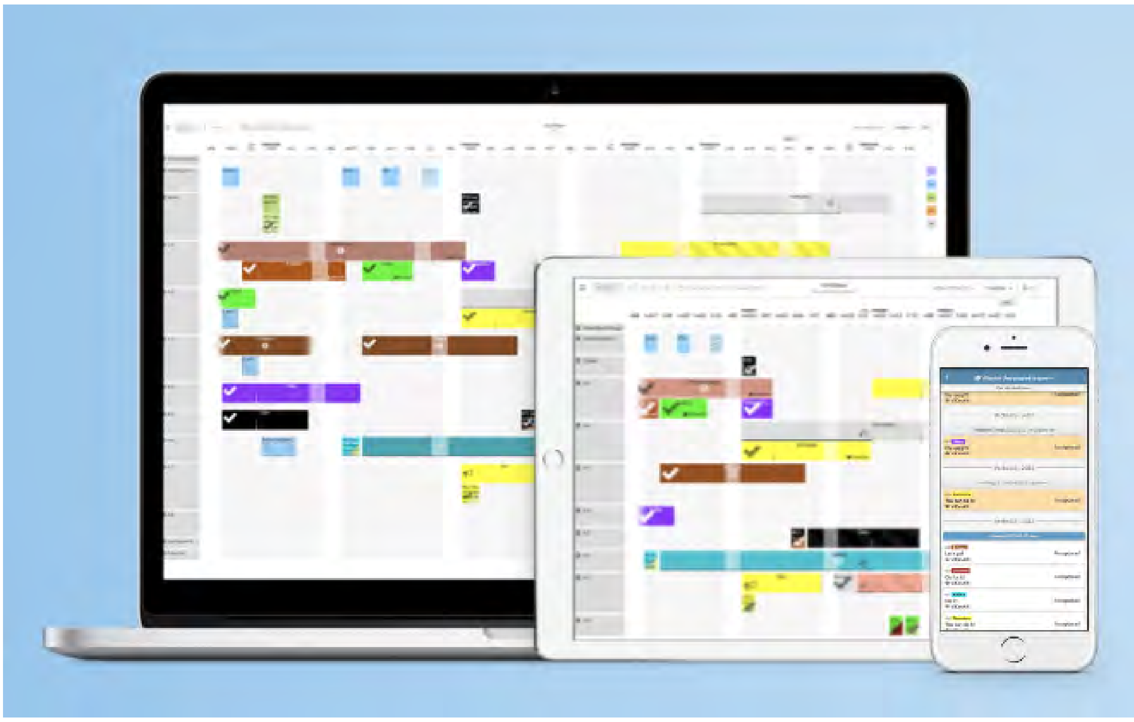


Figure 1: The Yolean Platform

2.3 Visual Planning

The purpose of employing visual planning as a method in construction is primarily to make communication more efficient and establish a shared understanding of commitments in a visual fashion [7]. It utilizes a canvas, commonly known as a board, for organizing elements representing key informational elements, such as activities, deliverables or issues. These elements are chronologically organized in the board's time axis, which conveys which day or week they are relevant or expected to be completed.

Yolean features the same elements and capabilities, and they have chosen to visualize most elements as sticky-notes in a 2D grid of rows and columns, where rows represent locations and columns represent either specific days or weeks. Colors are utilized to reveal the type of a note or the note's belonging trade, i.e work discipline.

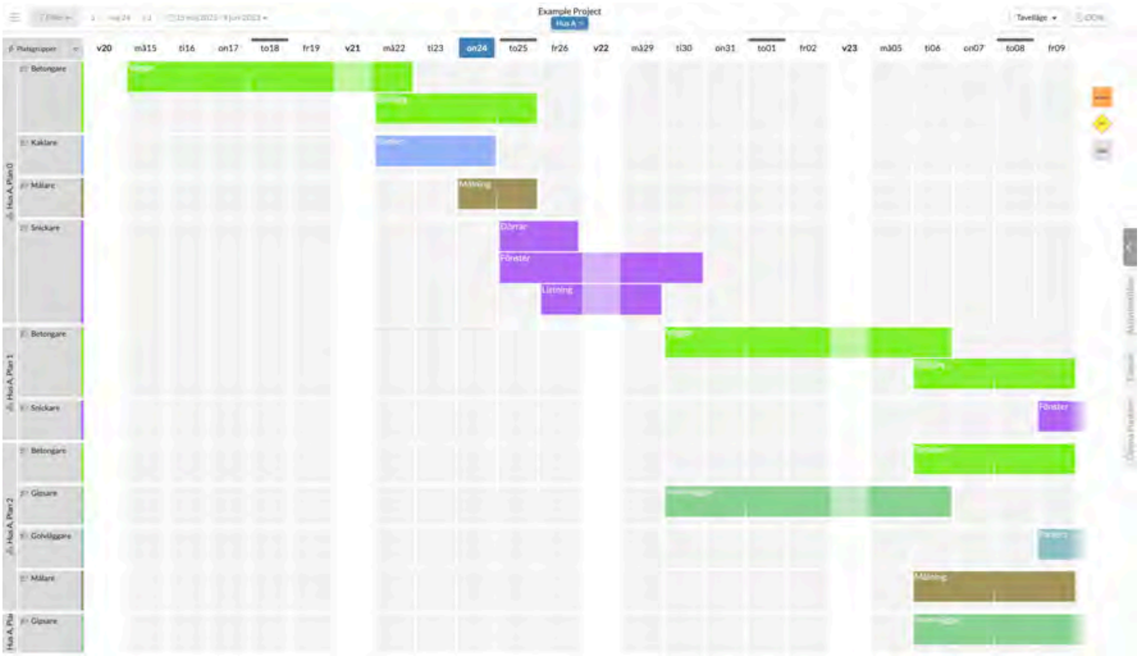


Figure 2: The Yolean Board with Trade-colored Activity Notes

While the two dimensions time and location are present in the application, it currently lacks 3D elements or models for visualizing buildings and objects in space. The stakeholders have reported that this absence might lead to problems for users who are dealing with challenges in physical space with geometric constraints currently imperceivable in the planning board, a potential bottle-neck for productive planning and collaboration for the fundamentally physical nature of construction.

2.4 Construction Domain

During construction planning and management it is vital that construction issues, events blocking the progress of the project, assignment of resources and teams are efficiently handled by the organization carrying out the planning or construction. Usually this requires effective communication, defined progress indicators, rigorous documentation and regular evaluation to accomplish. Visual planning tools such as the one Yolean has produced is one digital solution that can be beneficial in that regard.

2.4.1 Project Phases

Throughout a construction project, there are several phases of operation that require preparation and planning [8]. The two that are most relevant in our context is the Planning Phase and Production Phase. During the Planning Phase, schematics and schedules for the construction are created, and in the Production Phase these schematics and schedules are followed to construct the building as planned. Both of these phases can benefit from the use of software for construction planning, scheduling or management. Depending on the phase the customer is in, their wants and needs might differ, which is a concern to be taken into consideration.

2.4.2 Production Roles

The primary roles in production are:

Site Manager
The site manager oversees production and manages the activities carried out on the construction site. They have a series of responsibilities including:

- Coordinating personnel and teams
- Planning the construction and schedules
- Organizing meetings
- Mitigating risk and work hazards
- Reporting to project managers

According to stakeholders at Yolean, site managers are often the primary users of the Yolean application, both during and outside of planning meetings.

Subcontractor
Subcontractors are contracted to perform the specific tasks of their expertise. They manage and coordinate the tradespeople required for their task scope. Additionally, they attend the meetings held by the site manager and relay the information to their team of tradespeople.

Tradespeople
Tradespeople are skilled workers of a particular trade. They undertake the majority of work on the construction site. Examples of trades are electrician, painter and carpenter, all possessing a specialized set of skills.

2.5 3D Strategy & City-Builder Games

While strategy video games utilizing 2D graphics had existed for a long time, it was not until 2002 that 3D graphics became the industry standard [9] with the release of Warcraft III: Reign of Chaos [10] and Age of Mythology [11] . Both games are considered Real-Time Strategy games, a sub-genre defined by real-time base-building, resource-gathering and unit control. Games such as these require the player to successfully plan their building strategy, budget for expenses and micromanage large teams, problem solving challenges common in the construction industry.

Figure 3: Left: Warcraft 3, Right: Age of Mythology

City-building games are simulation games that, similarly to strategy games, have the player constructing buildings and managing a town. One of the city-builders claimed to be the best to this day [12] is SimCity 4 [13]. In SimCity, the player takes on the role of mayor and is tasked with managing the development of a city. Strategically planning zones, building and maintaining infrastructure and budgeting for the costs of doing so are all challenges part of the gameplay experience. Similarly to strategy games, city-builders pose problems frequently encountered during construction projects.

Figure 4: SimCity 4

3

Theory

This section aims to provide a detailed explanation of the theories, models, and frameworks utilized in the project.

3.1 Design Patterns and Frameworks

Cooper et al. describe interaction design patterns and their use for software development [14]. This provides a comprehensive understanding of graphical user interfaces and how they can be defined and analyzed. Furthermore, to properly define the domain of this thesis, extensive pattern libraries have to be referenced to make sure specific patterns are represented correctly within structural visualization as well as game design. A large library of user interface design patterns commonly found in interaction design environments is another valuable resource [3]. These will serve as a base for possible patterns to implement in potential prototypes going forward. Use of these patterns in the application will be largely influenced by analysis performed on how they can be connected to common visual design patterns found.

To be able to formally analyze games and their structural patterns, the use of a specific framework is highly beneficial. One such framework is the Game Ontology Project [15]. Instead of sorting games into lists with commonalities, it categorizes game elements into a set of hierarchies. Its hierarchy concept is particularly interesting as it provides a means of separating different parts of a game into sub-elements. This is especially useful when separating interface elements from gameplay, since the latter is of lesser importance for this thesis. Unfortunately, this framework is far from exhaustive and can not be exclusively used as a means of studying games. However, its interfaces sub-hierarchy can be used as a complement to previously mentioned frameworks and libraries to get a more complete analysis of a game's interfaces.

Further contributing to proper analysis of games is the book Game Research Methods [16]. It contains several chapters analyzing relevant concepts such as the representation of different temporal frames in games, systematic interviews for games, game visualization and more.

3.2 Related Work

This section presents previous work related to pattern library creation, a game design pattern library and 4D modeling.

3.2.1 Framework for Visualization Design Patterns in Games

All types of games have across history utilized visual interface elements to convey information to players, and a framework for defining visualization patterns in games exists [17]. This framework includes five parameters that are used to specify a visualization pattern:

- Primary Purpose - “Intended use;”
- Target Audience - “Intended audience;”
- Temporal Usage - “Timing of use;”
- Visual Complexity - “Level of visual sophistication of the visualization in the game;”
- Immersion/Integration - “Whether the visualization is in spirit with the game and whether it is inside the game or not;”

Furthermore, a list of predefined purposes exist in order to categorize the patterns according to their primary purpose:

- Status - “for conveying important information”
- Training - “to help players”
- Progression - “show the player how to progress in the game”
- Communication - “for communicating the game or the players state to others”
- Debugging and balancing - “for allowing the developer to debug, balance, and compare player performance”

The last purpose, debugging and balancing, will be mostly irrelevent to this project and the foundational tool (Yolean) the 4D application will be based on. Balancing is not applicable as there is no win condition present and users are not competing against each other, and debugging tools are not intended for the end user.

3.2.2 Game Design Patterns Library

Bjцrk provides a great foundation for game design patterns in general [18]. Although there are many gameplay related patterns listed, of which many do not directly contribute to web application development, this library also contains several useful structural design patterns that can be connected to patterns defined by Toxboe [3].

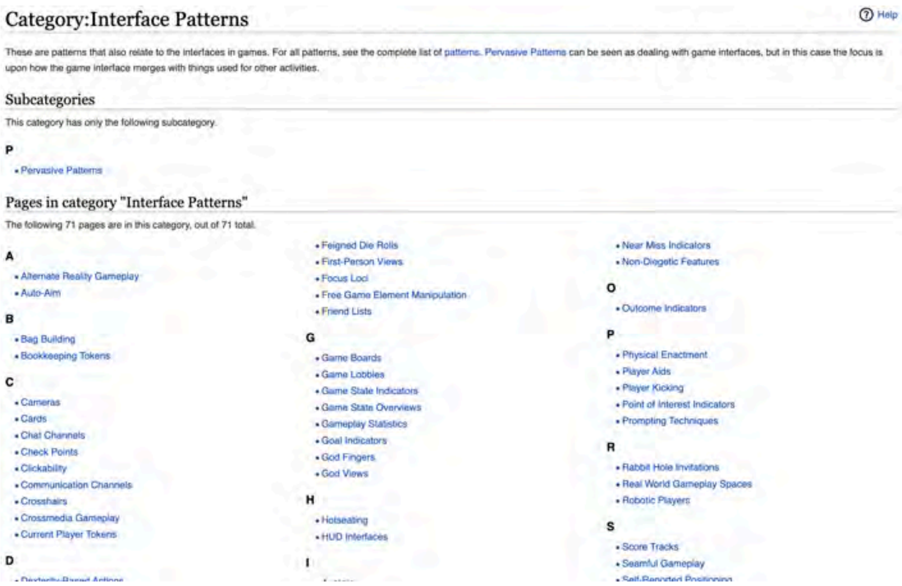


Figure 1: Screenshot of Interface Patterns on Bjцrk's game design patterns website [18].

3.2.3 4D modelling using virtual collaborative planning and scheduling

Building Information Modeling (BIM) is a process that has changed the way construction projects are looked at in general [19]. More specifically, it has highlighted the significance of the actual design during such projects. Furthermore, research has showcased the potential of 4D modelling construction sites in virtual spaces such as with a VR-headset [20]. This has not only explored 3D modelled representations of buildings in VR, but also the use of this together with a schedule or time-line to build a more comprehensive collaborative planning tool. The purpose of this is to improve communication between mainly stakeholders regarding the construction projects, through more easily being able to present their thoughts dynamically. Although some research has shown progress within BIM 4D modelling, it often points toward the fact that more research needs to be done to truly realize what traditional and non-traditional principles and methods are capable of together.

3.3 Visualization Design Patterns

This section presents the definition and model used for Visual Design Patterns throughout this thesis, with examples.

3.3.1 Definition & Model

In this report, Visual Design Patterns are defined as reusable design solutions for problems relating to Information Visualization in video games or other digital applications. The pattern category includes several aspects of design, including user interface design & data visualization. Their purpose is to convey information to the user through visualizations. The word visualization is important to highlight the focus on visually perceptible elements and to distinguish it from Gameplay Design Patterns, such as those mentioned in 3.2.2, who on the other hand are largely associated with gameplay mechanics and rules, and Software Design Patterns, which are related to technical patterns in programming.

The model constructed for classifying and categorizing visual design patterns in this project combines the preexisting framework mentioned in 3.2.1 with the game UI categories defined by Fagerholt & Lorentzon [21], with some adjustments:

- Includes all the predefined purposes, with the exception of Debugging and balancing, and 13 additional purposes identified during the course of the project.
- Immersion/Integration was excluded due to its resemblance to UI categories.
- Target Audience was excluded.
- The Geometric UI category was renamed Spatial.

Ultimately the following parameters were used in our VDP model:

- Name - A name used to identify the pattern.
- Example Image - An image of the pattern being used.
- Description - A short text describing the pattern.
- Purpose Tags - Tags identifying the possible purposes of the pattern.
- Temporal Usage - How the pattern usage relates to time.
- Visual Complexity - How visually complex the pattern is percevied to be.
- UI Category - Which one of four UI categories the pattern belongs to.

Purpose Tags

Progression	Information	Status
Assignment	Instruction	Preview
Spatial	Communication	Training
Representaton	Customization	Filtering
Emphasizing	Locating	Temporal
Options	Controls	

Temporal Usages
Intermittent | Continuous | Retrospective | Prospective

Visual Complexity
Basic | Intermediate | Advanced

UI Categories
Spatial (geometric) | Diegetic | Non-Diegetic | Meta

3.3.2 Design Pattern Examples

Some initial research has shown that there are several different types of design patterns to be found within strategy games.

Civilization VI
In the in-game view of Civilization VI [22], there are several patterns visible to the user [23]. The first thing apparent to the player is the virtual map being represented as a Game Board, a game design pattern (see figure 2) [24]. This is essentially the main view of the application. The map is represented as a top-down view of the 3D board, but is tilted slightly to provide a better view for the observer. Furthermore, the user interface (UI) pattern of Continuous Scrolling is present to better be able to represent the massive amount of data presented by the large size of the map [25]. This is a clear example of how a game design pattern connects with a traditional UI pattern commonly present in websites and applications.

Figure 2: Starter view of a new game in Civilization VI

Another example of a game design pattern present in Civilization VI is Fog of War [26]. The purpose of this is to only disclose the parts of the map the user has explored, while keeping the rest of the map hidden. It is commonly used to reduce the amount of information available to the user, where they have to keep on exploring to get a better view of the whole map. However, it can be adapted to be used as a means of reducing cognitive load for the user. With less information presented, it is easier to focus on the main task at hand. This is clear at the beginning of a match in Civilization VI, where almost the entire map is hidden, and finding resources close to the starting zone is the main objective. Thus, it can be connected to the Progressive Disclosure UI pattern [27]. The purpose of this is to "reduce feelings of being overwhelmed", through filtering information available to the user. Implementing this can be a great way to only show relevant information in a building application, such as hiding the completed parts of a building with transparency, while keeping the rooms that are currently being processed completely opaque and visible.

Using our model for describing VDPs, this pattern could be defined as following:

- Name: Fog of War
- Image: see figure 2
- Description: Limits visibility in the game world, incentivising exploration and reducing cognitive overload.
- Purpose Tags: Filtering, Information
- Temporal Usage: Continuous
- Visual Complexity: Intermediate
- UI Category: Diegetic

3.4 Defining Productivity & Collaboration

There exists several definitions for productivity and collaboration. Though these concepts are complex and therefore difficult to define, they are central for this thesis and will be referred to as mentioned in this section.

For productivity, one definition defines it as the ratio between output volume and input volume, which in simple terms means less labor for more produced goods [28]. Another design-related source defined productivity in the context of user interfaces as the ratio of useful output per work-hour [29]. In this thesis, it is defined as Output (Quality and Quantity of work) per unit of Input (Time and Effort invested). This definition ensures that not only the amount produced is valued but also its quality, and that not only the objective time factor but also the subjective effort required is incorporated as well. For qualitative evaluation, these variables presented might help the participants to understand how the definition relates to their efforts and feelings. For example, they might reflect on the effort they put into completing a task and compare it to how well and fast the task they assume it was completed.

Collaboration is more difficult to define, presumably due to its social nature. It might commonly be defined as the act of two or more people working together to achieve a shared goal. One elaborate scientific definition is “collaboration is a family of purposeful working relationship between two or more people, groups, or organisations. Collaborations form to share expertise, credibility, material and technical resources, symbolic and social capital” [30]. However, in the context of professional environments we deemed Ability to achieve mutual goals through clear communication and cooperative problem solving more suitable, due to greater importance of problem solving and communication and its simplicity.

Lastly, the changes in productivity and collaboration of interest come from the planning in Yolean itself, not in the construction site.

4

Methods

This section serves to present the prominent methods and techniques used to address this thesis' stated research questions and objectives. They are used to research, generate and evaluate designs, and to a lesser extent software.

4.1 Design Research Methodology

The following design research methods function as broad frameworks under which the project operated.

4.1.1 Design Thinking Process

The overarching design method for this project will be the Design Thinking Process (DTP). It is an iterative user-centered process used in design that is especially useful when dealing with wicked problems, i.e problems with countless factors causing them to seem impossible to solve (see [31]). Due to the iterative nature and structure of the DTP motivates, it forces the designer to acquire a deep understanding of the main stakeholders, be innovative when generating solutions and generate testable prototypes that help you design a solution that solves the user's problems. The DTP includes 5 phases that the design project should undergo [32]:

Empathize
Observe and understand the relevant users, their needs, what tasks they are trying to solve, how they feel.

Define
Narrow down the areas the design should focus on solving, form a problem statement based on the insights gathered in the first phase.

Ideate
Generate ideas as how to approach solving the design challenge at hand. The focus is not on generating the correct solution, rather a handful of possible ones.

Prototype
Demonstrate the ideas as physical or digital prototypes. This eases communication and makes it so you quickly establish the possibilities of your solutions.

Test
Present the prototypes to users. Testing should provide feedback, constructive criticism, a reality check, and further understanding of the user's wants and needs.

As previously mentioned, this process is not a linear process, rather the designer should jump back and forth between phases if deemed necessary. For example, if it is discovered that the prototype fails to deal with the problem experienced by the user, then going back to the ideate phase is necessary.

4.1.2 Research Through Design

Research Through Design (RTD) is an approach to research that emphasizes the creation of new knowledge through design and development of design artifacts, such as models, prototypes, products and documentation. It involves cycles of iterative designing, prototyping, and testing, with the goal of discovering new insights and understanding of a particular design problem. It states that the artifact outcomes of a design research project can change the world from its current state to a preferred state and this allows designers to employ their abilities in order to produce research contributions [33]. In order to guide this project to produce such artifacts and provide quality research findings, the following criteria will be accounted for:

Process
Designers should provide detail enough to reproduce the project and provide rationale for the methods used in the process. This mostly applies to the Process chapter (see 6) to describe project specifics.

Invention
Designers should produce a novel contribution and explain how it could lead to advancements in the field.

Relevance
Relevance of the methods used should be motivated as well as details of the current and preferred state. This includes this chapter of the thesis, as well as the discussion (see 8).

Extensibility
The possibility for future extensions that build upon the findings of the design and the knowledge obtained from the work can be leveraged in future work. These criteria will be weighed as the project is carried out.

4.2 Design Methods

This section describes the specific design methods used or considered in the project.

4.2.1 Interviews

Interviewing [34, p. 138] is a research method that belongs in the first or last phase of the DTP. This method entails interviewing users, key informants and stakeholders to gain empathy for them and their situation, or to obtain knowledge of the problem and its domain. They can be either structured with predetermined questions asked in a specific order, unstructured conversations without prepared questions, or the hybrid approach semi-structured.

4.2.2 Personas

The concept of Personas [34, p. 170] is a way to capture user behavior patterns using an archetype, or persona, per category of user. These are created in the second phase of the DTP using the insights gathered from the first or second phase. The personas provide user-centered guidance when making design decisions in the third phase.

4.2.3 Kano Analysis

Kano Analysis [34, p. 142] is a method for categorizing and prioritizing features and product attributes, usually relevant in the first two phases or during the final phase. It is done by answering how the customer would feel if a product attribute or feature is present and absent, and is helpful when attempting to choose the design strategy that produces the most value.

		Q1: If feature is present, the customer feels...		
		Satisfied	Neutral	Dissatisfied
Q2: If feature is absent, the customer feels...	Satisfied	Questionable	Anti-feature	Anti-feature
	Neutral	Exciter	Neutral	Anti-feature
	Dissatisfied	Desired	Required	Questionable

Figure 1: KANO Category Matrix

Through Kano Analysis, designers can categorize features into five different categories:

Required
Required features are of the highest priority, and are features that the user expects to exist no matter what. They are identified by having a neutral impression when present, and a negative impression if absent.

Desired
Desired features are the second highest priority to implement, they are important to implement and improves the user's impressions of the application. They are identified by having a positive impression when present, and a negative impression if absent.

Exciter/Delighter
Exticer/Delighter features are not essential, however their inclusion can evoke positive reactions when noticed by the user. They are identified by having a positive impression when present, and a neutral impression if absent.

Neutral
Neutral features have little emotional impact whether they exist or not. They are identified by having a neutral impression when present, and a neutral impression if absent.

Anti-feature
Anti-features should be avoided to the best of the designer's ability. They are identified by having a negative impression when present, and a neutral or positive impression if absent.

4.2.4 Flexible Modelling

Flexible Modeling [34, p. 114] is a participatory ideation or prototyping method, where separated components of a design are given to a user who is then asked to configure their preferred product using the components. This way the user acts as a designer, while the designers can gain valuable insights from observing the user make the design decisions.

4.2.5 Design Workshops

Design Workshops [34, p. 84] are collaborative sessions of intense and creative activities, such as other methods. These are useful in almost all phases of the DTP due to the versatile nature of the workshops.

4.2.6 Wizard of Oz

Wizard of Oz [34, p. 254] is a technique useful for prototyping and testing, the third and fourth phase of the DTP. The goal is to simulate rather than implement the functionality of a particular prototype or design to save time and resources while accurately resembling the end use experience.

4.2.7 Critique

Critique [34, p. 66] is a session where stakeholders are invited to give feedback on a design solution while also depersonalizing the critique. Similarly to Design Workshops, it is useful in many stages of a design project, especially for evaluating the results of a previous phase.

4.2.8 Focus Groups

Focus Groups [34, p. 118] entails gathering a small group of participants to discuss and provide feedback on a design solution, often in the form of opinions and feelings. The participants are hand-picked to yield insight from specific perspectives the user researcher believes to be valuable for the context of the research. It is useful for both exploring and evaluating ideas qualitatively, therefore suitable in the first or last design phase.

4.2.9 Role-playing

Role-playing [34, p. 186] is an exercise were participants are asked to act as the target users and immerse themselves in a realistic scenario to experience it from their perspective. It is a qualitative method that helps in gaining empathy and discovering problems and is preferably used in the second or third design phase, although potentially useful for evaluating design solutions in the later phases as well.

4.2.10 Questionnaires

Questionnaires [34, p. 178] serve as methods of collecting self-reported data from participants and can cover both quantitative and qualitative themes. Throughout a Questionnaire, the participants fill in a form containing questions related to the topic the researcher wishes to explore or the solution they want to evaluate, and are therefore applicable throughout the design process.

4.2.11 Experience Prototyping

Experience Prototyping [34, p. 104] entails actively participating in the use experience of a prototype instead of passively viewing it. Similar to Wizard Of Oz, an important aspect is simulating the real environment and scenario that the product would be used in. It is most commonly utilized in the fourth phase of the DTP. The method is important for activities in the process related to understanding existing user experiences, when trying to communicate an idea to an audience and for exploration and evaluation of an idea. To provide an example for the latter, a design team used the method in a full-scale simulation of the interior of an airplane to evaluate ergonomics and comfort. The team enacted various activities and social situations within this environment which helped form a shared goal and design direction [35].

4.2.12 Paper Prototyping

Paper prototyping is the act of creating primitive design concepts using pen and paper. Its benefits include low-costs, fast iterations, highly enjoyable for designers and simple to learn [36]. Overall, paper prototyping allows for several iterations to be tested in a remarkably short time.

4.2.13 Reverse Brainstorming

Reverse Brainstorming [37], unlike regular brainstorming, is about discovering problems instead of solutions. Instead of trying to invent solutions, designers who use this method seek out anti-features or solutions that negatively impact the user. By then implementing the reverse behavior, designers can ensure they avoid making problematic design choices. It is useful during the ideation and prototyping phase.

4.2.14 Prototyping

Prototypes are objects that regularly appear in software engineering or design contexts and represent a vehicle for designers to study, uncover, develop and improve designs [38]. For prototyping, these concepts are of interest for this thesis:

Fundamental Principle
Prototyping is an activity with the purpose of creating a manifestation that, in its simplest form, filters the qualities in which designers are interested, without distorting the understanding of the whole [38, p 4].

Economic Principle
The best prototype is one that, in the simplest and the most efficient way, makes the possibilities and limitations of a design idea visible and measurable [38, p 4].

Autonomy
Prototypes are filters that traverse a design space and are manifestations of design ideas that concretize and externalize conceptual ideas [38, p 4].

4.3 Pattern Libraries

Design patterns have the ability to provide assistance to solve design problems using proven design solutions and guidance for use, refined process, re-usability and consistency. However, in order to benefit from them they would have to be documented and published in a shape that promotes their usage. One such way is through creation of a pattern library [39]. A pattern library most commonly consist of the following focus sections:

- Pattern Name
- Problem Description
- Solution Summary
- Motivate Effectiveness
- Best Practices
- Related Patterns

They may also include the following supporting sections:

- Comments
- Research Evidence
- History or Changelog

It is also advised that reusable components are available in the document, as well as examples of use and possible accessibility or internationalization concerns.
Two examples of Pattern Libraries found online:

- UI Patterns [3]
- Material Design Components [40]

4.4 Software Engineering

4.4.1 Requirements Engineering

Requirements Engineering (RE) is an engineering discipline that aims to find what users want from a software system, i.e. which requirements they have for the design to meet their needs [41]. It shares concepts with the field of Human Computer Interaction, such as the focus on User-Centered Design, although the requirements process typically is more linear. Due to the limited time constrains placed on this project, and since a software prototype is ultimately being produced, an engineering process with numerous iterations might not be considered suitable. The practice involves the following activities deemed relevant to this project:

Scoping
Boundaries and constraints for the engineering challenge and produced system are set iteratively in consultation with stakeholders as the vision for and knowledge of the challenge grows.

Fact gathering
Data is collected from questionnaires, observations, interviews etc.

Analysis
Analysis using the scope and data usually includes answering the 5 'W' questions: What (goals), When (time), Where (system location), Why (purpose), Which (objects).

Modelling
The outcome of analysis is then used for modelling a representation of the system. These could manifest as flow or relationship diagrams of different kinds.

Validation
After the previous steps have been executed, the output of them should be validated by the users, agreeing and indicating that it reflects their needs. Here prototypes serve as valuable tools.

The DTP, RTD and RE are all overarching methods that impact the project on a higher abstraction layer and lay the foundation for the rest of the methods used and for the research questions to be answered. The DTP is generally applicable to design projects, RTD is significant to the research context of the project and RE is useful for the software development aspect that is especially important in the last prototyping phase. Further details of how they simultaneously impact and overlap throughout the project can be found in section 5.

5

Plan

This thesis has a time plan made in Yolean (see figure 1 in appendix). This section will describe the phases contained in the time plan, which provided the structure for the production of this thesis.

5.1 Requirements Gathering

During this phase of the project, stakeholders from Yolean, key informants and users will be interviewed (4.2.1) to gather empathy and knowledge of the domain and its problems, and derive fundamental requirements for the design of the application. This stage involves Scoping, Fact Gathering as mentioned in Requirements Engineering (see 4.4.1) and represents the first and second phase of the Design Thinking Process (see 4.1.1).

5.2 Literature and Game Research

In parallel to gathering requirements, relevant literature will be examined and three popular strategy or city builder games will be analyzed to identify VPDs. The two relevant strategy games chosen are Starcraft II [42] and Civilization VI [22]. Two games were also been chosen from the city builder game genre, which are Cities: Skylines [43] and Dyson Sphere Program [44]

The analysis procedure will include defining all identified patterns using the game visualization framework (3.2.1) with some possible extensions or compression.

5.3 Analysis and Definition

Input, data and observations from the first stage are then analyzed and synthesized using Personas (see 4.2.2) and Kano Analysis (see 4.2.3), as advised by the Analysis and Modelling phases in Requirements Engineering (see 4.4.1).

When requirements are approaching a defined state, it should be presented in a Critique (see 4.2.7) session with stakeholders from Yolean for feedback.

5.4 Compile List of Visualization Design Patterns Identified

The design patterns found from existing literature and from the game research phase will then be composed to a list where the patterns and their relevance to the project are explained. Here the problem solving capabilities of each pattern will be compared to the requirements previously defined.

5.5 Low-Fidelity Prototype

In order to demonstrate conceptually how the design patterns could be used when designing the application, a low-fidelity prototype will be created. Ideation from 4.1.1 will take place in Design Workshops (see 4.2.5), and Flexible Modelling (see 4.2.4) is a method useful to apply using the VDPs as components. Following the Ideation phase, Prototyping will commence with the goal to construct a Wizard Of Oz (4.2.6 prototype (4.2.14), suitable for the fourth phase of the Design Thinking Process (see 4.1.1).

5.6 User Testing, Feedback & Evaluation

The low-fidelity prototype produced is to be presented to the stakeholders at Yolean and user tested to procuce early input and critique of the initial design. This represents the fifth phase in Requirements Engineering (see 4.4.1) and the Design Thinking Process (see 4.1.1).

The gathered data will then be examined to impact the design direction taken for the second prototype.

5.7 High-fidelity prototype

The second and final prototype should be a fully digital developed software solution, which will illustrate the full scope of the application's functionality as well as be connected to an existing Yolean project. Experience Prototyping (see 4.2.11) is of use in this stage.

5.8 Final User Testing, Feedback & Evaluation

When the final prototype is complete, it is then tested with predefined questionnaires and tasks for the users to fill in and perform. These questionnaires together with notes and recordings during the final test will be used as a basis for a final analysis, where the final results of the thesis will be produced. Ultimately the methodology, patterns, designs, prototypes and evaluation findings are added to the thesis report.

6
Process

This section describes the actual process carried out during the project. It will also mention and explain eventual deviations from the plan described in section 5.

6.1 Phase 1 - Literature & Game Research

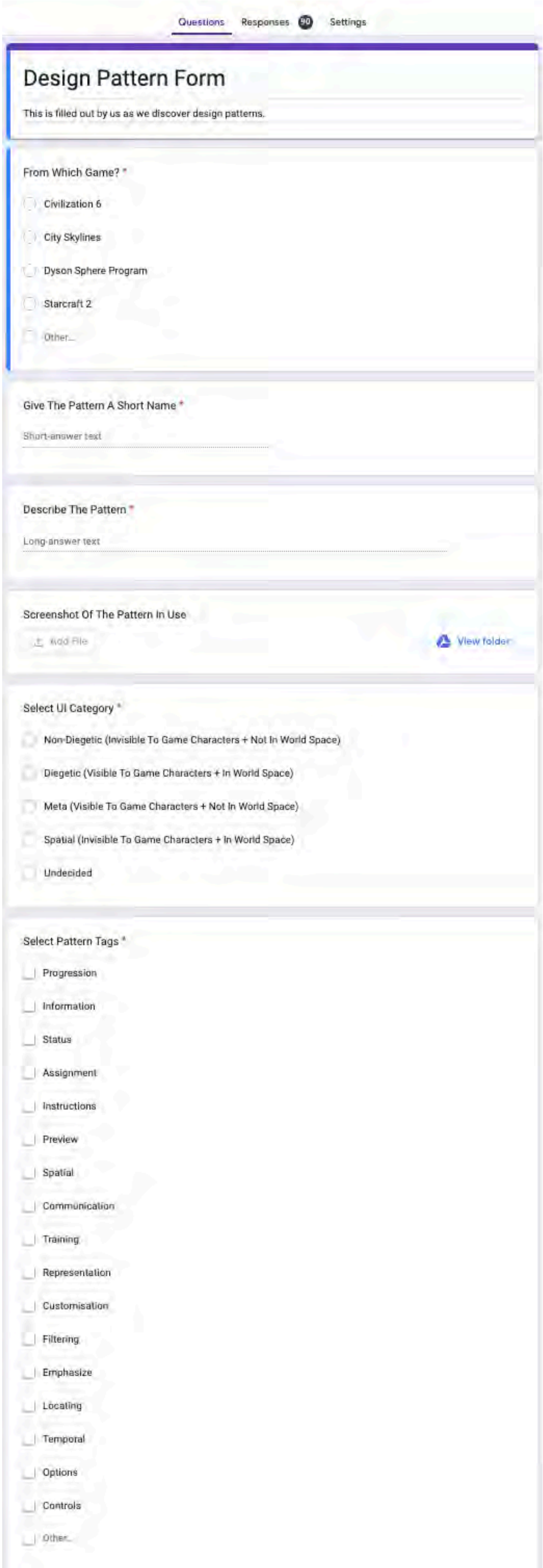
The first phase of the project created the foundation for the rest of the work in this thesis. This includes descriptions of how related literature was found and how the games were analyzed. Furthermore, this phase was carried out in parallel with process phase 2 to make use of the limited time frame (see 6.2).

6.1.1 Literature Research

Research was carried out to find literature that could contribute to RQ2 and serve as theoretical foundation for other aspects of the project. The literature examined was acquired in two main ways; searching for scientific sources, and asking researchers in the field for related work. While researching, it was common practice to use search engines such as Google Scholar [45] and Chalmers Library online service [46] for scholarly literature. This literature often refers to independent studies throughout the text, which could be further researched for additional information around related topics. Furthermore, it proved convenient to ask interviewees in phase 2 about researchers in the domain to further search for related literature, especially since phase 1 and 2 were carried out simultaneously. The literature found is further described in the Theory section (see 3).

6.1.2 Game Research

To find and produce Visual Design Patterns to address RQ1, games were played and analyzed to find elements in the game which could be defined as VDPs. Although four games were intended to be analyzed (see 5.2), Dyson Sphere Program was deemed to be out of scope due to the comprehensive number of design patterns identified from the first three games analyzed. Toward the conclusion of the game analysis, several patterns repeated themselves and only a limited number of new VDPs were identified. Given the limited time of the project, adding to the already saturated VDP library was predicted to not add enough value in comparison to the time required to analyze the final game.



Questions Responses 90 Settings

Design Pattern Form

This is filled out by us as we discover design patterns.

From Which Game? *

- Civilization 6
- City Skylines
- Dyson Sphere Program
- Starcraft 2
- Other...

Give The Pattern A Short Name *

Short-answer text

Describe The Pattern *

Long-answer text

Screenshot Of The Pattern In Use

Add File View folder

Select UI Category *

- Non-Diegetic (Invisible To Game Characters + Not In World Space)
- Diegetic (Visible To Game Characters + In World Space)
- Meta (Visible To Game Characters + Not In World Space)
- Spatial (Invisible To Game Characters + In World Space)
- Undecided

Select Pattern Tags *

- Progression
- Information
- Status
- Assignment
- Instructions
- Preview
- Spatial
- Communication
- Training
- Representation
- Customisation
- Filtering
- Emphasize
- Locating
- Temporal
- Options
- Controls
- Other...

Figure 1: The Input Form used for each Design Pattern found

During the playthrough of each game, the frameworks described in section 3.1 served as the basis for RQ2 to document patterns. When a pattern had been identified, it was cataloged by completing the form seen in figure 1. This form helped categorize the patterns through the VDP model described in 3.3.1. Patterns found and input into the form were then automatically inserted into a spreadsheet which provided an overview of the identified patterns from each game.

Figure 2: Example VDP Card

The initial attributes entered into the form were not final, rather they were iteratively changed throughout the process. The final attributes of each VDP were set through a design workshop (see 4.2.5), where each VDP was discussed and transformed into a VDP card as seen in figure 2. The complete library can be found in A.0.1.

Starcraft II

Starcraft II was chosen due to it having placeable 3D units and structures as well as real-time gameplay. The placeable 3D elements were particularly intriguing to observe since they provided insights into which patterns the game utilized to visualize both in 3D and in the 2D user interface. Two essential patterns were discovered in the 3D world; Units and Teams. The first represents in-game entities the player can move and control, while the latter connect these entities with the player's team through the use of a specific color.

The game requires the player to have a good understanding of what all of their units are doing and where they are on the map. Multiple patterns were found related to this, such as a 2D Minimap, Rally Point and Unit Status Indicator. There were also patterns related to the placement of structures, such as the Object Blueprint Preview, which showed a preview of where the building were to be placed before the action has been made.

Upon diving deeper into the different interfaces in Starcraft II, more specifically in the replay mode for viewing previously played matches, the Timeline pattern was identified together with a few related patterns. The timeline represented different points in time throughout the match, and could be moved back and forth to change the game world to its state during a specific point in time. Related patterns to this include Speed Controls and Restart/Replay, which are directly related to how the timeline functions.

Civilization VI
In contrast to Starcraft II, Civilization VI has a turn-based time structure. This implies more pauses in gameplay which results in a sequential planning sequence, similar to that of construction planning meetings. While there were similarities to Starcraft II's implemented patterns, such as the Units and Teams VDPs, the game utilized a tile system for positioning of 3D elements which differs from the XYZ-based position coordinates in the former game. This considerably affects the spatial capabilities and therefore the patterns. The VDPs found in Civilization VI were View Render Toggles, World Pins, View Lenses, Progressive Models, Object Information Tooltip, Resource Models and Dependency Tree, all of which can be found in A.0.1.

Cities: Skylines
Cities: Skylines similarly to Starcraft II playes out in real-time, though it differs primarily in two aspects. Firstly, it allows the player to pause time at any point, which essentially converts the experience into a turn-based one at the player's discretion. Secondly, it mixes world coordinate positioning for placement of certain objects like roads, with a grid-based placement system for others, like buildings and zones. The VDPs found in Cities: Skylines were Error Models, 3D Color Map, Notifications, Action Mode, Weather Effects, Contextual Representations, Spatial Paintbrush and Zones, all of which can be found in A.0.1.

6.2 Phase 2 - Requirements Gathering

The phase of requirements gathering consisted of both interviewing relevant people to prepare for the prototyping phases, as well as collecting information within the construction domain to increase the knowledge of and empathy for the potential users of the features, which would serve in answering RQ3.

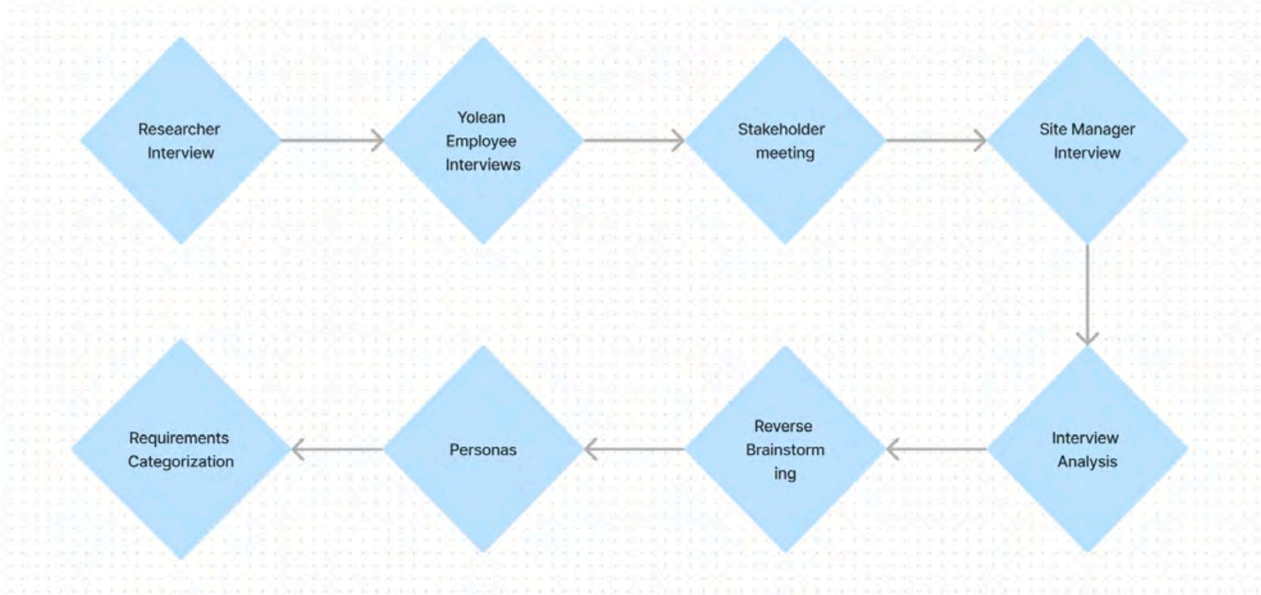


Figure 3: Steps of Phase 2

6.2.1 Interviews

The interviews were conducted in a confined space such as a meeting or conference room since it was likely a place the interviewee would be accustomed to, and to minimize external distractions. Before the interview took place, a consent form (see example A) was provided and signed by the interviewee to make sure they complied with their information being handled accordingly. Notes were taken during each interview to document key points made by the interviewee. Furthermore, the audio was recorded for future analysis as well as the ability to accurately quote the statements woth a potential a major impact on the design.

As more interviews were conducted, it was noticed that some questions prompted answers that provided less new information to the purpose of the interview. Since the interviewees had a tendency to be short on time, it was decided to dynamically skip such questions to produce more time for discussions at the end of the interviews, which almost always gave much needed valuable information which the questions did not prompt for. Discussion around this concluded that the interviewers were not experienced enough within the field of construction work to provide distinctly specific questions regarding the domain. Thus, the final question of each interview was entirely open ended as to prompt the interviewees to answer non-existing questions they had expected during the interviews.

Researcher Interview
The very first interview was with a researcher with experience within developing 4D applications related to the construction and planning domains. The purpose of the interview was to gain insights into the importance of 4D features for construction scheduling, which pros and cons exist when utilizing such features, which potential design related guidelines there are, and finally to get a better understanding of the construction scheduling domain.

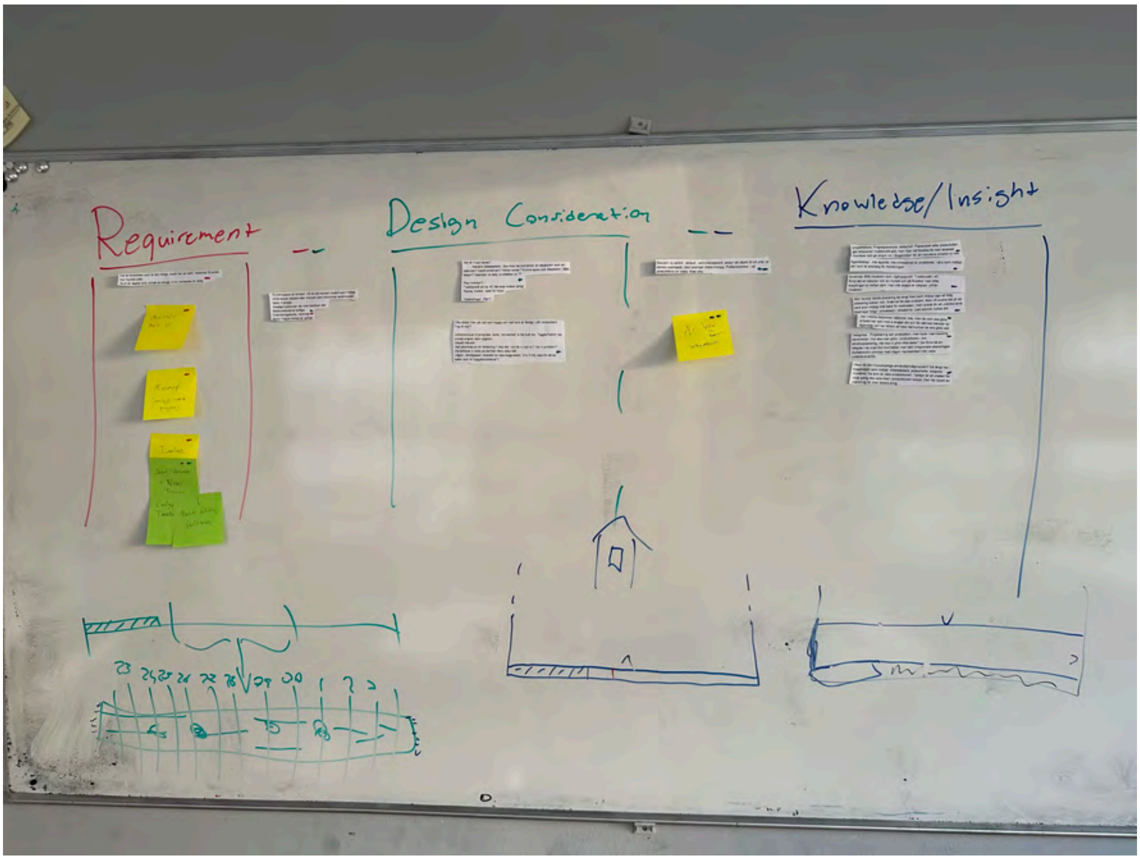


Figure 4: Requirements analysis board after first interview

The main takeaways from the interview were extracted from the documentation and placed on a board as seen in figure 4. Not only were some initial requirements found of what features the prototype had to include according to the interviewee, but also what should be considered when implementing them as well as general knowledge about the domain. Thus, these takeaways were categorized into three main categories: Requirement, Design Consideration and Knowledge/Insight for further analysis. The first category were aspects that immediately were identified as possible feature requirements. The second category symbolized items that could be considered yet their value was not directly apparent and required further research. The last category illustrated pieces of knowledge obtained that did not represent features or design considerations.

Interview Takeaways:

- The overview of the 3D model is the most important part since it contains the spatial information the user can utilize when conducting construction scheduling.
- As such, the number of visible User Interface elements should be kept to a minimum to increase screen space left for the 3D model.
- Other 3D viewing programs often include a 2D minimap or smaller view of the floor plan drawings. Could be useful to implement since users are often

familiar with the 2D layout.

- A timeline is essential to be able to traverse in time and view the state of the application at an earlier or later point.

- Multiple view modes for individual disciplines is of interest, this would enable them to filter the 3D model to only contain elements directly related to their trade.

- Traditionally, the site manager creates a time plan for the project by themselves. There have been attempts to include the subcontractors more in this process.

- There are two separate groups of people responsible for the project phase and production phase respectively.

- The interviewee recommended to focus as far down the production chain as possible, including individual workers or at the very least their supervisors, since they more often directly encounter the physical challenges of the plan.

Yolean Interviews
The following interviews consisted of three experienced developers from Yolean who were individually and independently interviewed to gain a better understanding of the general use cases for Yolean together with what may be improved with the help of our prototype. The questions asked were produced in a Figma board, where the answers were also documented (see figure 5.

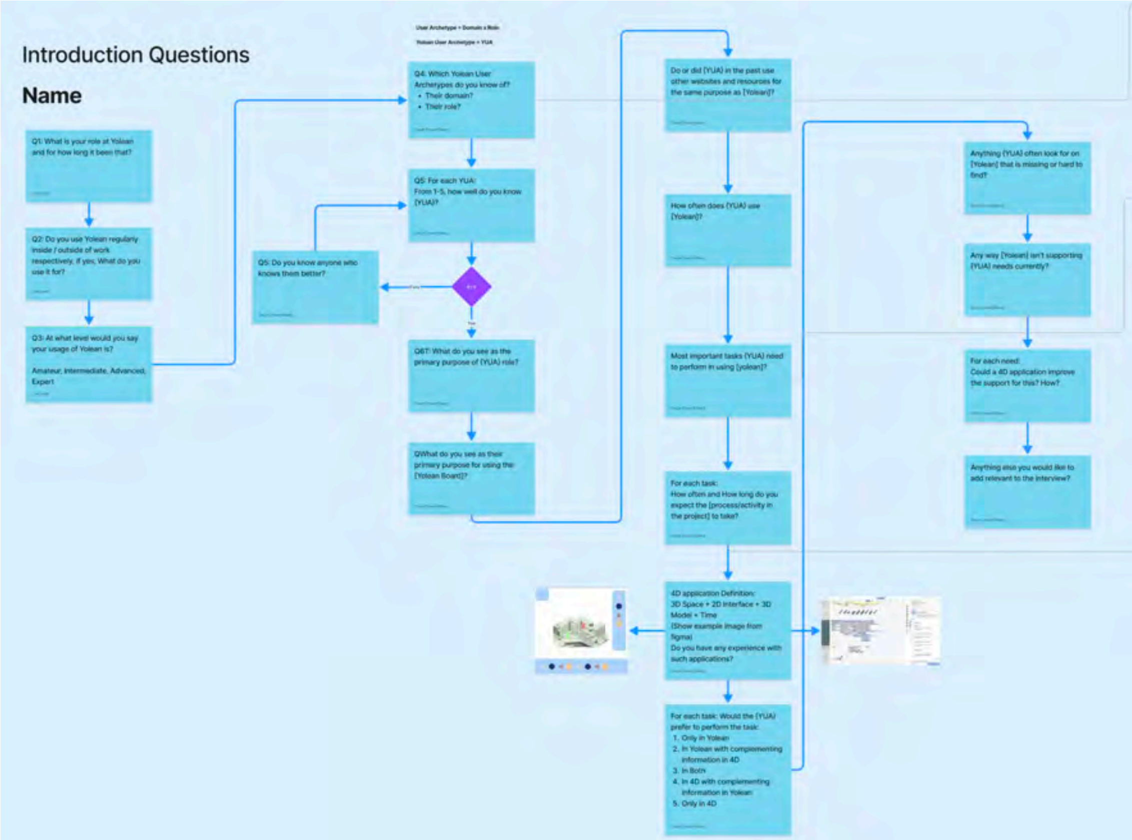


Figure 5: Questionnaire used for the Yolean Interviews

One of the main takeaways from these interviews was that project managers and construction workers use the board in different ways. The project manager uses the board actively approximately a few times a day to make sure the work being done is on track. The workers use it passively about once a week during the meetings lead by the site manager. Thus the focus pivoted toward developing either an application the project manager used in the planning phase, or an application to be used during the weekly meetings in the production phase. Furthermore, one of the interviewees mentioned that the feature of connecting rows in the board to a specific location in a 3D model had been previously requested by users of Yolean. This reinforced the need for 4D features to be added, and indicated the potential value the final prototype could have.

Interview Takeaways:

- Project Managers & Construction workers use Yolean differently
- Feature request: Connect rows in the board to locations in the 3D model
- Construction projects largely have the same types of disciplines (20-30 roughly), which have specific colors assigned. The workers know these colors by heart.
- Yolean and its color assignment feature between wheres and teams largely help the customers feel familiar within the Yolean board. It brings familiarity and recognizability to the application.

- All operations (e.g. email notifications) executed in both the Yolean board and 4D prototype need to be handled the same way.
- There is a need for investigating how the decision making process has changed through time. Especially how it has affected the 3D model (and therefore the construction)
- IFC files seem to be a snapshot of how a building looks at a specific point in time. There should also be a representation of the IFC file for which continuous updates have been made.
- Site managers have geometric and logistical issues which are currently hard to solve in Yolean.
- Regarding the overview being an important feature, Meeting and Question notes are of less importance. Activity tasks and their visual representation is much more helpful for a site manager.

Sales Interview
These three developer interviews mainly focused on one of the two main phases of construction projects; the project phase and the production phase. The purpose of this focus was to, given such a small set of interviews, gather as broad of an understanding of the two different phases as possible to find the main focus for the project. This gave a general sense of which phase to focus on, which was then further reinforced with a follow up fourth interview at Yolean. This interview was with a sales person with more hands-on experience in the field, where findings from the previous interviews were discussed as to confirm or deny conclusions that had been made. Most of the conclusions were confirmed, with further input regarding Yolean's user group and which features deemed to be of most importance to them. The interviewee specifically mentioned that during planning meetings where they had been present, some workers had placed pallets of materials in spots that obstructed work for others, and that there was no apparent way for them to plan this accordingly. A 4D prototype would make this problem much easier to handle if it contained a Material Placement feature.

Interview Takeaways:

- A 3D feature is much more applicable in the production phase than the project phase.
- Subcontractors tend to have little interest in the weekly meetings conducted by site managers. The motivation being that the meetings do not make their practical work any easier to perform.
- Ongoing work is not always defined by formal tasks. It could be a question note regarding a small issue to fix.
- Linking Activity tasks and Question notes are both potentially useful features.
- Since boards usually contain tens of tasks given a single day, filtering the elements present in the 3D view is of high importance to prevent cluttering.

- A zoning tool would be useful to reserve an area during a specific time. This can be useful for material deliveries that need a dedicated spot during an extended period of time, or work such as painting walls that need to be left to dry for several days. A suggestion to implement this would be a tool to place a pallet at a position in the 3D scene for a selected duration.

Stakeholder Meeting
After these initial interviews, a much better understanding of the construction domain had been gathered, and a meeting with the stakeholders at Yolean was planned. This meeting presented the general findings of all previous interviews, and concluded that designing for the production phase was to be the main focus of the project.

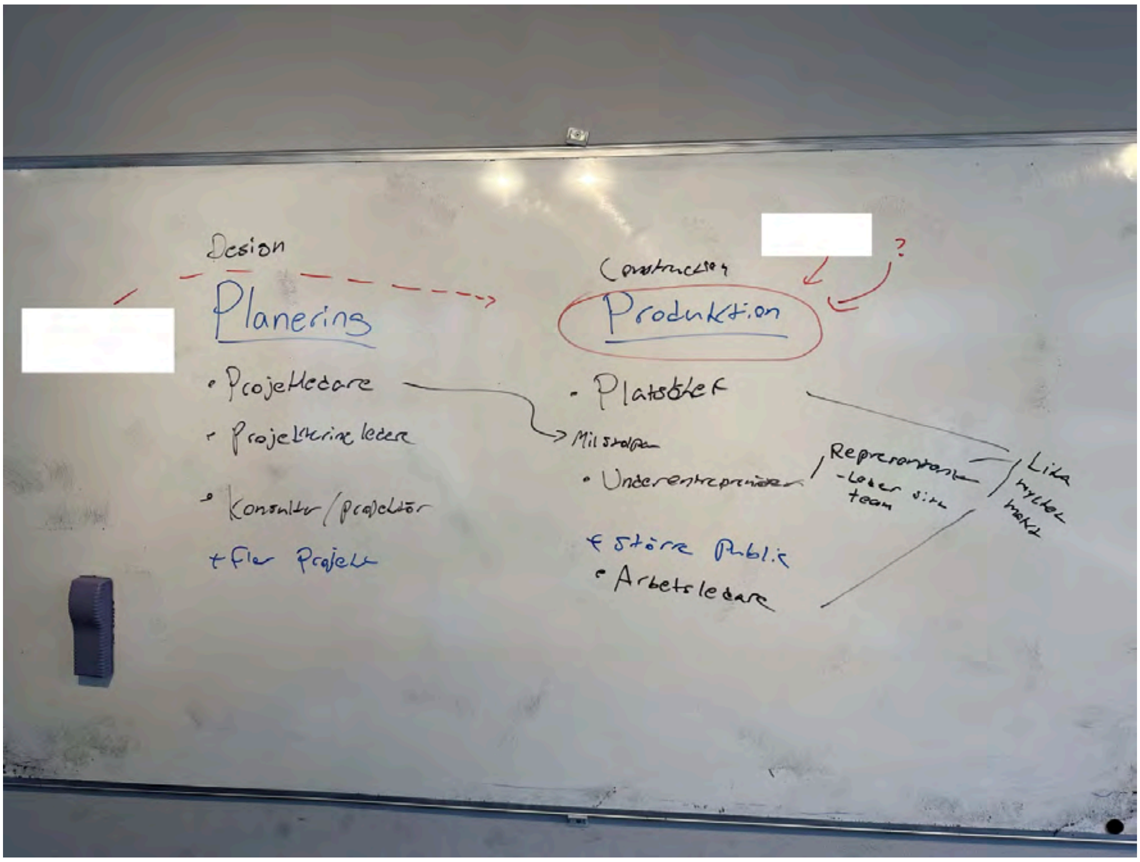


Figure 6: Whiteboard notes after meeting with stakeholders

Site Manager Interview
With the production phase set as the phase of focus, a site manager who uses Yolean was interviewed to determine what their main purpose for using Yolean was, and what the requirements for 4D features might be to aid their productivity and collaboration efforts. The interviewee mentioned Question notes, Activity tasks and the ability to show an overview of current and future progress to be their most valuable features of Yolean. Regarding a 4D solution, they mentioned that they are currently using other applications to satisfy their 3D viewing needs simultaneously with Yolean. However, this had proved to be a daunting process since it presented unnecessary overhead and excise when switching between the different applications.

Thus, 4D features directly connected to Yolean could be a much welcomed addition. The interviewee was also asked how and which of the previously mentioned important features of Yolean could fit into a 4D solution, to which they presented a potential work flow, mentioning specific features they needed during the process. These features included a smaller 3D view, a more complete full screen 4D application, creating Question notes and Activity tasks in the board while linking them to locations present in the 3D model. Furthermore, being able to move around in the 3D model to better position elements from the board was also mentioned to be of high priority. Another important aspect was the fact that they regularly work floor by floor, and a clipping tool that cuts the model horizontally or vertically could be of interest to view a suitable subset of the 3D model. Questions regarding how the locations were to be assigned to different Wheres (rows) in the board were also raised, which was noted to be a significant problem to take into consideration during development.

Interview Takeaways:

- Question notes, Activity tasks and the overview of the board are the most important features to a site manager.
- Other applications are currently being used to satisfy the interviewees 3D needs, however an implementation in Yolean would be very useful.
- Feature request: Two separate views, one small and one big.
- Feature request: The ability to link Question notes and Activity tasks to locations in 3D.
- Feature request: Movement controls in the 3D view.
- Feature request: A wall/floor clipping tool.
- It is unclear how to best assign rows in the board to locations in 3D. Site managers and subcontractors would most likely not have the time nor interest in assigning these manually.

6.2.2 Interview Analysis

After having gathered a significant amount of features and areas of concern from the interviews, this information had to be analyzed and compressed into more manageable pieces of data. Reverse Brainstorming (see 4.2.13) was used on notes and quotes from the interviews, to produce inadequate solutions to the issues which could then be extracted into anti-features or reversed into potential features. This produced a substantial amount of data points, which could then be analyzed and presented to stakeholders for further evaluation.

Figure 7: Reverse Brainstorming board in Figma

Although this method produced a wide variety of solutions, they still needed to be sorted and prioritized to find which features were relevant to our user group. Thus, another design method was utilized to ease this process.

6.2.3 Personas

Name	Age	Purpose	Wants	KPIs	Personality	Experience
Site Manager	44	Plans, organises and distributes work Works closely to customers Responsible for projects Make Decisions Leadership Develop personel "Spider in the web" Prioritise (between milestones and customers)	High Quality Planning Profitable Projects Happy Customers Safe Workplace Pleasant Work Climate Effective Cooperation Good Communication	Quality Time Work Environment Economy Sustainability	Cooperative Creative Leader Social Problem solver	University Education
Superintendent	36	Link between Platschef och Underentreprenörer Directs and communicates with Underentreprenörer Complete Assignments Lead Prioritise (individual tasks) Safety	Effectiveness Profitability Quality Pleasant Work Climate Good Customer Relations		Problem solver Leader Team player Stress tolerant Flexible Solution oriented Opportunist Tech Savy Coach Structured	Gymnasieutbildning

Figure 8: Two of the constructed Personas

To specify a user group for which the application was to be designed toward, a variant of the Personas (see 4.2.2) design method was used. As this is a widely debated means of producing a user group, it was also discussed to which extend this method was to be applied. One of the benefits of this method is the fact that designers receive enhanced ability to gain empathy towards potential users in comparison to pointing toward a list of static inanimate requirements. As such, it is recommended to create a Persona with human-specific traits such as age, name and living situation, of which many may not contribute directly to the final design of the application. Furthermore, some suggest tens of interviews to be conducted with potential users before finalizing the produced Personas [47]. As the amount of interviews conducted in this thesis was vastly lower than what may be recommended as prerequisite for this method, the Personas created were seen as complementary guidelines. This could be seen as a potential problem, however because of the ability to directly interact and communicate with the user group, something which is not always the case for design projects, the Personas created would act as a summary of a set of data points gathered through the Reverse Brainstorming method. Thus, the process of creating Personas were of more importance than the actual Personas, since it helped empathizing with the user group and served as a better way of separating the features which were respectively relevant and irrelevant for the target user group. The Persona which proved to be most useful was the site manager (see figure 8), due to the central role they possess during planning meetings in the production phase.

Figure 9: The results from the Reverse Brainstorming, categorized

6.3 Creating Requirements

A list of feature requirements was created as part of investigating RQ3. It would allow us to associate the needs of our stakeholders to related VDPs, ensuring the VDP choices stemmed from stakeholder input and were not arbitrarily implemented in the prototyping phase. To analyze the categorized features and create these requirements for the prototyping phases, Kano Analysis (see 4.2.3) was used. This was done by first scheduling a meeting with stakeholders to discuss features and prioritize them accordingly (see 4.2.3). However, because of scheduling difficulties and time restrictions, the meeting served as a short introduction to the Kano Analysis concept where a set of example features were presented and analyzed. The attendees were then sent individual lists of features which they would then use to categorize each feature according to the Kano Analysis standard presented in the meeting. The timeline, rotating 3D model and project sync features are examples of Required features according to the Kano Analysis. An example of a Desired feature is the ability to link an Activity task to a specific location in the 3D environment. Exciters/Delighters included features such as removing walls or adding transparent clipping planes to the 3D model. The ability to scroll infinitely in the timeline was deemed to be neither positive nor negative if it was present or not, thus it was categorized as a Neutral feature. No discovered features were categorized as Anti-features, which reinforced the features relevancy to the target user group.

When Kano Analysis had been applied, the discovered VDPs were connected to each feature by filtering the VDPs through the following process:

- What temporal usage does the feature indicate? Keep the VDPs that match.
- What UI categories are suitable for the feature? Keep the VDPs that match.
- What purposes does the feature serve? Keep the VDPs that match.

This process resulted in the construction of the following table, mapping each feature and its KANO category and the filtered list of VDPs:

Name	KANO	VDPs
Window modes	Required/Required	
Full screen mode	Required/Required	
Small window mode	Required/Required	
Timeline	Required/Required	Timeline
Rotating 3D model	Required/Required	Resource Models God Fingers Contextual Cursor
Access levels same as in board	Required/Required	
Project sync	Required/Required	
Optional Task Locations	Desired/Desired	World Pins Rally Point Contextual Representations
Zoning	Exciter/Exciter	Spatial Zones Action Mode Contextual Cursor
Zone duration	Exciter/Exciter	Spatial Progress Indicators
Material Placement	Exciter/Exciter	Object Blueprint Preview Resource Models Contextual Representations Error Models
Timeline Timespan	Exciter/Exciter	Timeline
Location Questions	Exciter/Exciter	World Pins Contextual Representations
Wall modes	Exciter/Exciter	Shown/Hidden Element Work Area Perspectives View Render Toggles
Actions in 4D trigger email notifications	Exciter/Exciter	Notification
Task in timeline	Exciter/Exciter	Dependency Tree

Figure 10: Table of Features, KANO categorization and related VDPs

Ultimately this list represented the VDPs that would be used in feature development in the two forthcoming prototyping phases.

6.4 Phase 3 - Low-Fidelity Prototyping

This section describes the phase of low-fidelity (lo-fi) prototyping, which methods were used and how the prototype iterations evolved through time.

6.4.1 Paper Prototyping

The very first lo-fi prototype iteration was made with simple sketches on plain paper. Paper prototyping is a common method for designers to present their ideas quickly and effectively. Based on the information gathered during the first phase of the project, an initial sketch was made to represent a possible interface solution with multiple features present that would implement a set of discovered VDPs.

6.4.2 LEGO Buildings

The paper prototypes served as a good medium to present ideas regarding 2D user interface elements. However, a rotating 3D element and features related to it proved to be very difficult to present accurately on paper. Thus, a 3D model in LEGO was built to complement the paper prototypes. The initial idea was for the LEGO building to be included in the testing of the paper prototype, which through the Wizard of Oz method could be dynamically rotated when buttons in the paper interface were pressed (see 4.2.6).

Figure 11: The LEGO Building, together with two task units, and a curved paper background.

However, combining the paper interface with the LEGO model presented a new problem in the form of scale and depth perception. For the prototype to be feasible for user testing, the experience of a large three dimensional building together with a small two dimensional paper had to be much improved. Not only was the size of the building a problem, but also the way it was to be positioned in a small windowed mode as well as a larger full screen mode. One attempt to eliminate these problems was to make a cut out in the paper, having the user hold it vertically and then have the building stationary in the background, with the test conductor moving it back and forth to represent zooming, and rotating it when prompted to. During tests, this proved to be too frail for the user to effectively handle, since they had to both hold the paper as well as interact with the user interface elements on the paper.

Either the paper had to be kept stationary, or some other means of interacting with the user interface had to be implemented. It was decided to attempt to make a container for the paper.

6.4.3 Advancing the LEGO prototype

Because of the apparent issues with paper prototyping a 2D/3D hybrid model, it was decided to try to make a more durable physical prototype that could make use of the created paper prototypes. The goal was to keep the positive aspects of a paper prototype 4.2.12, while simultaneously increasing fidelity without much work. Thus, sketches of a wooden frame were made with specific dimensions to be able to fit a regular A4 paper. This would allow the user to interact with the prototype in a more similar way to using a digital interface, without having to develop a digital prototype. To increase depth perception and immersion, a cohesive long sheet of paper was set in the background of the prototype with the building on top (as seen in the background of figure 11). This gave the illusion of a solid white background instead of staring into a box or a wall by having the paper being slightly curved, in a quarter-pipe type slope. This was very effective, and solved the 3D visualization problems sufficiently enough for a test to be made. However, sliding the 2D paper prototype in and out of the wooden frame resulted in an unforeseen roughness which slowed down the testing of each paper prototype significantly. It was therefore decided to scrap the wooden frame, and attempt a new method for the next iteration.

6.4.4 Figma Prototype

The previously mentioned wooden frame proved to be subpar compared to the expectations and the fact paper prototypes do not provide a sophisticated enough user experience for 3D testing. Thus, the fidelity had to further be increased to achieve a preferred method of showing the 3D model. The design tool Figma [48] had previously been employed in the project for methods such as brainstorming, and was chosen as the tool of choice for the next prototype iteration.

Through the previous phase and the current phase's iterations, it was made apparent that multiple different window modes could prove to be useful for the user. This resulted in the prototype being split into two separate parts, one smaller version with a subset of the feature set, and one full-screen mode application with the complete feature set. The already created paper prototypes had still been tested throughout the process of making the initial iterations of the low-fidelity prototype, and the later iterations were used as a base to build the digital low-fidelity prototype from. Futhermore, pictures were taken of the LEGO building to be used in the Figma prototype. The photos were taken from different points of view to represent rotation, as well as with walls and floors being selectively excluded to represent different states. LEGO figures were placed in the model to represent Activity tasks placed at specific locations in the building.

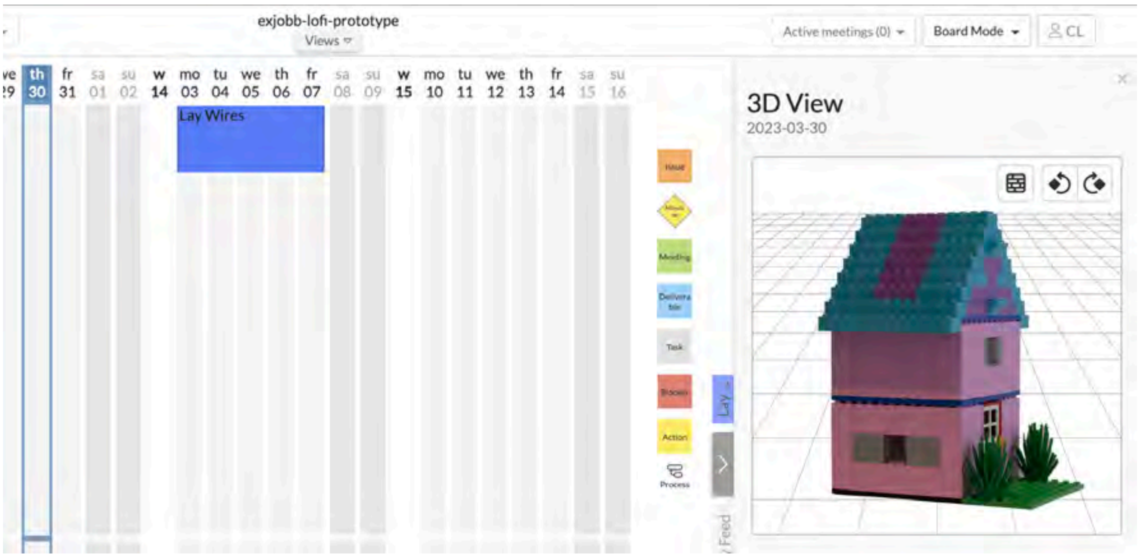


Figure 12: Small Sidebar Prototype representing a chosen task in the board

6.4.5 Small Sidebar Prototype

As previously mentioned, the prototype was split into two separate parts. The first of which being placed in the existing side bar of the Yolean application, as seen in figure 12. This 3D view included simple controls such as rotation buttons and a toggle for viewing walls. The user could also select a specific date in the Yolean board that the 3D view would filter its data from.

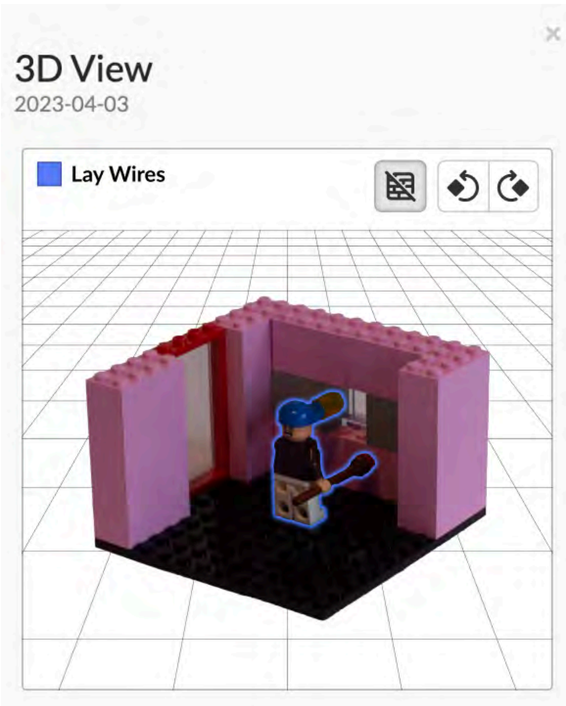


Figure 13: Small Sidebar Prototype representing a chosen task in the board

A legend was present that would showcase Activity tasks located in the 3D view which overlapped the current selected date (see figure 13.

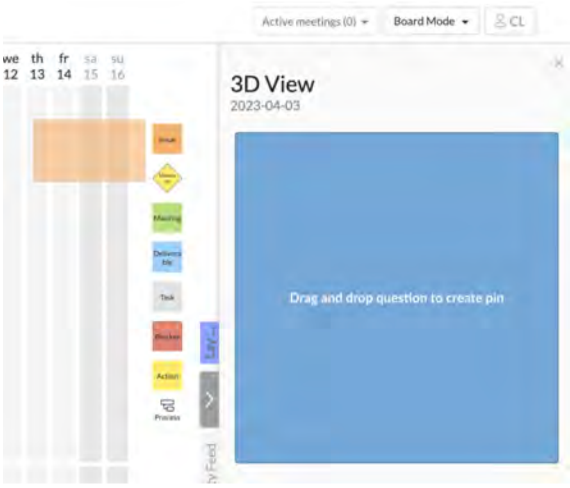


Figure 14: Small Sidebar Prototype representing a chosen task in the board

It also showcased a feature where the user could drag a Question note into the 3D view window to assign a location pin at a selected position (see 14). All of these features were extracted from the requirements acquired from the Kano Analysis as mentioned in 6.3. This smaller prototype implemented some required features from the Kano Analysis such as project sync and rotatable 3D model, but because of its size lacked features requiring more space such as the timeline.

6.4.6 Full Screen Prototype

The full screen prototype expanded upon the features present in the smaller side bar part. With increased screen size to work with, the interface was designed to further expand on the features implemented.

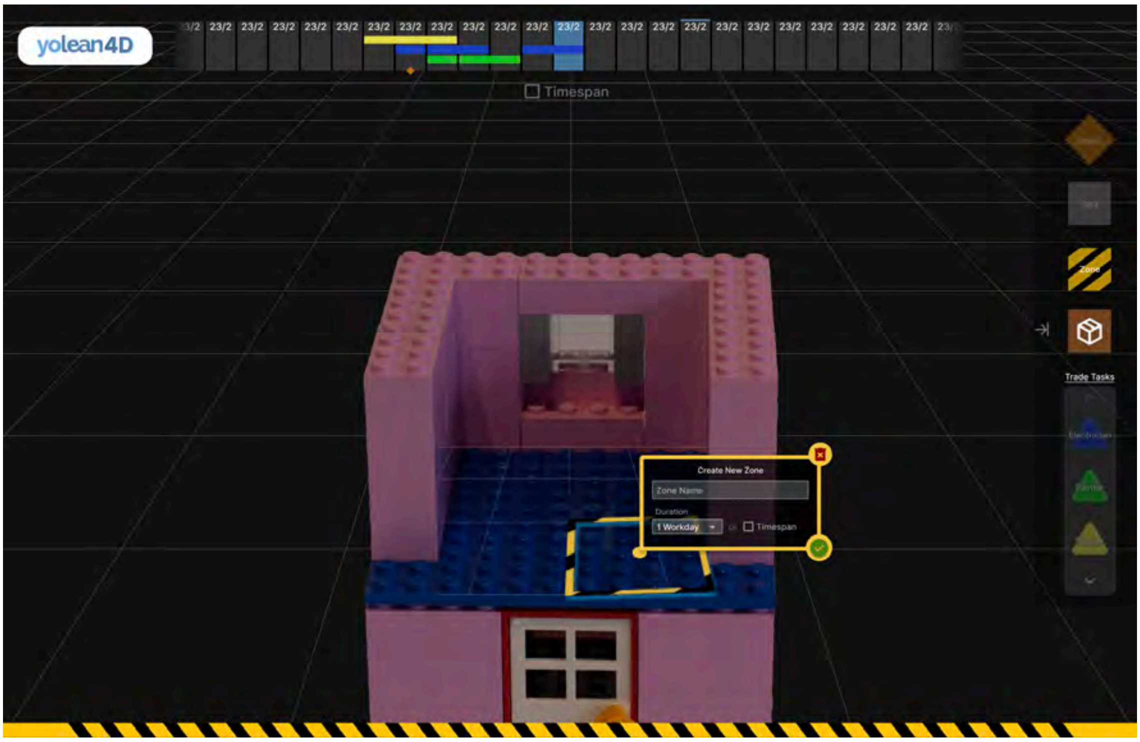


Figure 15: Full screen prototype creating a zone

As the full screen application lacked the ability to create Activity tasks and Question notes through the Yolean interface, a separate sidebar with creatables was made to enable this in the 3D view, as seen to the right in figure 15. Some features not present in the Yolean board were also implemented, such as a zoning tool and a material placement tool.

Figure 16: A selected time span in the timeline of the lo-fi prototype

As seen in figure 16, a timeline was added together with the ability to enable a time span of dates, which further increased the user's controls over the 3D view. The timeline also included visual representations of active zones (marked by a striped black and yellow indicator), active issues (marked by an orange rhombus), current selected date (represented by a blue background in the timeline), today's date (a smaller blue border at the top of a timeline object), as well as Activity tasks present in the Yolean board. To separate the visualization of the time span and selected date, a darker shade of blue was used together with draggable gray borders for easy selection.

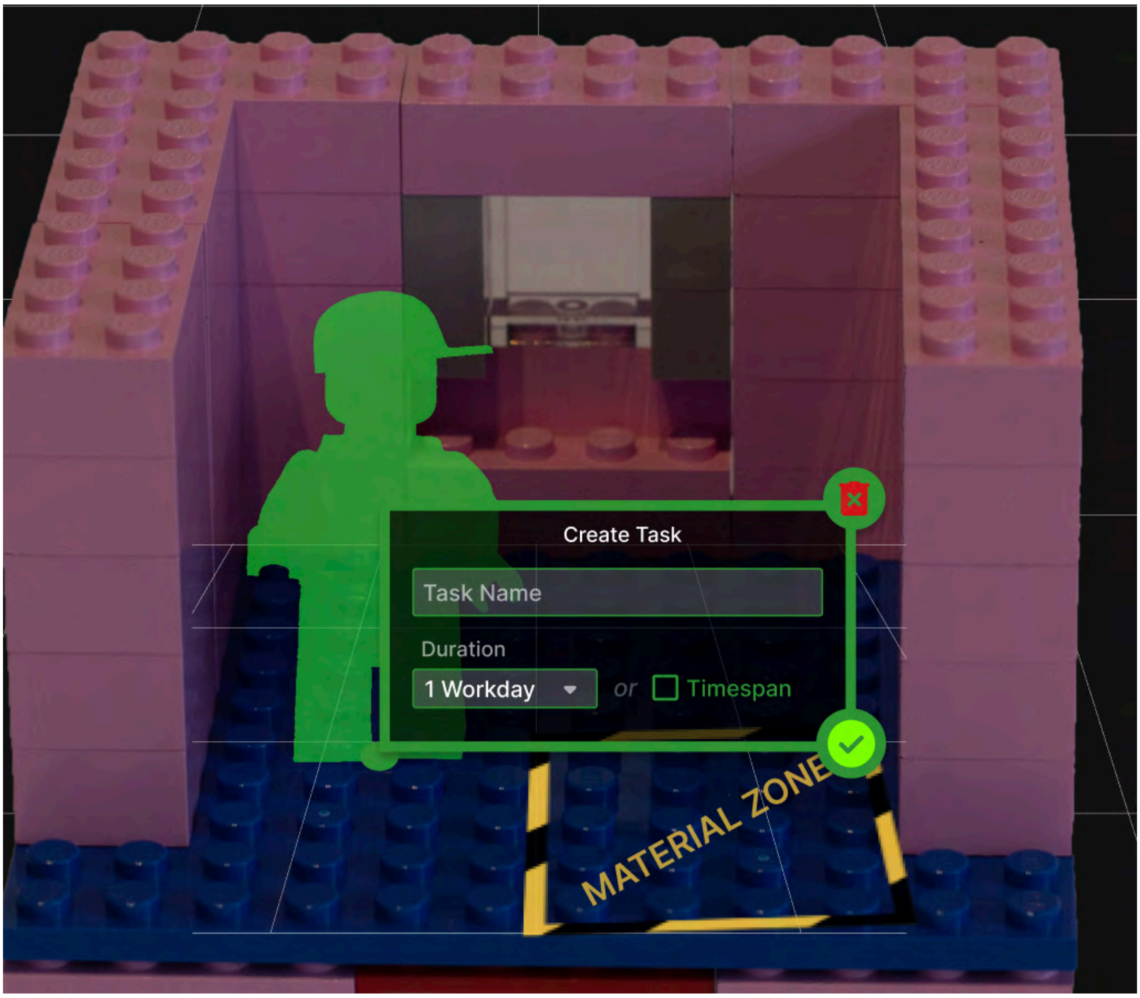


Figure 17: Placing an Activity task in the lo-fi prototype

The time span selected would filter the 3D view to only show elements present during that time, while the selected date would act as the start point from which a creatable element would be initiated from. When creating Activity tasks from the creatable sidebar, a draggable unit with the respective color of its selected Trade would appear. When placed, a small input window shows more options for the user to input, as seen in figure 17.

6.5 Phase 4 - Lo-fi Evaluation

As stated by the Design Thinking Process (see 4.1.1), the final step is to test the produced solution. Thus, to evaluate the Low-fidelity prototype, stakeholders were invited to a critique session (see 4.2.7). During this session, the two parts of the prototype were presented in an interactive Figma environment. Ideas and features were discussed to make sure the project was on the right track.

Small Sidebar Prototype
The response on the small sidebar prototype part was positive, and no negative

aspects were highlighted during the critique session. It was mentioned that the smaller windowed view did serve a purpose in the interface, and should be examined further. Another interesting point of discussion was the feature to create a Question from the board into the 3D view, which the stakeholders saw as a good way to connect existing features in Yolean to the expanded feature set in the 4D application.

Full Screen Prototype
Since the full screen part of the prototype contained a larger set of features, it became the main focus of the critique session. First of all, the zoning feature was suggested to be an extension of the Activity task feature in the Yolean board, instead of being its own feature solely present in the 4D feature set. The stakeholders also pointed out that the Activity tasks present in the timeline were quite few in comparison to what a real Yolean board would contain. At most, Activity tasks in the test on a single day only amounted to a total of three, when a Yolean board commonly contains tens of Activity tasks during a single day. Thus, it was suggested to add a similar filtering feature as available in the Yolean board to single out the elements of importance to the user. Another concern that was raised by the stakeholders was the amount of time required to recreate the lo-fi prototype in actual code. More specifically, the timeline presented had enough features to run the risk of not being developed in time. Therefore, a discussion around what would be lost if the timeline was omitted took place. However it was decided that the timeline was an essential element for the applications to meet the requirements set in the previous phase. This lead to the timeline gaining a high priority for the high-fidelity prototype, as the time invested into completing the feature would prove to be worth it for the end result.

6.6 Phase 5 - High-Fidelity Prototyping

As with the low-fidelity prototype, the 2D and 3D elements presented different problems respectively. Although this phase took up a moderate amount of time during the project, the development process will not be described exhaustively due to the limitations set by this report (see 1.4).

6.6.1 2D Elements

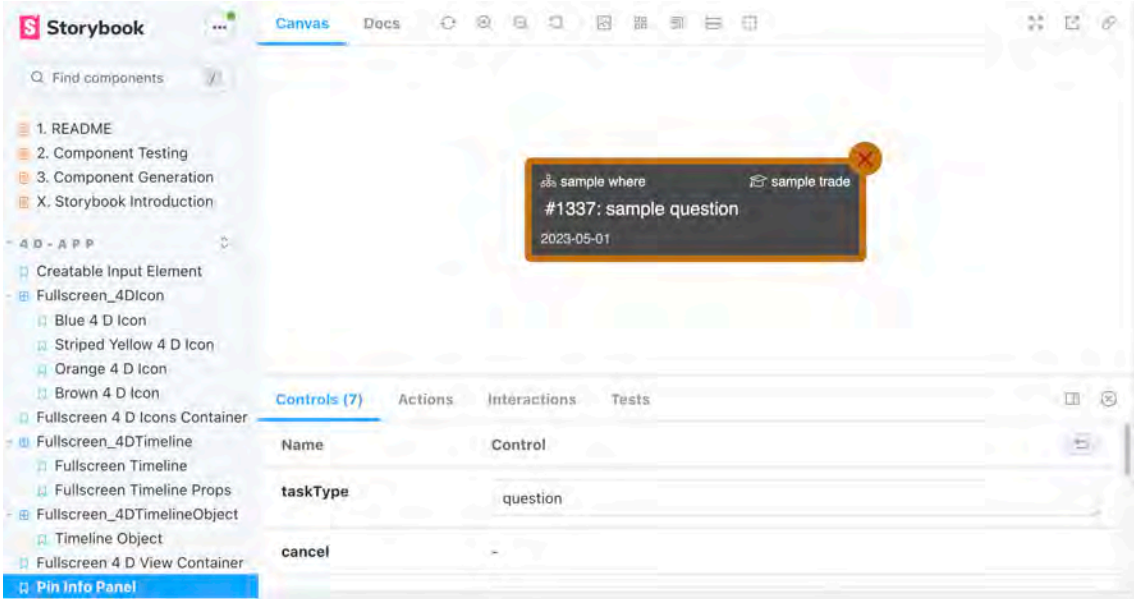


Figure 18: Object Information Tooltip component in storybook

Developing for a complex live site can present an intimidating development loop, which proved to be the case for this project. One tool used to assist this process was Storybook (see 18). This allowed quick local development for separate components, with a low waiting time for changes in code to appear. This came especially in handy when developing the 2D elements since the majority of them were able to be independently developed as single components.

Figure 19: Early view of the timeline and its sub-components

A limitation when developing locally is the lack of real data available, since there is no straight forward way to fetch live data from the servers to insert into the components in Storybook. Thus, the data inserted when creating the user interface elements had to be simulated by hard-coding data that mimics actual data as accurately as possible. This allowed for developing complex components that had dynamic states which essentially behaved as if they were implemented in the real website.

Figure 20: First functioning view of the 3D model

6.6.2 3D Environment

To render the 3D environment, the code library web-ifc-viewer [49] was used, which provides functionality for rendering Industry Foundation Classes (IFC) files utilizing another library called three.js [50]. Together they allowed construction building models of the common file type mentioned previously to be loaded into a scene along with easily implemented camera and object controls. This scene was added to the Yolean board, after which the styling was modified and the requested functionality was implemented combining the capabilities the Yolean code base and the libraries.

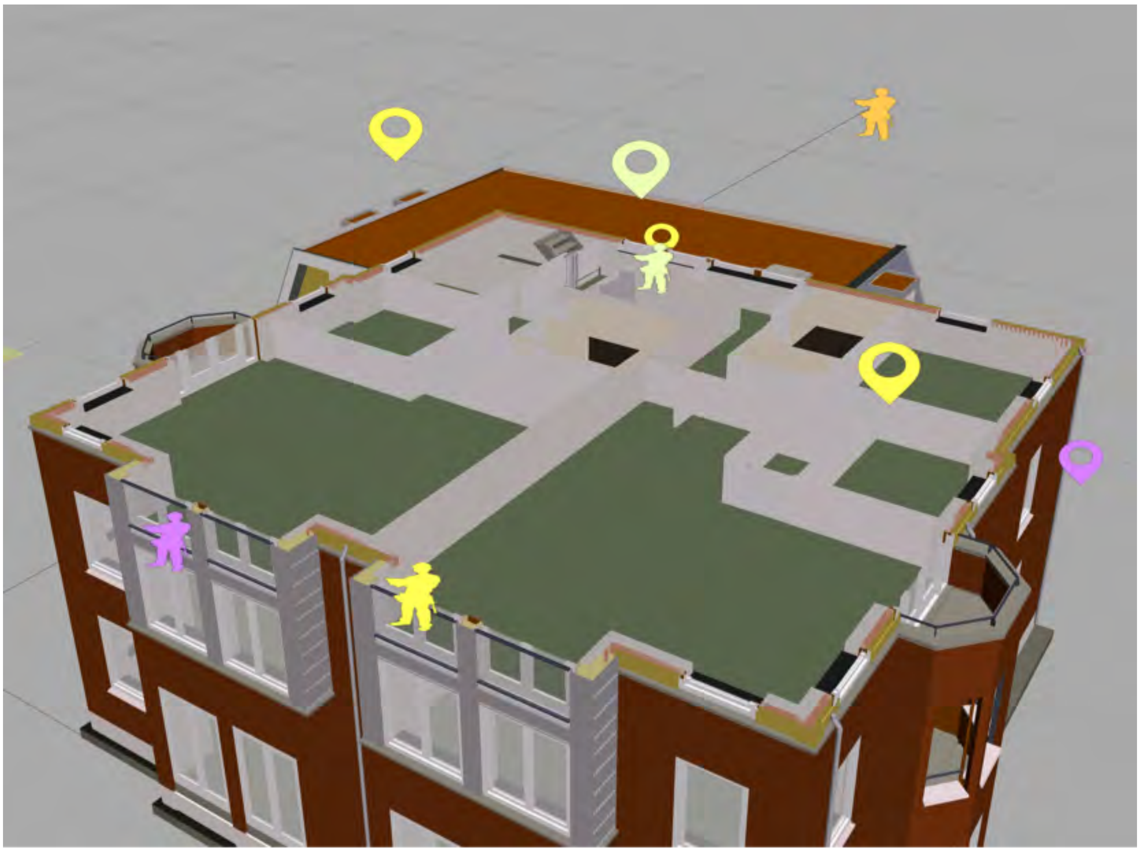


Figure 21: Early view with trade-colored units and pins implemented

The full overview of the final prototype can be found in section 7.2.

6.7 Phase 6 - Hi-fi Evaluation

6.7.1 Evaluation Goals

The goal of this evaluation was to receive feedback and opinions on how the features, and VDPs in extension, were perceived to affect productivity and collaboration. The data would serve as the basis for answering RQ4: Which VDPs can contribute to increased productivity and improved collaboration in construction projects?

6.7.2 Participants and Environment

The participants recruited to participate in the experience prototyping, role-play and focus group session were 5 voluntary employees at Yolean, chosen due to their potential expert insights, availability and knowledge of the application.

To evaluate our high-fidelity software prototype, we designed a user test session that included the following evaluative design methods:

- Experience Prototyping 4.2.11

- Role-playing 4.2.9
- Questionnaires 4.2.10
- Focus Groups 4.2.8

The test was structured to mimic planning meetings in real construction projects on a smaller scale, which is why the roles site manager and four common subcontractor trades were included.

6.7.3 Procedure

The testing session was structured as following:

1. Prior to the testing session began, all 5 participants were asked to fill in a questionnaire asking for fundamental information about the participant (see 2).
2. The Site Manager role was assigned to the participant with the best knowledge about the role and would be in control of the application device. This decision was made to reduce errors and delays related to lacking experience leading meetings or using Yolean in a fashion similar to that of a real site manager production planning.
3. The other participants were each randomly assigned roles as Subcontractors of one of four specific trades: Electrician, Painter, HVAC and Drywalls. Unlike the Site Manager role, the participants previous experience mattered less and it was therefore not required to distribute them in a non-random fashion.
4. All participants were then presented with the rules and objectives of the testing session: They were to role-play their assigned role and be given a sheet of paper including role-specific instructions, information and objectives. They were not allowed share any of the information on their specific sheet until the testing session started.
5. Each sheet included: a number of work activities that had yet to be planned, their location, required materials and activities they were dependent on, a number of questions and information required for them to answer other roles' questions. The questions labeled as Pre-Meeting Questions were placed in the 3D model right before the session started, while the During Meeting Questions were supposed to be raised by the participant during the meeting. (see 4 & 5)
6. They were all asked to sit down in a meeting room to perform construction planning given a prepared project board in Yolean. Each role had to make sure their objectives were accomplished during that time.
7. They were then given 30 minutes to plan using a Yolean board with our developed features enabled.
8. After the second test, all participants were given another questionnaire which they spent 5-10 minutes answering individually. The purpose of this was to avoid losing opinions, feelings or critique that might be impacted by the social

climate of the focus group session, while also motivating the participants to reflect on their experience (see 3).

9. Finally, a focus group meeting was held with the participants. A moderator first asked the group which features in the post-session questionnaire they rated as either Very Negatively or Very Positively impacted productivity or collaboration, which would lead to further discussion and reveal how they felt these variables were impacted by the features included in the test, what features could be changed, replaced or added.

Figure 22: Images taken during the hi-fi evaluation.

6.7.4 Data and Analysis

During the session, notes and audio recordings during the test and discussion were taken. After the evaluation session, the questionnaire results were compared with the comments made by the participants.

The final stage of qualitative analysis was performed using deductive coding. The selected code pairs for the analysis were "Positive/Non-Positive" feedback. Each statement or data point connected to a feature was assigned the codes. Approving feedback was considered Positive, and neutral or adverse feedback Non-positive.

Highly Positive (p >= 4) Questionable (p = 2 or p = 3) Highly Non-Positive (p <= 1)

Productivity

Feature	NP	P
Window Modes	3	2
3D Model With Controls	1	4
Wall / Floor Clipping	1	4
Timeline & Timeline Elements	0	5
Data Filtering	3	2
Object Placement Preview	0	5
Pins	2	3
Units	1	4
Material Placement	0	5
Hover Tooltips	4	1
Info Panel on Object Click	2	3
Colors & Data Synced	0	5

Collaboration

Feature	NP	P
Window Modes	3	2
3D Model With Controls	2	4
Wall / Floor Clipping	2	4
Timeline & Timeline Elements	0	5
Data Filtering	4	2
Object Placement Preview	1	5
Pins	1	3
Units	0	4
Material Placement	0	5
Hover Tooltips	4	1
Info Panel on Object Click	1	3
Colors & Data Synced	0	5

Figure 23: Evaluation Coding Results

7

Results

Throughout this thesis, the following contributions have been produced:

1. A system for classification and categorization of VDPs (3.3.1).
2. A library of VDPs used in Strategy & City Builder Games applicable in design of visual construction planning applications (A.0.1).
3. A set of software features developed through the use of the VDP library (7.2).

This section will present the results of the thesis and aims to answer the set research questions:

1. Which Visual Design Patterns can be identified in popular strategy and city-building games? (RQ1)
2. How might these VDPs be modelled and categorized? (RQ2)
3. Which VDPs are useful when designing features for a visual construction planning application? (RQ3)
4. Which VDPs can contribute to increased productivity and improved collaboration in construction projects? (RQ4)

7.1 Discovered Visual Design Patterns

During the first half of this thesis a number of VDPs were extracted from the researched games Starcraft II, Civilization 6 and Cities: Skylines. In total, 30 VDPs were discovered in the games we analyzed and categorized according to our model and definition (see 3.3.1). The patterns were visualized as cards for simplicity to include all the variables of the VDPs and the example image. Here one from each game examined will be presented as examples while the full library along with legend cards can be found in 6, 7, 8 & 9.

Timeline represents a non-diegetic pattern of intermediate visual complexity that is continuously present in the application. The key purpose of this pattern, temporal, is to provide time-related information and controls to the user, as indicated by the additional purposes. The time intervals can be discrete, or continuous as in the example image.

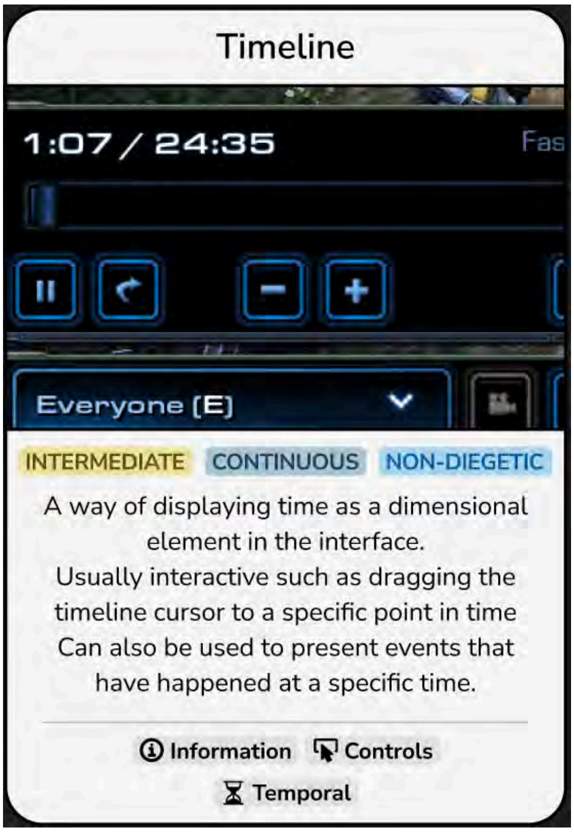


Figure 1: Timeline from Starcraft II

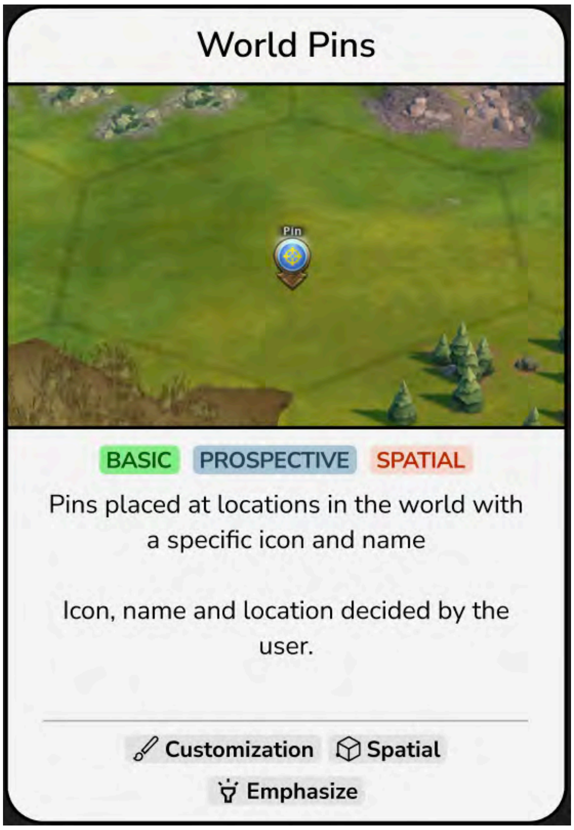


Figure 2: World Pins from Civilization 6

World Pins is a basic spatial pattern for prospectively emphasizing spatial positions. The user can customize its placement, appearance and label. The position can be either tile-based or a specific XYZ coordinate in 3D space.

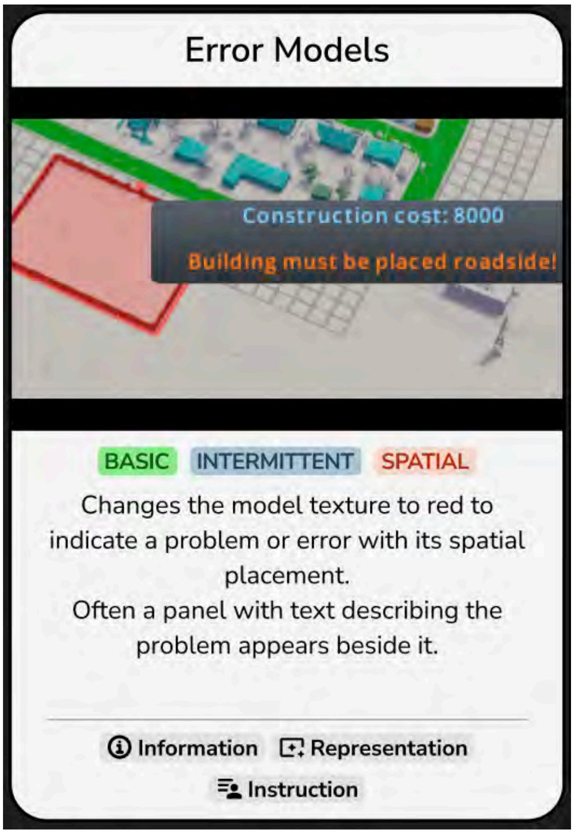


Figure 3: Error Models from Cities Skylines

The Error Models pattern is also basic and belongs to the spatial UI category, although intermittent in its time-dependent use. Models in the world are represented in red to inform the user that their placement or position is improper. The red texture disappears when correctly positioned, which indirectly instructs the user. Incorrect positioning might be when a model extends beyond a defined grid or collides with another object.

7.1.1 VDPs for Visual Planning

After the requirements gathering and KANO analysis was completed, the following list of believed to be beneficial VDPs for feature requirements (see 6 for their respective VDP cards) was produced as explained in 6.3:

Timeline	Resource Models	Dependency Tree
Contextual Cursor	World Pins	Rally Point
Contextual Representations	Spatial Zones	Action Mode
Spatial Progress Indicators	Object Blueprint Preview	Error Models
Shown/Hidden Elements	Work Area Perspectives	View Render Toggles
Notification		

7.2 Software Prototype

The final software prototype presented contained several features which were identified during the requirements gathering phase (see 6.2). These will be described in this section together with the respective VDPs used to implement them.

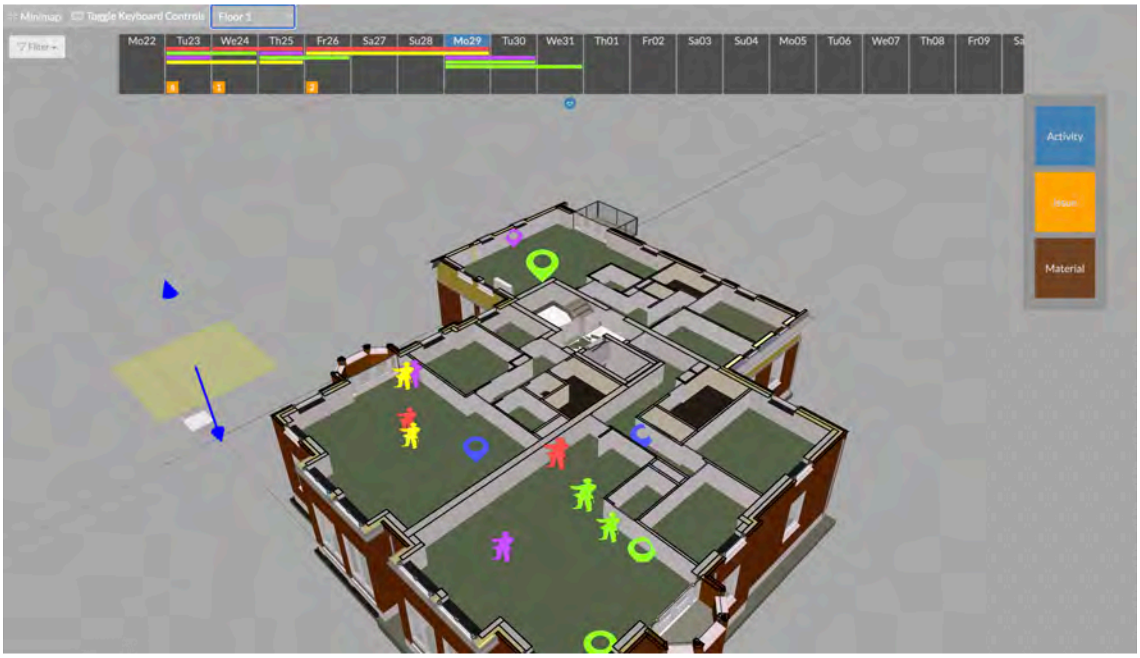


Figure 4: An overview of the final full-screen software prototype.

A complete overview of the features can be seen in figure 5. The VDPs used to implement the features are:

Object Information Tooltip	Shown/Hidden Element	Work Area Perspectives
View Render Toggles	Timeline	Dependency Tree
Object Blueprint Preview	World Pins	Tooltips
Contextual Cursor	Loading Indicator	

7.2.1 Rotating 3D Model

The centerpiece of the 4D view is the rotatable 3D model as seen in figure 5. Although the 3D model itself has no VDPs directly connected to it, the ability to rotate and move around in the environment around it was implemented through the Contextual Cursor VDP (see 7).

7.2.2 Wall Modes

The Wall Modes feature was implemented through being able to hide parts of the building by introducing a clipping plane into the environment. This clipping plane made use of the Shown/Hidden Element, Work Area Perspectives and View Render

Toggles VDPs. This feature was useful for viewing and placing objects inside of the building, without having to move the camera inside the building walls.

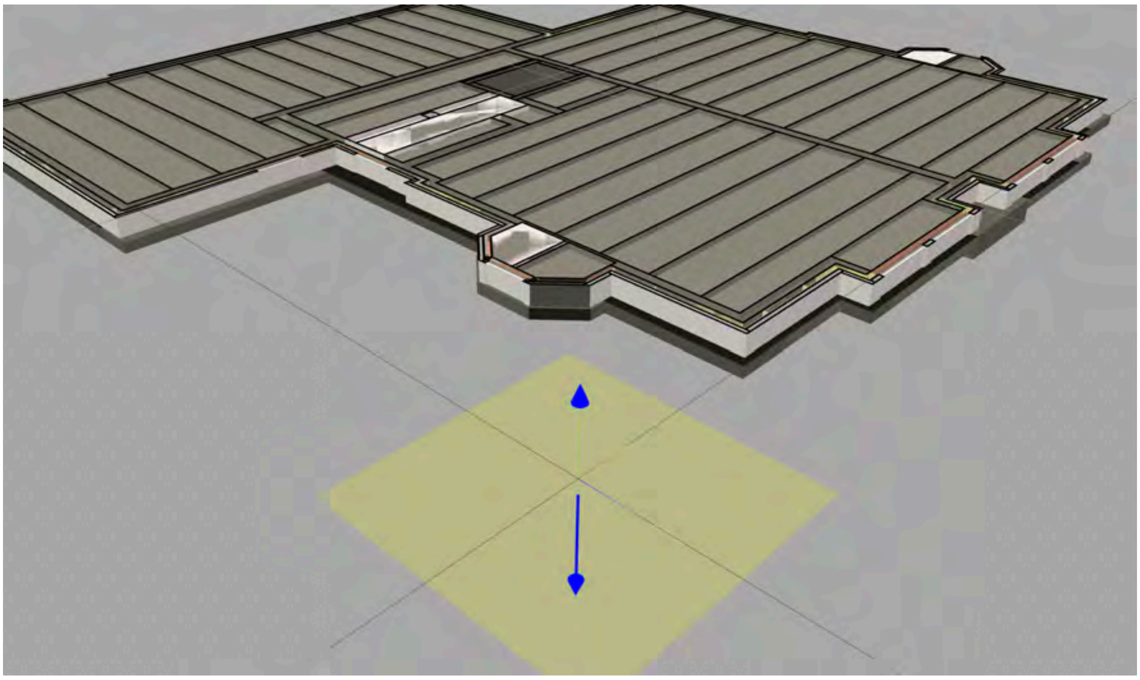


Figure 5: Clipping plane example

7.2.3 Timeline with Time span

Another core feature that is the Timeline and time span, which was primarily based on the VDP Timeline.

Figure 6: The timeline with highlighted Activity bars and Question notes according to the two selected dates.

This feature consists of a scrollable timeline which shows activities currently visible in the view of the board. The colors of these bars represent their respective Trade colors which is the same as in the board view. This is meant to reduce visual confusion when switching between the regular board view and the full screen 4D view. Furthermore, the current date header is also highlighted in blue, similar to the board view. A selectable date was also added in a lighter shade of blue, to represent which elements the user currently sees in the 4D full screen environment. This selectable date can be further expanded into a time span by holding the Shift button and pressing a date further into the future, which highlights all of the activities and questions present during that interval. It also filters the 3D elements rendered in the view according to the selection of dates.

7.2.4 Tasks and Questions in Timeline

While the Timeline VDP contributed to the ability to select a specific position in the Timeline, the Dependency Tree inspired to place Tasks in the Timeline to bring a better visual representation of the board. As the example of the Dependency Tree VDP mentions (9), there are elements visible in the scroll bar of the interface, which were then implemented through the activity bars in the scrollable timeline (see figure 6). Additionally, if there are any Question notes on a specific date, the amount of Question notes is also displayed in the bottom left corner of a Timeline date in an orange square.

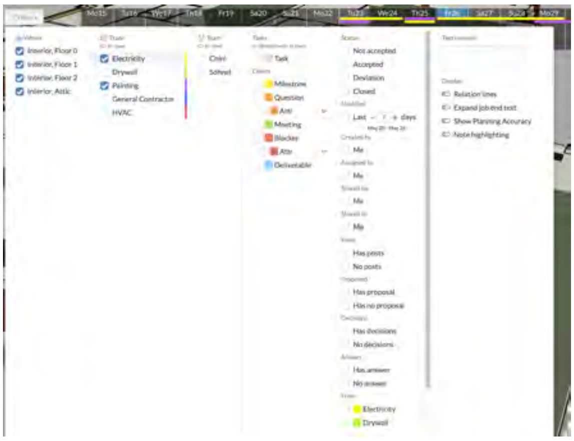


Figure 7: The filtering menu open in the full-screen app.

7.2.5 Filtering

A specific request from the lo-fi prototype evaluation (see 6.5) was the ability to filter elements in the Timeline. Thus, the filtering menu from the Yolean board was extracted and placed at a similar position in the 4D full screen view.

7.2.6 Material Placement

A problem statement that was discovered early in the requirements gathering phase (see 6.2) was that construction workers encountered logistical problems when placing pallets of material in locations where it would interfere with other disciplines' work. Thus, the Material Placement feature was created to provide a visualization of these pallets during a specific time duration. These were represented by a box in the 3D environment with an Object Blueprint Preview at the user's mouse position to visualize where it may be put. When placed in the 3D model, it received the respective Trade's color to represent what Trade is responsible for that material.

7.2.7 Optional Task Locations

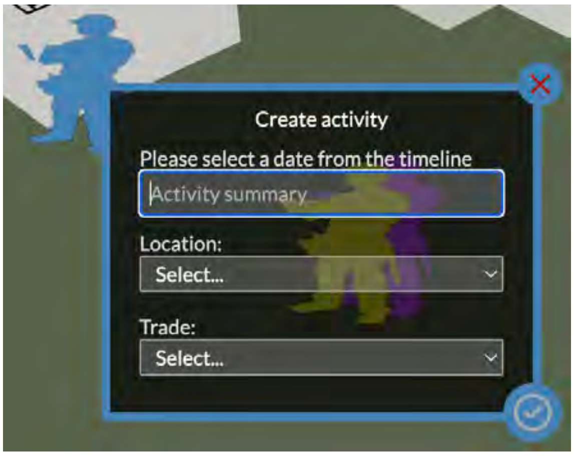


Figure 8: The input window when creating an Optional Task Location

Utilizing the Task placement tool displays a unit under the mouse cursor, similarly to the Material Placement feature. When placing, the user creates an Activity task at the chosen position, which prompts an input form window to appear. The time for the Activity task is chosen by selecting a time span in the timeline, while the rest of the attributes are selected by the user in the input window (see figure 8). On creation, the Activity task is created in the Yolean board, while simultaneously receiving a position in the 3D view. The VDP connected to this is Units, as the Activity tasks created are represented by a 2D sprite of a construction worker placed in the 3D model.

7.2.8 Question Pins

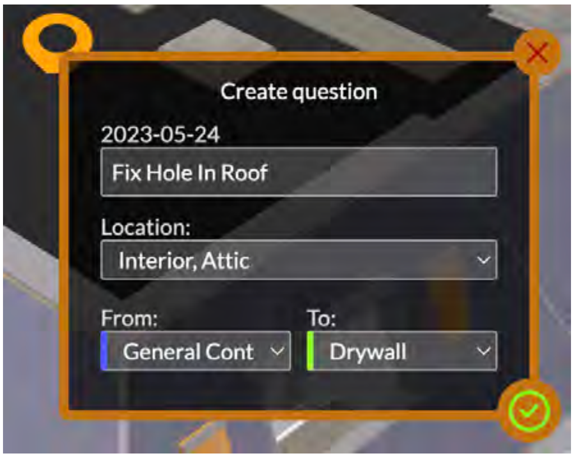


Figure 9: The input window when creating a Question Pin

During the requirements gathering phase (see 6.2), the site manager mentioned a potential problem scenario as "This sprinkler right here is a problem, how do we solve it?". Their proposed solution to this was to create a Question note from that specific position. Thus, the Question Pins feature was implemented. The World Pins VDP was utilized to create this feature.

7.2.9 Window Modes

While the two different window modes did not have any VDPs directly connected to them, they were a commonly recurring feature requested during the interviews of the requirements gathering phase as well as the lo-fi evaluation phase (see 6.2.1 & 6.5). Being able to see a smaller view of the 3D model while in the board provides the user with easy-to-access information without having to switch to an application that takes up the entire screen. However, the smaller form factor did not have enough space for a Timeline or the additional features proposed such as the Material Placement and Wall Modes features. Thus, the combination of a smaller 3D view and a larger 4D view provided the user with a choice between which view to use depending on their current use case.

7.2.10 Project Sync

Developing for an already existing complex application such as Yolean comes with the challenge of synchronizing data. On one hand, there is already an underlying infrastructure where developers can fetch information, such as the Wheres, Trades, Activity tasks and Question notes. On the other hand, the developers need to adapt to features already implemented in the board for the new features to feel coherent and connected to what already exists. The goal was to match features from the board, such as Trades, Wheres and their respective colors, to the 4D features. Therefore, the features extended upon existing feature sets, adding 3D functionality.

7.2.11 Additional Features

Other than the requested features from the requirements gathering phase, some additional VDPs were used to implement features to fill gaps in the user experience, especially relating to navigation and onboarding.

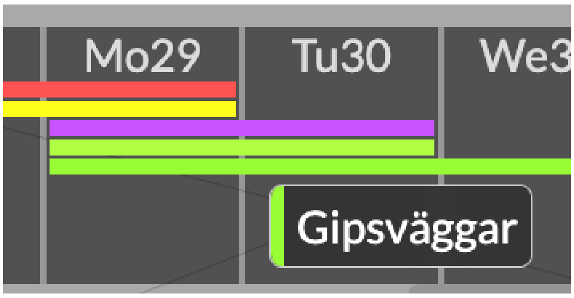


Figure 10: Activity Bar hover tooltip

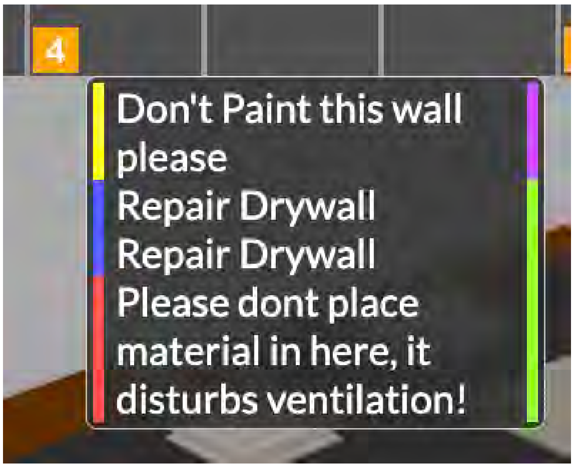


Figure 11: Question note hover tooltip

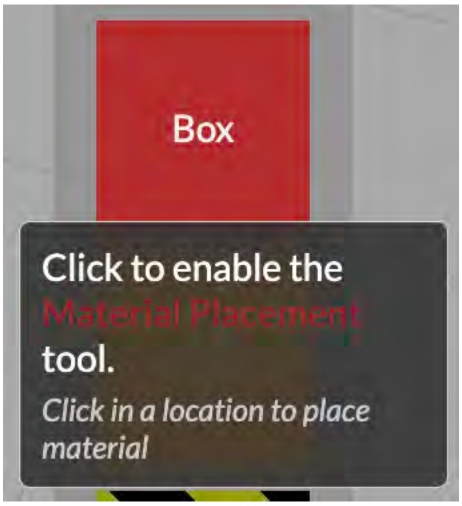


Figure 12: Tooltips in the user interface

Tooltips
First off, hovering Activity bars or Question count notes in the Timeline provides a Tooltip (see figure 12) that displays a piece of information about what is hovered. Activity bars show their Trade color as well as title, Question amount notes show the To and From Trade colors as well as title for each Question note for that date. The other creatable entities also show a Tooltip that describe their function and usage as seen in figure 12.

Contextual Cursor
Another commonly occuring VDP found in every single game analyzed is the Contextual Cursor. In its most primitive form it is used to show which interface elements are clickable, draggable or selectable, which was the case for the interactive elements. However, more creative cursor visualizations could have been utilized to communicate the meaning of the available mouse-pointer actions.

Figure 13: A spinning loading indicator covering the small windowed mode of the final prototype

Loading Indicator
When loading the 3D model in the application, a Loading Indicator was implemented to show that the application is loading the model.

Figure 14: Hovering

Object Information Tooltip
When clicking a Task Unit or Question Pin in the 3D model, a small window appears with essential information related to the object clicked.

7.3 Testing & Evaluation Results

The following images show the results from the questionnaires in the evaluation of the high-fidelity prototype. These results will further be discussed in section 8.2.2. See also the deductive coding results in 23.

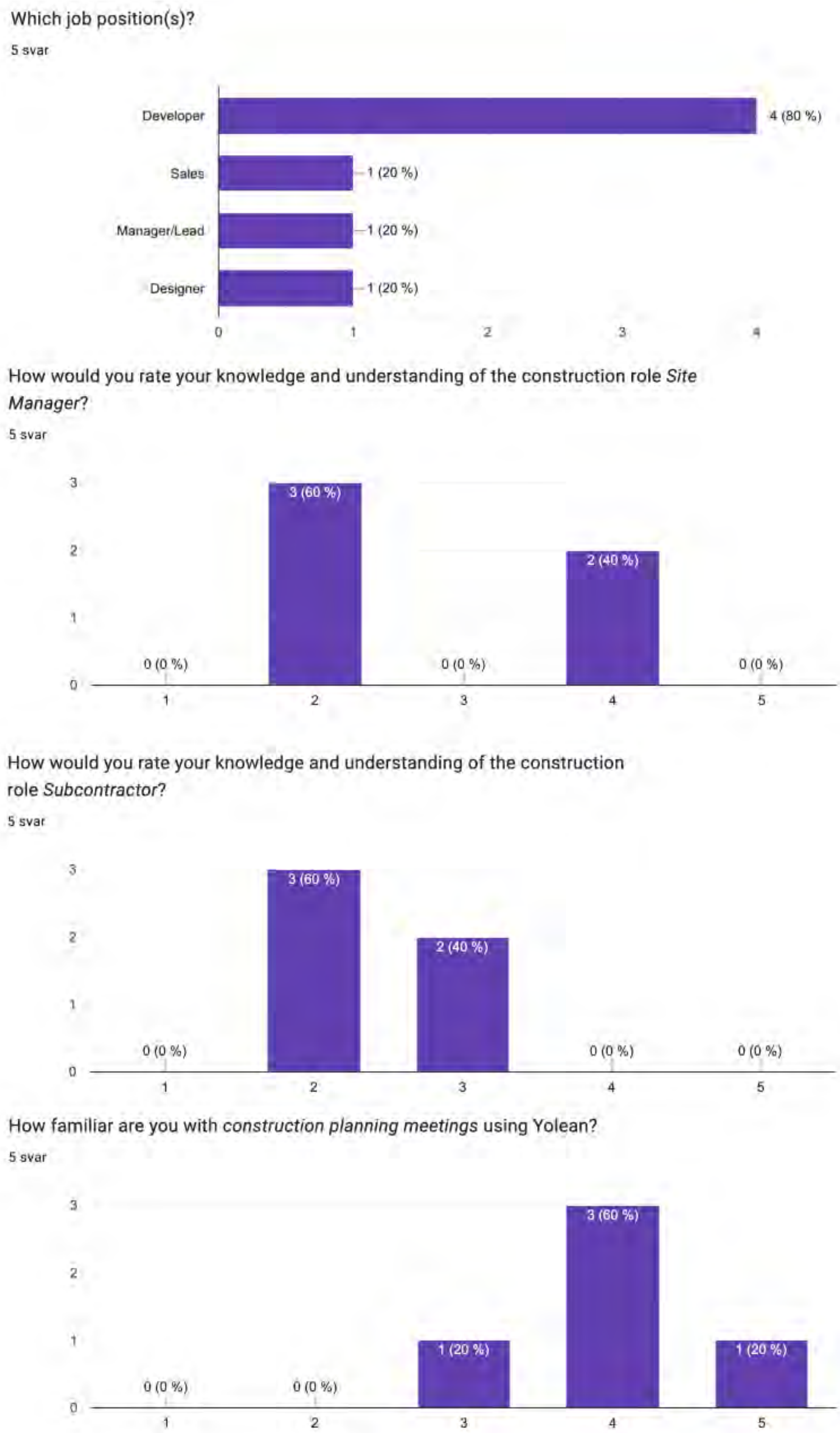


Figure 15: First Questionnaire Results

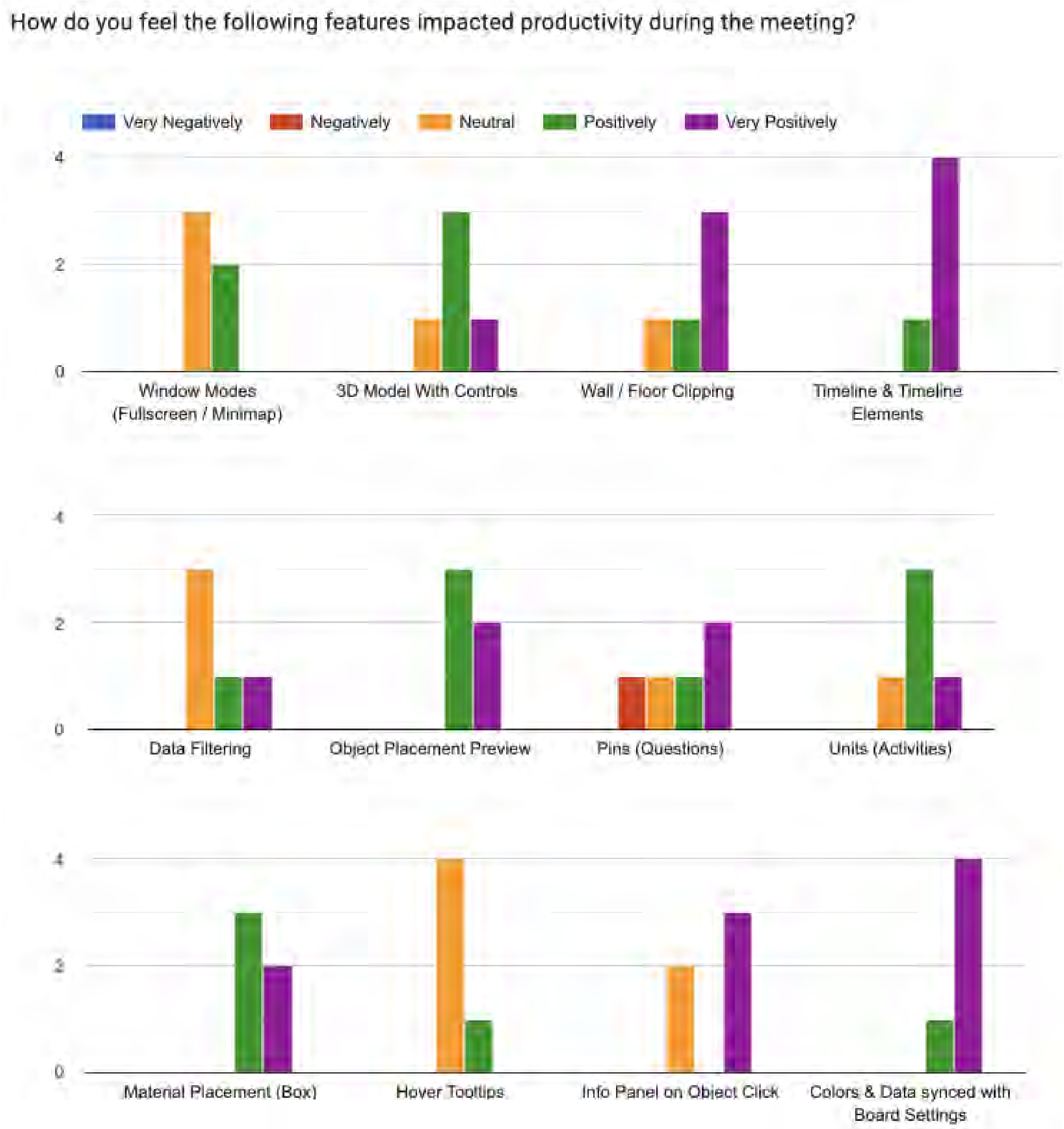


Figure 16: Productivity Results

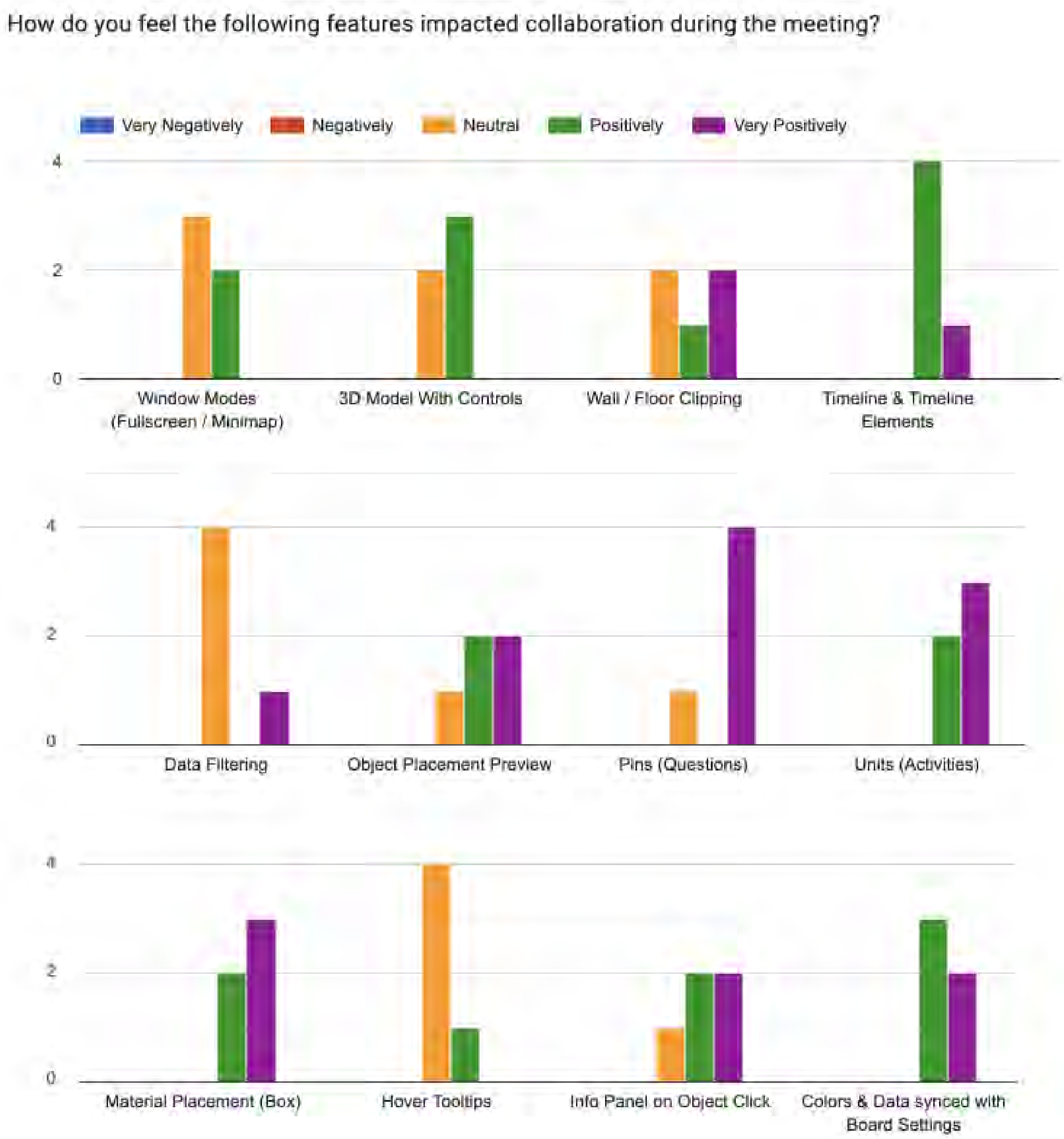


Figure 17: Collaboration Results

Below is a compressed list of exemplar quotes made by participants during the final test:

- It's empty in here [in this room], I will be working alone.
- Good thing there aren't any other units [in here], that means there won't be overlap.
- *Looking at an activity in the timeline* Carry-in of drywall must be in the evening between the 31st and the 1st, good it works!
- How can you see those [activity bars]?

Below is a compressed list of exemplar quotes made by participants during the focus group discussion after the final test:

- *regarding question pins* Now we are talking about a specific place.
- *regarding activity elements in the timeline* ...although the pro's have rock solid awareness [of their tasks], I liked it! Re-planning is not possible, but very useful when planning from scratch.
- I felt the urge to place activities in the board and then navigate to the [3D] view to find questions and issues.
- It felt disruptive to return to the board from the 3D view. What about splitting the view in half?
- How do you divide the building into places?
- In larger rooms we need more information than just the unit to know what they are working on.
- When I am in 3D I miss the time axis, when I am in the board I miss the 3D features.
- The units disappeared and reappeared depending on which date or time span was selected, that was nice!
- Placing tasks in 3D takes longer.
- Risk for mistakes is lower, especially with the material placement feature.
- It was nice to see that we could fit two palettes of materials in the room.

8

Discussion

In this chapter we critically discuss the process described in 6, the results presented in 7, as well as ethical considerations and suggestions for future research.

8.1 Process

This section covers discussion of the process, its potential weaknesses, strengths or improvements.

8.1.1 Test Participants

The sample size of the interviews conducted during the Research Gathering phase (6.2) was relatively small compared to our ideal target. The majority of our interviewees provided second-hand expert perspectives on the construction domain. Considering the limited access to appropriate test participants, we were only able to interview the one site manager, one researcher and employees at Yolean. Given improved contacts and resources, it would have been advantageous to include additional end-users with professional roles that use Yolean in their workflow. This would have allowed us to with greater precision explore the potential benefit regarding the use of our 4D features in their work.

Furthermore, although one interview was conducted with potential end-user and relevant researcher, the participants who took part in the evaluations were, as mentioned, all employees from Yolean. This particular decision could have had both positive and negative impact on the process. The advantages were that this group of test participants could easily be recruited and communicated with, had previous experience and knowledge of the application and domain, and understood the purpose of our project. The disadvantages were that this group might not accurately represent the end-user group, might have predispositions to favorably answering questions due to the preexisting workplace connection, and offered a narrower range of perspectives due to the less diverse pool of participants.

8.1.2 Model and Prototypes

The VDP model we developed to answer RQ2 was solely evaluated and tested by us. Our initial plan was to interview a game designer or game researcher to utilize their insights and opinions on our proposed VDP model to evaluate it. Unfortunately, due to limited time available, these interviews never took place. While we believe that our VDP model has a solid foundation based on the frameworks we researched and utilized (3.2.1), obtaining an expert's perspective would have likely provided valuable insights and further improved our model.

The creation of the lo-fi prototype uncovered unexpected obstacles. The wooden frame initially used was an experimental solution, which could have been successful if we had explored options such as laminated papers or different dimensions. However, we determined that the amount of time required to make it work would outweigh the potential benefits. Considering our experience with using Figma and inexperience in developing physical prototypes, we decided that investing our time producing a Figma prototype would lead to preferred outcomes. The Figma prototype was indeed valuable during the development of the hi-fi prototype, since it provided us with pre-developed components with pixel dimensions, specific colors, and CSS properties. Although the outcomes of that decision was uncertain at the time, we believe that the choice did not restrict our ability to design and evaluate.

8.2 Results

Below we examine the results produced, their quality and potential explanations.

8.2.1 Visual Design Pattern Library

The produced VDP library contains a wide variety of pattern types which were utilized in the production of the software prototype. First it is important to discuss the libraries benefit to developers and users, thus providing answers to RQ3, Which VDPs are useful when designing features for a visual construction planning application? Furthermore, discussing how existing features of an application might be improved utilizing VDPs from the library.

The VDPs gave value to the developers/designers of the interface by giving concrete blueprints to create features from. Each of the VDP attributes were experienced to have the following impact on development:

Example Image
The images gave a sample reference for the graphical characteristics of the feature, which reduced time spent on design.

UI Category
The UI category helped pinpoint which technical solution was required for its implementation. For example, the Spatial or Diegetic category implied that the feature had to be implemented using the 3D library, while Meta or Non-Diegetic suggested standard 2D website elements could be used.

Purpose Tags
The purpose tags reminded us of the intentional use case which aided in specifying functionality. For instance, the purposes Status and Filtering signal the ability to

switch between or configure certain state variables, while Controls and Locating express the need for handling keyboard and mouse input, and managing camera positioning.

Visual Complexity
By analyzing the visual complexity we could predict how much effort the related feature could require. This helped to effectively plan and prioritize throughout the development process.

Temporal Usage
Temporal usage helped us foresee which data was necessary and when it needed to fetched. For example, continuous temporal usage likely requires continuous data communication while intermittent can be more sporadic or on-demand.

It is however difficult to assess what specific value the library of VDPs provides for users, as they are mostly unaware of the underlying design patterns of the features they interact with. It would presumably be challenging to evaluate the value of design patterns directly as they are possibly too abstract or general in their description for a user without deeper knowledge of design patterns to draw conclusions from. Instead, the value of the implemented feature materialization of a VDP can be evaluated. However, the feature in such a case acts as a proxy for the VDP, therefore no definite conclusion can be drawn, only a positive or negative correlation can be determined.

8.2.2 Feature Evaluation

This section aims to discuss RQ4: Which VDPs can contribute to increased productivity and improved collaboration in construction projects? This is done through examining the produced results from the final user test as described in section 7.3. It is also important to acknowledge that the sample size is relatively small, meaning the precision and reliability of any statistical conclusions drawn about perceived productivity and collaboration is poor.

By explicitly defining the two concepts productivity and collaboration (see figure 3), the participants who completed the questionnaires had the opportunity to evaluate the identified patterns and experiences using the definitions stated in the form. The results of the questionnaires pointed toward a largely positive impact on both productivity and collaboration, as seen in figures 16 & 17 and in the compiled results of the deductive coding procedure as seen in 23.

According to some participants, they experienced unnecessary excise when viewing a specific floor and having to manually select that floor as a Location or Where (row) when creating a task at that location. By linking task and pin positions to specific rows, this problem would be solved by automatically assigning the Where (row) in the input form to the selected location in the 3D model. Furthermore, one participant during the focus group discussion asked: How do you divide the building into places?, pointing toward the process of how the locations were to be assigned to rows in the board. This remains as a problem we still have not found a solution to, since the time required to manually assign locations to rows is not considered to be worth the value provided according to the participants of the final test, as well as the previously interviewed Site Manager (see section 6.2.1).

A particular point of interest are the features which were deemed to have non-positive impact on productivity or collaboration. These were Hover Tooltips and Data Filtering. Hover Tooltips was labeled Highly Non-Positive for both categories (23, presumably due to the feature having no direct association to the workflow and merely providing hints for usage of the other core features. Furthermore, a feature rated as questionable, Question Pins, had the only explicitly negative data point of any feature (see figure 16), but was on the other hand rated to have a positive impact on collaboration (see figure 17).Impact on productivity might be motivated through the perceived increased time it took to place questions in 3D in comparison to the preexisting board, which in turn lowered its ability to increase productivity, and this was explicitly stated by one participant. However, because of the 3D element assisting in communication and cooperative problem solving, the feature was seen to have a positive impact on collaboration.

Due to time limitations, we focused on a singular specific use case for the final evaluation of the 4D features. Other potential scenarios, such as the site manager using the features in a non-meeting context, creating tasks without the presence of other workers, or analyzing the project overview in the application, could have been explored given more time.

Furthermore, the participants role-playing as workers and site manager had no first hand experience in the field. They at most had observed others in real planning meetings, and tried to mimic their behavior as per the instructions of the role-play. Further evaluation tests are therefore desired, preferably with workers and site managers in the field, to reinforce the results of this one test.

8.2.3 Future VDP Implementations

The final prototype had several feature implementations of the discovered VDPs. This section aims to discuss potential future VDP implementations as well as the extensibility (see 4.1.2) of the final prototype.

Currently, the Activity tasks are sprites rendered in 2D, which are positioned toward the camera regardless of rotation or position. It would be interesting to examine the effect of 3D objects instead, as they currently give the impression of being non-diegetic stickers placed throughout the 3D model rather than diegetic entities.

The Material Placement feature has room for future improvements through VDPs such as Contextual Representations and Error Models. The first of which would include hiding everything not related to the placement of the pallet, such as all of the 2D elements present in the 3D environment that the pallet does not risk intersecting with. Error Models would be implemented through changing the color of the 3D element to red if it intersected with walls or other materials previously placed in the model. This together with a configurable size for the Material Placement box would enable workers to set custom sized pallets and evaluate if they would fit in a certain room or through a door way before they arrived at the site. One additional idea was to create an Activity task in the board or connect the pallet placed to an already existing Activity task. Thus it could share the same time attributes as the connected Activity task. Optional Task Locations would benefit from Contextual Representations, if the zoning feature would have been implemented. If a custom zone was set to a specific room, and an Activity task were to be placed in that zone, the color of the whole zone would change to the Trade color to indicate which trade occupied the space during that time. This is a feature that the interviewed site manager (see section 6.2.1) already keeps track of by hand on paper printed floor plans. Another feature mentioned during the evaluation was the possibility to see where the workers were going to go next, such as in the Rally Point VDP.

During the final evaluation, the two windowed modes were seen as useful, but not optimal. During the Focus Group (see 4.2.8) session, all of the participants agreed that in the 3D view, they wished for the ability to use the board, while in the board, they wished for the ability to use the 3D view. Thus, a split-screen mode was proposed for the next iteration of the 4D application, where the board would act as the Timeline, and the dedicated Timeline in the 4D application would be omitted.

While developing in the 3D environment, the walls of the 3D model incidentally had the same color as the background of the environment. Furthermore, advanced shadowing or graphical shaders were not utilized which, given certain angles, made the walls blend in with the background, reducing visual clarity. This resulted in an illusion of invisible walls, which was partly solved by changing the background color of the 3D environment. This problem did raise the question of using more complex rendering functionality, to get a more realistic and immersive view of the building, albeit with the potential cost of performance issues. Adding this would also increase the depth perception when placing Activity tasks, Material pallets or Question pins in the 3D model, which would help significantly in correct placement of the entities.

8.3 Ethics

This section covers potential concerns regarding user research, design and development. It also discusses examples where design decisions have had unexpected consequences, and how they can be minimized in this project.

8.3.1 User Research & Interviews

Research collection can be a very sensitive topic relating to ethics. When doing user research or interviews, there are several guidelines one can follow to be as ethically mature as possible. An example of such guidelines presents six main elements to be considered [51]:

1. A code of conduct
2. Research ethics training for all people who carry out user research
3. Guidance documents
4. Standardized consent forms and information sheets

5. Ethics experts
6. Data policies for user research

These become especially important to consider when doing research for a company, as they may not have the same ethical guidelines as one has previously used when conducting research. They need to be carefully discussed to ensure both the company and the researchers agree on what policies and standards to apply. A standardized consent form (see A) was used for all of the conducted interviews, to make sure we had their consent in using their information as well as to ensure proper handling of data they did not want to share. Names and faces have been blurred or cut out in images, as well as their names and companies not being mentioned in the report. The one exception to this rule being Yolean, from which we got explicit permission to use their company name.

8.3.2 Application Design & Development

While designing applications for a specific work group, there are several possible ethical issues that may arise [52]. One such issue is the consideration that the designers are developing the program with use cases they may not be as familiar with as the targeted user group. Furthermore, choosing specific design patterns defines the way the application is to be used. Thus, the designers are implicitly stating which work methods are better than others when implementing a set of design patterns. Even with significant user testing, interviews and research prior to applying chosen design patterns, the designers in question may not always provide the best of solutions to the users. As a designer, one has to be especially careful when designing an unexplored area of work. It may also become a subject for debate whether or not a specific work style, such as the one proposed by the designers, is an appropriate approach to solving the issues presented by the user group.

There are specific examples where designers have created a problem from trying to solve another. In a specific example from a study [52], designers observed a singular event of a person deleting a colleague's work in a collaborative space. This was without said colleague's consent and was noted as a problem in the design research process. This one event motivated a major design decision which partly solved the social problem of performing an action without consent, however in turn created a technical problem in the interface that in some cases caused both frustration and a worsened workflow. This is a prime example of designers creating technical solutions to social problems based on moral issues. To prevent long term negative side effects in interfaces created with such solutions, careful and extensive observation needs to be applied to make sure the solution works as expected.

In projects such as this, similar problems may present themselves when designing how the users are expected to be using the application. It has to be made clear which activities the interface is supposed to enforce, which purposes they serve and what benefits they are to provide the users. As such, the user base needs to be explicitly stated e.g. through the creation of personas. Through personas, one can define where the main concerns are relating to the work process and how to relate each one, if they are based on a real group of users of a varied number of backgrounds, ages, socioeconomic stats etc. Thus, the designers can properly evaluate how their solutions cater to the users, which problems they solve and what trade-offs may have to be made. Furthermore, if any trade-offs have been identified, they in turn should be evaluated and tested to make sure no unexpected consequences appear. Potential negative consequences that remain undiscovered could severely impair the workflow, which in turn compromises the usability of the design.

8.3.3 Future Work

We suggest the following list of points for future research on the topic of Visual Design Patterns in Construction Planning Applications:

- Evaluate VDPs with a single focus parameter at a time, such as specifically Productivity or specifically Collaboration
- Conduct A/B Tests with and without VDP-based features
- Find a method for evaluating the model proposed in this thesis (3.3.1)
- Analyse more games to discover additional VDPs
- Attempt to recruit and evaluate with a greater amount of end-users

9

Conclusion

This thesis has examined how and to which extent strategy and city-building games can be used for creating a design pattern library, from which Visual Design Patterns can be extracted and utilized as a basis to design and develop a features for a software application within the construction planning domain, Yolean.

The research questions to be answered were:

1. Which Visual Design Patterns can be identified in popular strategy and city-building games?
2. How might these VDPs be modelled and categorized?
3. Which VDPs are useful when designing features for a visual construction planning application?
4. Which VDPs can contribute to increased productivity and improved collaboration in construction projects?

These questions were answered through a research-through-design approach incorporating existing design methods and frameworks, analysis of digital games related to the domain, requirements gathering through interviewing people in the field, as well as feature analysis and creation of a software prototype. This software prototype was ultimately tested in a scenario intended to accurately replicate a construction planning meeting.

The study resulted in creation of a VDP library of 30 patterns (as seen in figures 6, 7, 8 and 9 in the Appendix), as well as a model for categorizing VDPs (see Legend Card 1 and Legend Card 2 in figure 6). The feature requirements acquired throughout the project were used to find VDPs in the produced library that matched the feature's temporal usage, UI category and purpose. This resulted in 17 matching VDPs, which were all deemed to have a possible use case in the final application. These VDPs were used to implement features for the final software application, which were then tested through the aforementioned scenario. The test showed that the implemented features and their respective VDPs tended toward having a positive impact on both productivity and collaboration throughout the simulated planning meeting.

While this test showed positive results, it only tested one out of many possible use cases. It was also only tested with participants in the domain role-playing as subcontractors and site manager. Thus, more work needs to be done to verify or refute the results of this thesis. This could be done both through testing with real site managers and subcontractors in the field, as well as with more use cases other than a planning meeting.

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A

Appendix

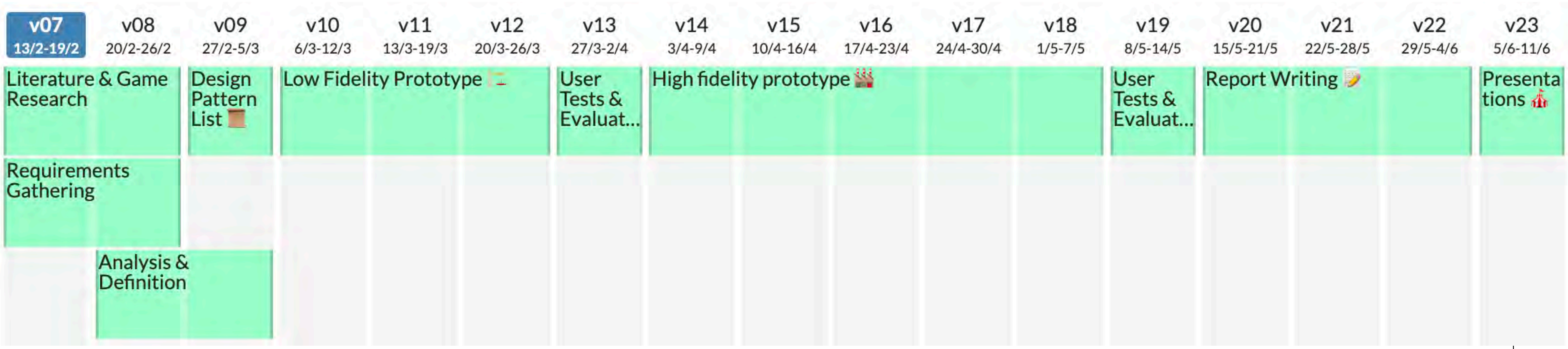


Figure 1: Plan In Yolean

CHALMERS
UNIVERSITY OF TECHNOLOGY

Interview Consent form

Student Researchers: Carl Lindh and Oscar Orava Kilberg

Purpose:

This user study is intended to learn from your experiences with construction projects and applications related to said topic as part of our master's thesis in Interaction Design. The study consists of one or a set of interviews spread out during the master's thesis. We will use the gathered information to evaluate and examine how a 4D application can be built to satisfy the needs of a selected user group. We intend to record the audio of the interview. The results of eventual questionnaires and interviews will be analyzed and published in the thesis. All data will be treated anonymously, we will not reveal your name in the thesis or any other public documents. There will, however, be a description of the participant's experience within the area to provide a better understanding of from which perspective the interviewer answers the questions.

Declaration of Consent:

By signing this document, I am indicating my consent to the researchers to use the collected data, as stated above.

I have a clear understanding that my participation in this research is voluntary.

I have the right to refuse to participate or withdraw from the research at any point in time.

I have the right to retract my data before the 4th of June 2023.

I understand that all the data collected from my participation will be anonymized.

Participant's Signature Researchers Signatures Date: _____/________/_______

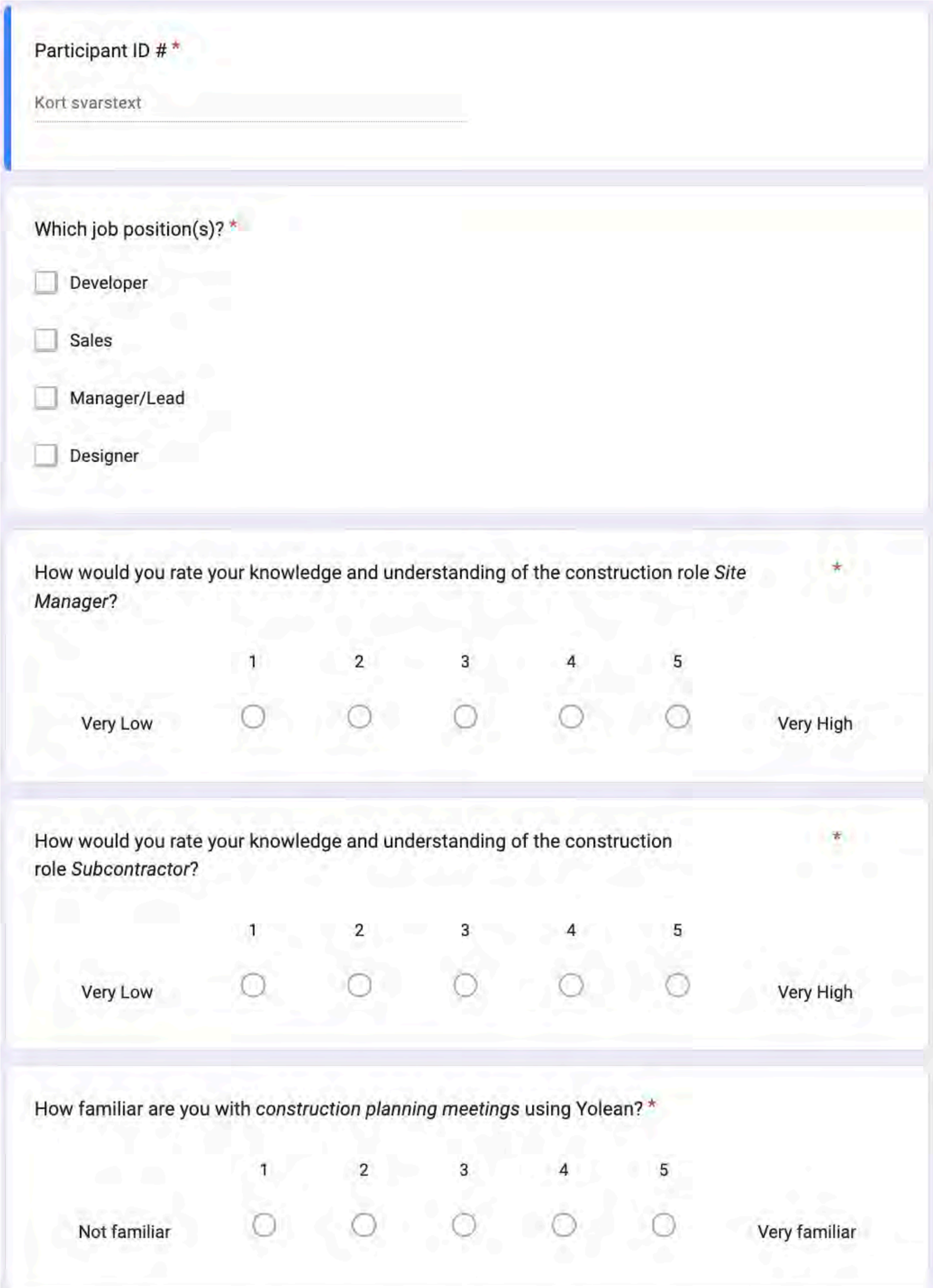
Name:

____

Signature:

____

In case of enquiry, do not hesitate to contact Carl Lindh (lindhca@chalmers.se) or Oscar Orava Kilberg (oscarki@chalmers.se)


Participant ID # *

Kort svarstext

Which job position(s)? *

- [ ] Developer
- [ ] Sales
- [ ] Manager/Lead
- [ ] Designer

How would you rate your knowledge and understanding of the construction role *Site Manager*? *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

How would you rate your knowledge and understanding of the construction role *Subcontractor*? *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

How familiar are you with *construction planning meetings* using Yolean? *

	1	2	3	4	5	
Not familiar	○	○	○	○	○	Very familiar

Figure 2: The Initial Questionnaire

A.0.1 Visualization Design Patterns

Participant ID # *

Kort svarstext

Definition of Productivity:

Output *(Quality and Quantity of work) per unit of* ***Input*** *(Time and Effort invested)*

How do you feel the following features impacted productivity during the meeting? *

	Very Negatively	Negatively	Neutral	Positively	Very Positively
Window Mode...					
3D Model With ...					
Wall / Floor Cli...					
Timeline & Tim...					
Data Filtering					
Object Placem...					
Pins (Questions)					
Units (Activities)					
Material Place...					
Hover Tooltips					
Info Panel on O...					
Colors & Data s...					

Definition of Collaboration:

Ability to ***achieve mutual goals*** *through* ***clear communication*** *and* ***cooperative problem solving***.

How do you feel the following features impacted collaboration during the meeting? *

	Very Negatively	Negatively	Neutral	Positively	Very Positively
Window Mode...					
3D Model With ...					
Wall / Floor Cli...					

HVAC (RÖD)

Pre-Meeting Question To Drywall

- Can you avoid placing drywall palettes in the Lounge, it disturbs ventilation.

Task	Durations (Days)	Location (Floor, Room)	Required Material	Prerequisite Task
Install Ventilation	1	Floor 0, Entrance	Pallet Ventilation Pipes	
Install Ventilation	2	Floor 1, Kitchen		
Install Ventilation	2	Floor 2, Office	Pallet Ventilation Pipes	

Painter (LILA)

During Meeting Question To General Contractor

- Can we place a scissor lift in the kitchen?

Other Information

- Repainting a wall takes 1 day.

Task	Durations (Days)	Location (Floor, Room)	Required Material	Prerequisite Task
Paint Walls	2	Floor 0, Lounge		Install Drywall
Paint Walls	1	Floor 2, Cafeteria		

Drywalls (GRÖN)

Other Information

- Repairing a drywall takes 1 day.

Task	Durations (Days)	Location (Floor, Room)	Required Material	Prerequisite Task
Install Drywalls	2	Floor 0, Lounge	Pallet Drywalls	Install Lights
Install Drywalls	2	Floor 2, Office	Pallet Drywalls	

Figure 4: Roles Sheet 1

General Contractor (BLÅ)

Pre-Meeting Question to Drywall (& Painter)

- Two walls in the Living Quarters needs to be repaired then repainted.

Safety Regulations To Follow

- Materials can not block any windows or doors.
- No material is allowed in the Kitchen.
- Materials must not be placed further than 1 room away.
- Two trades can not work on the same wall on the same day.

Other Information

- To answer questions about specific measurements you must contact the architect. (=> question while waiting for their response)
- To answer questions about the kitchen you must contact someone higher up in your organisation (=> question while waiting for their response)

Electrician (GUL)

Pre-Meeting Question to Painter

- A wall in the balcony room should not be painted yet, electricians are adding spotlights to it.

Safety Regulations To Follow

- No materials other than your own are allowed in the room you are currently working in.

During Meeting Question To General Contractor

- How wide is the hallway outside the Living Quarters?

Task	Durations (Days)	Location (Floor, Room)	Required Material	Prerequisite Task
Install Lights	2	Floor 0, Lounge		
Install Kitchen Appliances	1	Floor 1, Kitchen	Pallet Appliances	

Figure 5: Roles Sheet 2

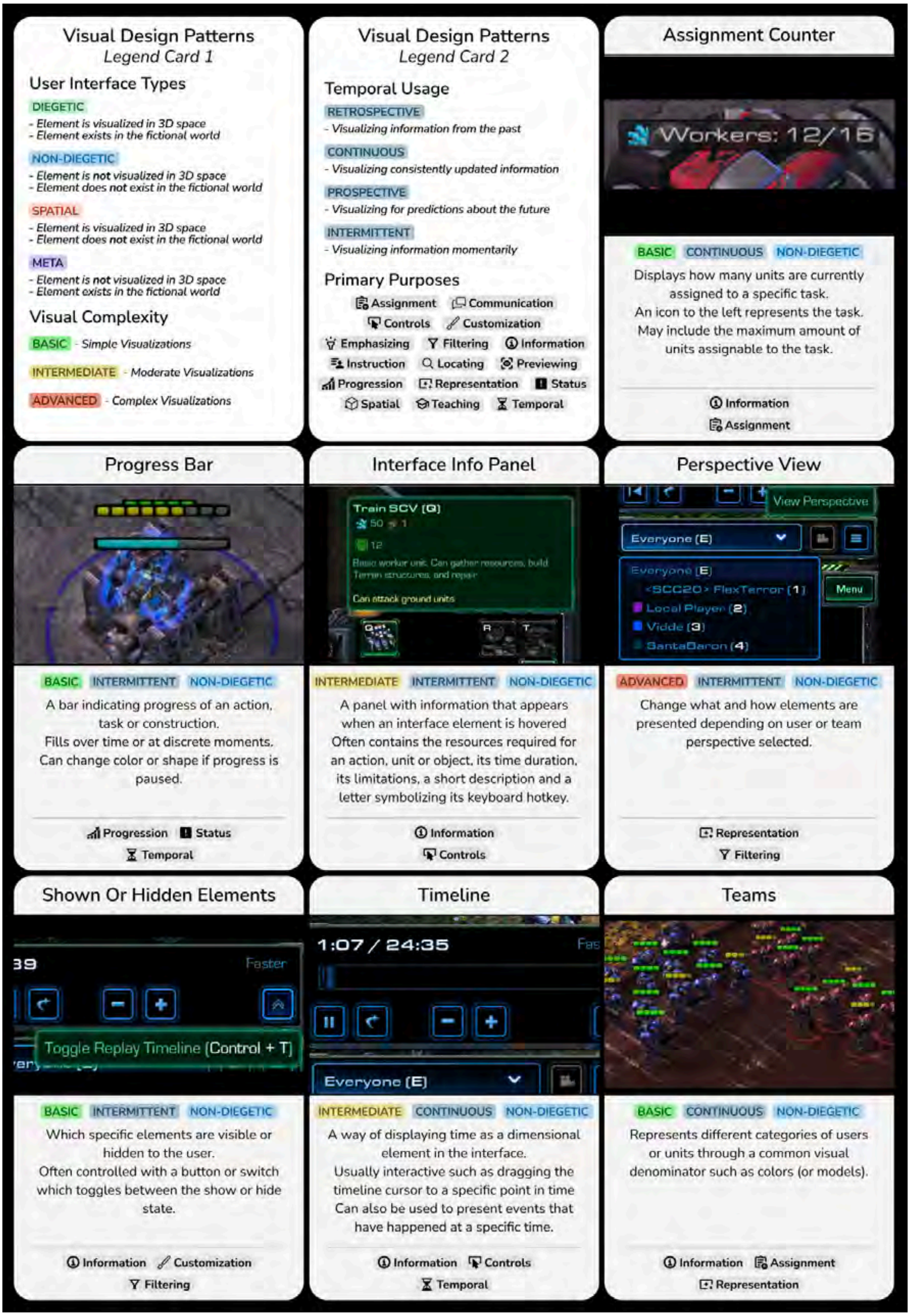


Figure 6: VDPs 1

Figure 7: VDPs 2

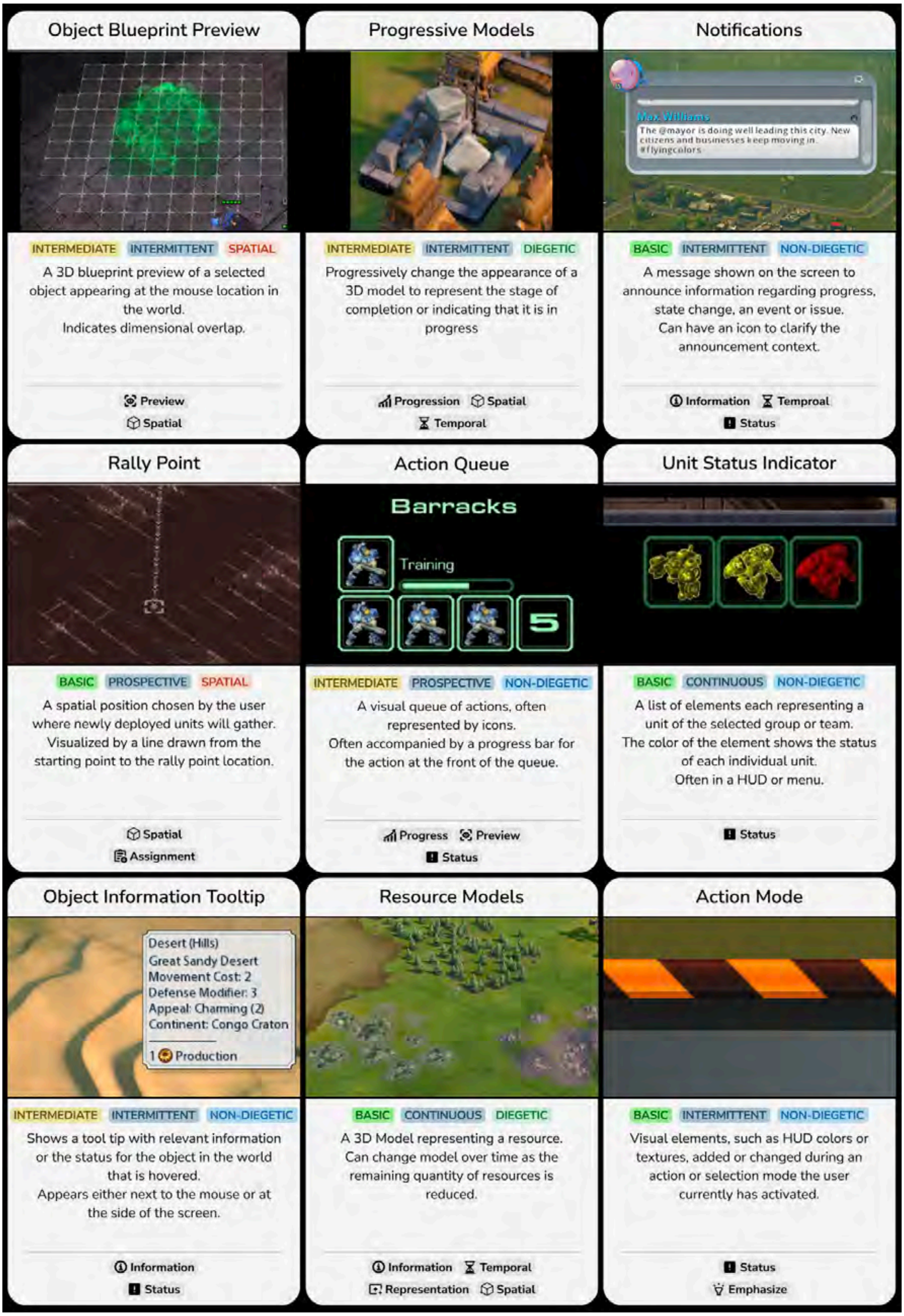


Figure 8: VDPs 3

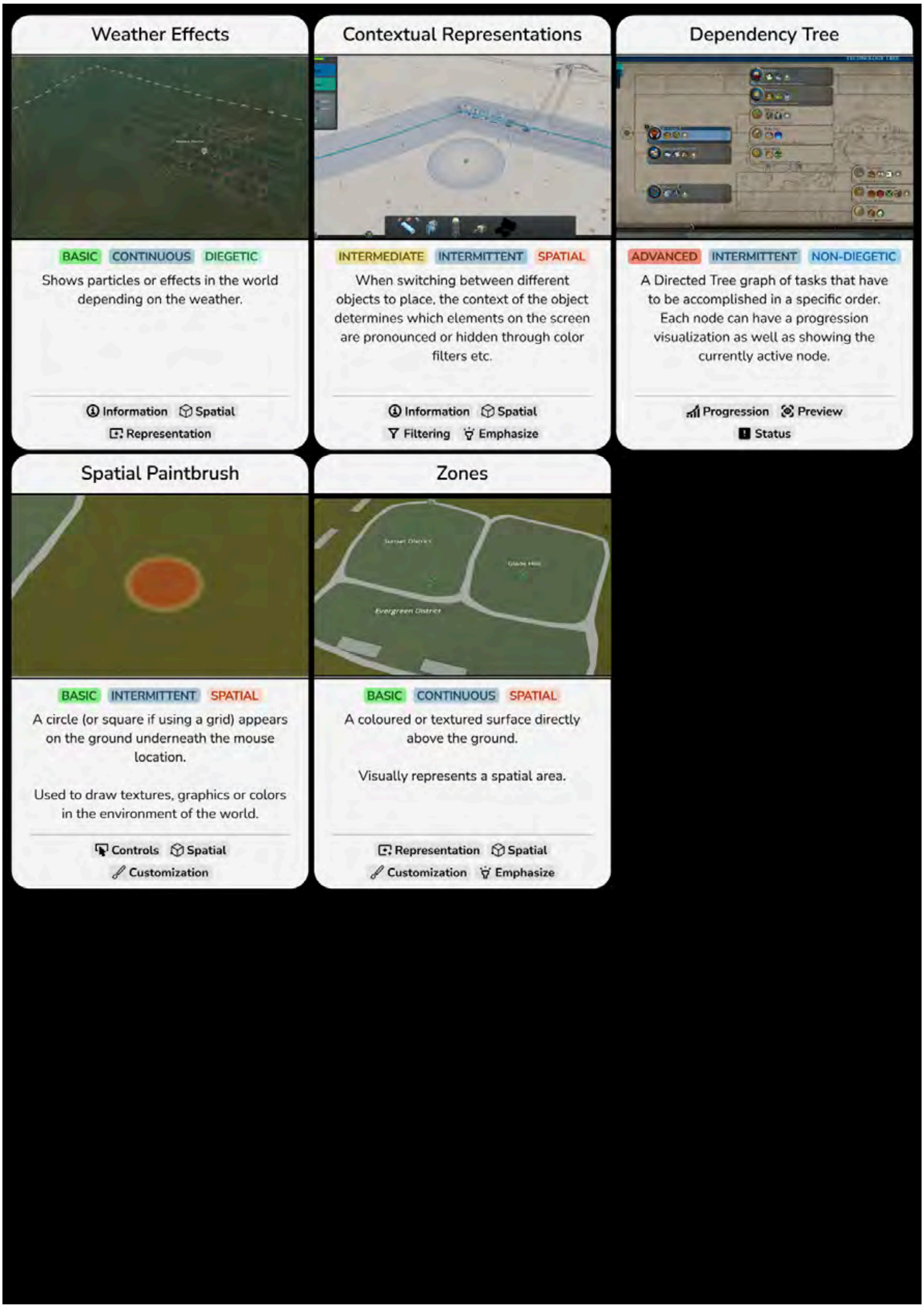


Figure 9: VDPs 4