CHALMERS UNIVERSITY OF TECHNOLOGY | UNIVERSITY OF GOTHENBURG

Facterra

Raising Awareness of Environmental Impact and the Circular Economy Through Games

Bachelor's Thesis in Computer Science and Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

A massive amount of waste is generated globally, and the circular economy offers a promising approach to reduce it by reusing resources and minimizing environmental impact. Raising public awareness is a key step toward supporting this transition. One potential method for raising awareness is through video games. This project aimed to design and develop Facterra, a 2D factory simulation game that is both fun and educational, with a focus on environmental impact and the circular economy. To evaluate whether the game achieved its goals, playtesting was conducted where players experienced the game and answered a combination of surveys and interview questions. The results indicated that Facterra successfully engaged players and conveyed its intended message, further showing that games indeed can be used to raise awareness. However, feedback also highlighted areas for improvement, particularly in terms of polish, depth, and clarity of educational elements.

Sammandrag

En enorm mängd avfall uppstår globalt, och den cirkulära ekonomin erbjuder ett lovande sätt att minska detta genom att återanvända resurser och minimera miljöpåverkan. Att öka allmänhetens kunskap och förståelse är ett viktigt steg för att stödja denna omställning. Ett möjligt sätt att sprida sådan förståelse är genom datorspel. Det här projektet syftade till att designa och utveckla Facterra, ett 2D-fabrikssimuleringsspel som både är roligt och lärorikt, med fokus på miljöpåverkan och cirkulär ekonomi. För att utvärdera om spelet uppfyllde sina mål genomfördes speltester där deltagare fick spela spelet och svara på en kombination av enkäter och intervjufrågor. Resultaten indikerade att Facterra lyckades engagera spelare och förmedla sitt budskap, som vidare visar att spel faktiskt kan användas för att sprida kunskap. Däremot lyfte feedbacken också fram förbättringsområden, särskilt när det gäller finish, djup och tydlighet i de pedagogiska inslagen.

Keywords:
Serious Games, Game-Based Learning, Production Chains Simulation, Environmental Awareness, Circular Economy

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Introduction

This chapter discusses the goals of the project, how a game was to be developed to raise awareness of the circular economy and the environmental impact of manufacturing. It then goes on to detail limitations that were set to constrain the scope of the project. Lastly, a small discussion is brought up on some of the societal considerations that is touched on by the project.

1.1 Background

This section goes over the background for this bachelors project; how waste is currently dealt with, what the circular economy entails, how awareness of the circular economy is not high among the general population and how a game can increase awareness of a subject.

1.1.1 Approaches to Dealing with Waste

According to Eurostat, the statistical office of the European Commission [1], out of the total 2 233 million tonnes of waste produced in the European Union during 2022, manufacturing was responsible for 230 million tonnes [2]. Additionally, approximately 21 percent of all waste produced within the European Union, excluding major mineral wastes, went to landfills [3].

Something that has previously been adopted by the European Commission [4] and more recently within the Swedish government [5] is a readjustment towards what is known as a circular economy. In practice a circular economy means a reduction of waste generation.

In a circular economy, when a product reaches the end of its lifespan, it or its materials are returned to the economy through a combination of repairs, reuse of materials, and recycling of parts [6].

Eurostat divides treatment of waste into two main categories; recovery and disposal. Recovery is further divided into energy recovery, backfilling, and recycling [7]. Energy recovery refers to practices wherein waste is transformed into energy through some process, an example being incineration [8].

Backfilling is explained by Eurostat as follows:

"...the use of waste in excavated areas for the purpose of slope reclamation or safety or for engineering purposes in landscaping... "[9]

Recycling is a resource recovery method wherein a product or part of a product is reused either as is or as raw material in the creation of the same or a similar product [8] and of the three waste recovery categories it is the one the circular economy concerns itself with.

The European Commission adopted its first circular economy action plan in 2015 [4]. In 2014, 750 million tonnes of waste was recycled, 216 million tonnes were used for backfilling, and 108 million tonnes were used in energy recovery [7] in the European Union. During the same year total waste generated in the European Union was 2 243 million tonnes of waste [2]. This meant that approximately 33.4% of all waste generated was recycled, 9.5% was used for backfilling, and 4.8% was used in energy recovery. By dividing the amount of waste recycled [7] by the amount of waste generated [9] one can see that the percentage of waste recycled has increased at every measurement done since the circular economy package was adopted, reaching its highest point yet of 36.5% in 2022. Meanwhile the percentage of waste going towards backfilling and energy recovery has fluctuated but has generally increased.

Year	Waste produced (tonnes)	Waste recycled (tonnes)	Proportion recycled
2014	2 243 830 000	749 610 000	33.4%
2016	2 258 950 000	768 900 000	34.0%
2018	2 338 310 000	826 200 000	35.3%
2020	2 153 170 000	761 720 000	35.4%
2022	2 233 120 000	816 130 000	36.5%

Table 1.1: Table of total waste produced by tonnes in the European Union [2], waste recycled by tonnes in the European Union [7], and proportion of total waste that was recycled.

While the circular economy model is said to be able to reduce [6] waste production, studies also show that knowledge of the term as well as its factors may differ greatly between professions and nationalities. Among people working within the manufacturing sector, approximately 70% of respondents had heard the term before while 63% claimed they were familiar with the term rather than just having heard of it [10]. Notably, awareness was much greater in Asian countries, especially China where the awareness instead was closer to 90% [10]. A different study conducted on Brazilians over 18 years of age, not restricted by profession, concluded that 34% of respondents showed some level of ignorance regarding the term [11]. Furthermore, it has been shown that stakeholder pressure has a direct impact on green product innovation as well as on green process innovation [12], of which the circular economy model is the latter. An example of this happening is the Oxfam *Behind the Brands* campaign launched in 2013 which attempted to get 10 large food companies in the UK to take action concerning a list of issues, among those being the climate. The campaign did this by assessing the companies and assigning them a score card containing their performance for each issue and then making this public, thus increasing consumer awareness [13]. A progress report released in 2016 containing updated score cards showed increased scores for every company concerning the climate issue [14].

A second example of customer pressure leading to industry action was observed in 2019. Years of cattle farming in Brazil had lead to deforestation of the amazon rainforest [15] which in turn contributed [16] to an increase in forest fires. The public outcry that resulted from this lead H&M, a prominent fast fashion brand, to stop their purchases of Brazilian leather [17], [18], [19] showcasing how brands are careful to not go against public opinion. Therefore, raising awareness of the circular economy is likely to have a positive impact in reducing waste.

1.1.2 Our Part in the Solution

One way of raising awareness is through games. An early example of such a game is *Floodsim* which aimed to raise awareness of flooding policy within the UK. In a study compiling people's opinions of the game a large proportion of players commented that they felt the game was good at raising awareness of flooding policy [20]. Slightly more recently, there is the game *Eco*. This game won the grand prize at the Climate Game Challenge in New York City 2016 during the Games for Change festival [21] for its role in making students environmentally literate, a claim that was backed by increased scores pertaining to environmental strategy among students who had played the game.

On the current gaming market there are multiple games that are commonly referred to as "factory games". These games differ in a multitude of ways but they all share a common factor, this being that manufacturing is either a goal of the game or a large part of it. These games have seen a surge in popularity in recent years. For the purpose of games sold on Steam a game should have the following tags to be considered a factory game; 'Automation', 'Base building', and 'Resource management'. This classification resulted in a list of 228 games [22]. Of the 228 factory games 107 were released during 2024, almost double the games released the year prior [22]. Additionally, player numbers for at least two of the most popular factory games in the genre, *Factorio* [23] and *Satisfactory* [24] saw rapid growth towards the later half of 2024, possibly caused by the full release of *Satisfactory* on September 10th [25], [26] and the release of the *Space Age* expansion for *Factorio* [27], [28] on October 21st. This all points to 2024 being a good year for the factory game genre.

1.2 Purpose

The goal of this project was to create a factory simulation game that is both engaging and educational, with a focus on environmental impact, circular economy, and industrial symbiosis. In the context of the game, the *circular economy* refers to designing systems where resources are reused and waste is minimized, rather than following a traditional linear model of production and disposal. *Industrial symbiosis*, a part of this model, means that the byproducts of one process can become the input for another [29], encouraging players to think strategically about how to connect different production systems.

A core design principle of the game was ***"show, don't tell"***. The player should naturally realize the importance of managing the byproducts through gameplay, rather than being explicitly told [30]. The player should be penalized for being too greedy by choosing the environmentally worse decision or just not caring about the waste. Choices driven primarily by greed, such as prioritizing profit over sustainability or neglecting waste management, will lead to consequences, reinforcing the environmental message through in-game penalties.

1.3 Problem and Assignment

In this section, the broader challenges that motivated the creation of this project will be examined. By identifying key societal and industrial problems, the project could be structured around specific areas of focus, helping to guide the design of a game that raises awareness about the environmental impact of industrial activities.

1.3.1 Lack of Awareness About Industrial Impact on the Environment

Sustainability and environmental responsibility are pressing global issues, yet many people have an oversimplified understanding of how industries affect the environment. Public discussions often focus on reducing carbon emissions, switching to renewable energy, and implementing stricter environmental regulations [31], [32]. However, the environmental impact of industries extends far beyond CO_2 emissions, encompassing resource depletion, waste mismanagement, and inefficient production processes.

One of the key challenges is that industrial processes are largely invisible to the public. Many people do not fully understand the complexity of creating a circular economy [33]. A significant proportion of industries still follow a linear model of production, in which they extract raw materials, manufacture products, and dispose of waste, without prioritizing resource efficiency or industrial symbiosis [34]. An increased awareness among consumers would speed up progress toward sustainable practices [12].

Another issue is the misconception that solving climate change is easy [35]. This leads to ineffective discussions and policies, as people may not recognize the systemic nature of industrial waste and its impact on ecosystems and human health. Addressing this knowledge gap is essential for promoting more effective sustainability strategies.

1.3.2 Addressing the Problem Through a Video Game

To help bridge this awareness gap, a factory game was planned to be developed that highlights the complexities of industrial impact and the benefits of a circular economy. Video games are an effective medium for education because they engage players through active participation and experiential learning. Unlike passive forms of education, games allow players to make decisions, observe consequences, and develop strategies, which makes the learning process more engaging and impactful [36].

The game builds on earlier concepts by deepening the player's understanding of sustainable industrial systems. As players expand their factory networks, they encounter increasing pressure to deal with both production efficiency and environmental impact. Rather than simply presenting waste as a minor inconvenience, the game treats it as a central challenge that players must actively solve. This includes designing loops where byproducts are reused and aligning production flows to support symbiotic relationships between buildings. These mechanics aim to simulate the trade-offs real industries face when balancing profitability and sustainability. Through this, players experience first hand the complexity of transitioning from a linear to a circular production model, reinforcing the game's educational message without relying on direct instruction.

1.3.3 Subdividing the Problem

Developing an effective game that conveyed these ideas presented several questions:

- **Understanding Industrial Waste and Circular Economy**
  - ❖ How do industries currently handle waste, and what are the key obstacles to implementing a circular economy?
  - ❖ What are the real-world examples of industrial symbiosis that can be incorporated into the game?
- **Balancing Realism and Accessibility in Game Design**
  - ❖ How can complex industrial systems be simplified while maintaining educational value?
  - ❖ What game mechanics best represent real-world challenges without overwhelming the player?
- **Encouraging Sustainable Decision-Making Through Gameplay**
  - ❖ How can the game design naturally lead players to make environmentally responsible choices?

- What types of in-game incentives and penalties effectively reinforce the consequences of poor waste management?

- **Visualizing Environmental and Social Impact**

  - How can the negative impact of industrial waste on human health and ecosystems be effectively shown?

  - What visual and numerical feedback will help players understand the consequences of their actions?

The goal of this project has been to raise awareness about industrial sustainability by providing an interactive and engaging experience. The game is meant to educate players on how industries can reduce waste through industrial symbiosis, resource efficiency, and strategic production planning. By allowing players to experiment with different strategies and witness the long-term consequences of their decisions, the game aims to create a deeper understanding of the challenges industries face and the importance of sustainable practices.

1.4 Limitations

The limitations of the project were mainly time, resources and knowledge. One outcome of this was the decision to create a 2D game, instead of a 3D game.

Time did undoubtedly have the largest impact, since developing in 3D would require substantially more effort and time from the group. Modeling, texturing, and animation would create an unrealistic workload with the timeframe and size of the team in mind. With this choice, more time could be spent in creating a polished game that ensured the educational aspect of the game was successfully implemented.

Furthermore, the technical challenges that a 3D game brings, such as camera controls and physics calculations, demand knowledge which the group did not have. Given the aim of the project, the simpler option of creating a 2D game allowed more focus towards the core mechanics of the game without needless complexity.

Finally, accessibility was also a consideration, 2D games run on a wider range of computers, not requiring high-end hardware. With the goal of raising awareness in mind, reaching a wider audience of players was more important than the visuals. Thus, including all of the previous points in mind, the logical and more practical approach for the project was 2D.

In addition to this, another limitation was that there would not be be an analysis of the impact of the game on the general public. Since there were not any plans to release the game during the course, large-scale feedback would not be possible to obtain. Measuring the game's influence was limited to internal tests and playtests from selected individuals.

One of the most fundamental limitations is that there are not any other private companies in the game. This means that the company the player runs is a conglomerate, responsible for the entire production chain. While the goal of the project was to highlight aspects of the circular economy, it was never meant to fully simulate real-world industry in all its complexity. To keep the game playable and focused, significant simplifications had to be made. In reality, many different companies are involved in a product's life cycle, and a major challenge is that they often do not communicate well enough to support an effective circular system [37]. By removing that complexity, the game presents a more streamlined — but less realistic — version of how industrial systems operate.

1.5 Societal and Ethical Aspects

The aim of the project was for the game to have a positive impact on the environment by increasing player awareness of the circular economy and other aspects of the environmental impact of manufacturing. Raising player awareness of these factors could in turn lead to an increase in consumer pressure towards green product and process innovation. Raising awareness of the circular economy can draw attention and resources away from causes with more proven benefits, such as the abolition of fast fashion. [38]. Additionally the game may make light of the difficulties with implementing the circular economy and environmental changes. Because the game needs to be engaging to keep people playing some processes have been streamlined which may in reality increase the difficulty of implementing green process changes, an example of this being the construction of buildings. Within the game buildings are built instantly and always cost a set amount compared to reality where delays are somewhat common and lead to cost increases. The game also disregards the emissions produced while the building is under construction. Careful consideration was taken to make sure the game was developed in such a way that it would not cause anger or frustration towards any specific person or group of persons.

The way in which the game is being developed means there should be no need for any personal information from the player, nor should the game restrict their autonomy. To make sure this is the case the report does not include identifying information of the play testers.

2

Theory

In this chapter, certain theories are considered regarding how to raise awareness through games. The chapter also examines popular factory games such as *Factorio* [23] and *Satisfactory* [24] in more detail.

2.1 Raising Awareness Through Games

To get a better understanding of how to raise awareness through video games, theories that help design engagement in games, and an example of such a game that raises awareness relating to the environment were studied.

2.1.1 Engagement and Player Motivation in Games

One crucial part of creating a potentially successful game includes designing an engaging game [39]. Engagement in the stages *before*, *during*, and *after* gameplay, and also the *disengagement* and *re-engagement* of the game are all of importance here. The following theory section will consider the types of engagement that were relevant or considered for the project.

When designing a game with ecological themes, consideration of the target group is important [39]. Variables such as culture, age, and gender can influence how the player engages and responds to the game. Any previous experience with games could motivate or demotivate the player to play the game. Moreover, focusing on an engaging and fun game to play could raise awareness and spread knowledge about sustainability.

Before the player has even started playing, the player will approach the game with a set of pre-existing real-world conditions, motivations, and expectations [39]. A player's motivation to play is an important factor, as that will determine the amount of time they will invest, and how much effort and energy will be spent towards interacting with the game.

For an ecological game, raising awareness depends on the player's knowledge, abilities, thoughts about the environment, and prior experience with gaming [39]. A successful ecological game therefore needs to be tailored to or be adapted for players with varying backgrounds. To facilitate a positive initial experience, an introductory sequence or tutorial is beneficial. Such features help orient players by clarifying the overall layout of the game, controls, game mechanics, and objectives.

2.1.2 Types of Engagement During Gameplay

During gameplay, there are several different types of engagement [39]. These types of engagement may vary during gameplay and be interconnected with each other. For this project, *intellectual engagement*, *narrative engagement*, and *emotional engagement* are mentioned. These three types of engagement during gameplay are mentioned due to their relevance, particularly in the context of designing a factory game aimed at raising awareness.

Intellectual engagement relates to activities that involve critical thinking and creativity [39]. Where it can be in the form of motivation for solving complex puzzles or challenges. This could be seen as the strategic decision-making from the player, where choices are made with consideration of what the potential consequences and results are.

Narrative engagement refers to how immersed and involved the players are when experiencing the story in the game [39]. When the narrative incorporates themes that challenge players to take conscious actions, in ways that interest and excite them, then they may be more motivated to continue playing the game.

Emotional engagement relates to the engagement that positively and negatively affects the player in terms of emotions that influence the game experience [39]. This type of engagement can stem from feelings towards any elements that elicit an emotional response and what the player's emotions are. A way of implementing emotional engagement in an ecological game could be by having surprises in the game such as sounds that alert the player and disasters that appear suddenly. Narrative engagement also plays a role in creating emotional engagement [39], by connecting players through elements such as story, narrative, and characters.

2.1.3 Post-Gameplay Impact

In the after stage, player engagement after having played the game should ideally lead to outcomes such as raised awareness, increased learning, or change in behavior [39]. Observing and analyzing these outcomes is challenging since the impact of a game varies from one player to another. And, even when there is an impact observed from the player after having played a game, these outcomes may not specifically relate to the ecological themes.

Re-engagement, or the motivation to return and keep playing again, can be driven by different factors, such as gaining new knowledge or completing specific objectives regarding environmentally friendly practices [39]. It is important to mention that, re-engagement is not mainly about positive experiences, as even failures or losses can encourage players to play again.

In contrast, disengagement, or the lack of motivation to return to play a game again, can come from interruptions to the flow of the game [39]. These can be technical issues such as software bugs or hardware incompatibility that disrupt the game experience. Furthermore, a lack of challenge may demotivate players from playing.

2.1.4 Eco

Eco is an online game with a focus on simulating environmental ecosystems [40]. The game plays out over a real-time period of about 30 days. In which players have the main objective of preventing a giant meteor from colliding with the earth. However, at the same time, actions carried out by the player impact the ecosystem in terms of pollution. Therefore, the player has to find a suitable balance between preventing the meteor from hitting the earth and keeping the ecosystem intact at the same time.

In their study, Fjællingsdal and Klöckner [40, p. 1] investigated "how playing *Eco* might promote environmental consciousness surrounding ecosystems.". Within the study, participants were recruited to play *Eco* and were then interviewed.

The results from the study [40] showed that visualizing and highlighting the impact of player actions on the environment is a way to increase environmental awareness. This visual and interactive representation could help players in understanding environmental issues that are often perceived as abstract or difficult to grasp.

Moreover, the study [40] describes the cooperation between other players in the game. Collaborative efforts among players to prevent threats to the environment could enhance the understanding of how collective action can address real-world environmental challenges.

Another important point is the immersion and flow of the game [40], as interruptions and downtime can hinder enjoyment. As *Eco* is a game that plays out for 30 days in real-time, the pacing may be too slow, which may impact the enjoyment of the game experience.

Fjællingsdal and Klöckner [40] highlight the importance of making a game fun, where a fun experience can more effectively introduce complex or unfamiliar topics to learners. Notably, while most participants in the study did not report learning new information, the game mostly reminded them and reinforced any existing knowledge related to the environment.

2.2 Factory Games

As mentioned in section 1.1.2, some popular games can be classified as factory games, such as *Factorio* [23] or *Satisfactory* [24]. These games were used as inspiration for the game design in this project. The following sections summarize both games.

2.2.1 Factorio

Factorio is a 2D top-down game in which the player lands on a procedurally generated alien planet and builds factories. The game begins with the player manually collecting resources, such as chopping trees and mining ores. With time the player will have to automate the manual labour to progress in the game at a reasonable rate. Both the collection and processing of resources are automated using various tools and components, such as conveyor belts, trains, and miners. It is important to note that the resources have a certain quantity per tile, therefore they are depletable, meaning the players have to find new groups of resources to gather when raw materials run out.

However, expanding and building factories in *Factorio* impacts the environment significantly. As factories grow, they emit pollution that spreads across the world. For example water will start to change colour from blue to a more toxic dark green, and trees will start to degrade and eventually die out from the pollution. Increased pollution means the local alien life will start to evolve and react, where they will increasingly attack factories and the player, requiring the player to construct defenses to counter the attacks.

A central gameplay element involves researching new technologies that not only improve the efficiency of existing production processes but also unlock advanced machinery and infrastructure. This progression enables the player to scale up their factories and optimize the production chains. Research plays a crucial role in pollution management within the game. Achieving better technology can enable cleaner production methods and more efficient machinery that emit less pollution.

2.2.2 Satisfactory

Satisfactory is a 3D first-person game that begins with the player landing on an alien planet. Unlike *Factorio* the world is handcrafted instead of being procedurally generated. Similar to *Factorio*, the player starts by manually collecting resources to create factories and automating more of the manual labour.

What makes *Satisfactory* quite different is that the game is in 3D. The added dimension allows for factories to be built vertically, giving the player an additional layer when planning and creating their factories compared to *Factorio*, which is played in 2D.

The resources in *Satisfactory* are not depletable and can be mined forever, execpt in a few cases such as trees or bushes. The nodes that host the gatherable resource can vary in quality, which determines the amount that can be gathered per resource node.

Unlike *Factorio*, *Satisfactory* does not incorporate environmental pollution as a gameplay mechanic. However, the player may encounter alien wildlife that are either hostile or non-hostile. Somewhat similar to *Factorio* there are ways for the player to defend against enemies.

One of the main progression in *Satisfactory*, as in *Factorio*, comes from researching technologies. Through research, the player gains new upgrades and tools, and machinery that improve production chains and factory efficiency.

The other main progression in *Satisfactory* is reaching milestones. Milestones are achieved by manufacturing specific parts to unlock new buildings and parts to produce.

3

Methods

The project followed an Agile-based iterative development process consisting of design, implementation, and testing. The design phase started by gathering theory and insight from relevant literature, to get a foundation for addressing the project's problem and goals. When possible, user feedback was incorporated to further improve the design. The implementation phase used the design to develop prototypes or incremental versions of the game for testing and evaluation. In the testing phase, the developed game went through playtesting by other users to gather feedback on questions the group wanted answers to. The feedback was analyzed and used for further iterations, guiding the group and the project on how to achieve its goals.

3.1 Workflow

The development of the game used some practices from Scrum to work in an Agile manner [41], [42]. The Agile development methodology is a way of thinking about project management, focusing on collaboration and developing a product focused on customer needs. Meanwhile, Scrum is an agile methodology that organizes work into sprints, development cycles where work is done and added to the product at the end of each cycle.

For this project the group used a collaborative and iterative process to have a constant focus on improving the game according to the project goals. As previously mentioned, this iterative process consisted of design, implementation and playtesting.

To structure the workload and streamline the development process, some areas of the game were divided into issues for further development where there were areas to delve deeper into, such as UI, audio, animation, and so on. However, all group members were to contribute towards both the game development and the writing of the bachelor's thesis. This task distribution was done in order to make sure there was a shared responsibility for the success of the project.

Effective planning and prioritization of the features were needed to implement the game in a more manageable way. Therefore the MoSCoW method [43] was used to categorize requirements into “must have”, “should have” and “could have” groups. The MoSCoW method orders the priority of features by first “must have” then “should have” and after that “could have”.

- **“Must have”** requirements focus on what is the most important to the project, which for this project would be some of the requirements that were needed to get an MVP, a minimal viable product.

- **“Should have”** requirements are important but not as foundational to the project compared to “Must have” requirements.

- **“Could have”** requirements are useful to the project but are of lesser importance for completing the project.

The method also includes “won’t have” requirements. However, as the project states what its limitations are, these types of requirements will already be addressed.

The development of the project was structured into sprints, each focused on completing relevant tasks for project completion. Sprint meetings were held to plan, evaluate progress, and to create and assign new tasks. Tasks were managed on a Scrum board, where they were categorized by their status, such as “Backlog”, “Ready”, “In progress”, “In review”, or “Done”. This helped the group in planning and distributing the work throughout development.

3.2 Design

Given that the project is about creating a factory game aimed at raising awareness about environmental impact, a well-considered design and background theory was required for effectively relaying this information. Therefore, studies of relevant literature and other games for inspiration were needed for topics such as game design and UI/UX patterns. While the project did not focus on researching UI and UX, the design of the UI/UX can impact how users interact and experience the game.

Due to creating a factory game, previously mentioned popular factory games like *Factorio* [23] and *Satisfactory* [24], were studied to understand their features that could have contributed to their success. Additionally, aspects for raising awarness were studied from an article about the game *Eco* [40], as seen in chapter 2. The group hoped that something useful could have been found to incorporate and improve the raising awareness aspect of the game.

Based on knowledge gathered from studying and game testing this was then used to brainstorm ideas to create and reinforce what the game concept should be. One of the techniques that was used to facilitate brainstorming was mind mapping [44]. With mind mapping information is structured around a central theme in which related information and topics get linked to.

Thereafter a Game Design Document (GDD) was needed to collect ideas and design for the game [45]. In the GDD aspects such as target audience, genre, game idea, game loop, and requirements list could be stated for the game. As mentioned by Schell, there is no definitive format for how a GDD should look. However, it does state that "Game documents have exactly two purposes: memory and communication." [45, p. 382]. The GDD served as an overview and a reference to the group, with updates to the GDD made throughout the development process to reflect evolving design decisions.

3.3 Implementation

To begin the first implementation of the game the project started with paper prototyping based on the initial design [45, pp. 88-89]. Paper prototyping is a cheap and effective method to create simple versions of the game using paper. This allowed the group to do quick testing of early design ideas and the collection of feedback to identify potential improvements in the game concept and design.

Following the paper prototyping phase and testing, and with a clearer understanding of the game concept, the group started creating a digital prototype. The result of this led to an MVP for the project based on the requirements set by the group. This part of the development involved programming and coding using a game engine, with the game being iterated on throughout the project to enhance and include more of the requirements.

3.3.1 Game Engine

Implementing a game from the ground up requires significant time and effort. Therefore, the use of a game engine was beneficial in the development of the game. Within the group, some members had prior experience with the Godot game engine [46], while others were more familiar with the Unity game engine [47]. The selection of the game engine was determined mainly with a majority vote. As Godot received the majority of votes, it was chosen as the game engine for the project.

Godot is an open-source game engine supporting the development of applications or games in both 2D and 3D [48]. It enables the deployment of games and applications for desktop, console, mobile and the web. The Godot game engine is under the MIT license [49], allowing for free usage and modification. Godot is maintained and improved by its large community of contributors who work to improve the engine. The engine's source code is open and can be accessed on a git repository, hosted on GitHub [50].

Godot provides its own interconnected programming language to code the game in, GDScript, which is similar to Python and object-oriented programming languages. Another supported programming language that could be used is C#. Other programming languages could be used to code within Godot but with less support, such as C or C++. Ultimately, GDScript was chosen for this project, due to its integration with the game engine.

3.3.2 Version Control

A version control system was needed for this project in regards to storage, management, and collaboration on the game as a group. Git [51] was chosen as the version control system with GitHub [52] serving as the hosting platform for the source code. To make sure there was a structured and organized workflow, the group adopted a branching strategy called feature branches, where a branch is created to work on a feature during development [53]. When that feature is deemed to be done, then it is reviewed by other group members to see if it is acceptable to be merged with a development or main branch. This was done to maintain the code and project in a more safe and structured process.

3.4 Assets

The project required the use of premade assets as well as the creation of custom assets with tools for the development of the game. These assets may include textures, animations, models, sprites, audio, user interface elements, or more, all of which should align with the game design and enhance the player experience.

In the creation of custom assets Godot [46] was used for creating some of the animations, UI elements, and visual effects in the game. For the pixel art in the game a combination of tools such as Asesprite [54] and ChatGPT [55] were used.

Asesprite is a tool for creating pixel art and animating sprites. In this project custom handmade pixel art was made in Asesprite. Then ChatGPT, which is an AI chatbot, was used to generate pixel art with higher detail. These assets were then modified with Asesprite to make them fit with the game. These tools enabled the group to produce visual content more efficiently and flexibly, bridging the gap created by the lack of suitable existing assets.

3.5 Use of AI-assisted Tools

Throughout the project, AI-assisted tools were used in several supportive roles to help overcome challenges and improve workflow efficiency. AI was used during brainstorming sessions to explore alternative gameplay ideas and mechanics when the team felt creatively stuck. During the research phase, Scopus's AI-assisted search function [56] helped in locating relevant academic references more efficiently. To improve the quality of written English in the report, especially since English is not the group's native language, AI grammar tools were used to enhance clarity and correctness.

In terms of development, AI proved helpful in several areas. It was especially useful for solving small, specific programming problems, especially those that were hard to locate in documentation or required quick examples. AI assistance also played a role in testing, where it helped identify potential bugs or inefficiencies in the code during internal debugging phases. Additionally as mentioned above, AI-assisted tools were used in the generation of game assets, particularly for creating consistent 2D pixel art elements.

3.6 Testing

An important aspect of playtesting is gathering feedback. To gather feedback questions needed to be asked, and there are multiple ways to do this. The group decided to use surveys and interviews during different times. There are also a lot of different ways to conduct interviews, but the two ways the group did it were unstructured interviews and semi-structured interviews. Unstructured interviews mean that no questions were prepared before the interview and were instead asked based on the interviewer's observation [57]. For semi-structured interviews there are pre planned questions which help contain the feedback to areas the group wanted more information about [58]. Comparatively, a survey can be seen as a structured interview in the way that all questions are preplanned with no followup questions. The advantage of a survey was that the interviewer did not need to ask the questions themself which saves a lot of time [59].

To properly evaluate the project, testing was conducted to determine how well it was going according to project goals. The group did this through two types of testing. The group first did internal tests to find bugs, errors in logic, and figure out how the group wanted the game to play among numerous other things. The other type is external playtesting, which focused on player responses to the gameplay and interface. How feedback was collected from external playtesting depended on the phase of the development process. The two different phases were paper prototyping and digital prototyping.

For the internal testing the group achieved this through pull requests. Whenever someone in the group finished their feature they posted a pull request where another group member tested the changes and read the code that was changed. This helped the group remove and fix most issues before they were even added to the main game version.

For the first external playtesting the plan was to have in-person observations of the player testing the game and then conduct an interview. The interviews were unstructured during the paper prototyping since the time spent on the actual prototypes were relatively short and multiple iterations were made. Therefore it was deemed unnecessary to have any sort of structure for the interviews and instead focus more on observation and the playtesters own thoughts. During the development of the game there were a lot fewer major changes to how the game was played. The group therefore decided a semi-structured interview was a good idea for the external playtests on the digital prototype. With a semi-structured interview the group could get answers that were comparable and therefore get a better understanding of the state of the game. The questions for the first external playtesting can be seen in Appendix A.1.

The second external playtest used a questionnaire in order to more easily gather information from a greater number of people and get even more comparable answers. With the answers from this test the group could get a much clearer view how well the game achieved its goals. See Appendix A.2 for the questions used in the questionnaire.

The questions asked in the paper prototype were made to get a clearer understanding of how the testers thought of the game. The questions asked during the semi-structured interviews were based on the factors of what contributes to being effective at raising awareness in video games and if Facterra's game design resulted in a fun game to play, which would be somewhat based on related theory stated in chapter 2. To determine if the game achieved what the project has set out to achieve the group needed to analyze the collected data from testing other users. The same is true for the questionnaire, the difference is that the questions regarding if the game is fun comes from GUESS (Game User Experiance Satisfaction Scale) [60] but not all questions from the GUESS were asked. This is due to Facterra not being developed to the same level as a fully released one which meant not all parts of GUESS applied to the game. Another reason is that the group estimated it would take around 30 minutes to fully play the game for most people and the full GUESS takes 10 minutes [60]. With there also being open ended questions the group believed it could take 15-20 minutes to complete the survey. The group therefore reduced the questions taken from GUESS so it would take around 10 minutes to complete to survey. The group believed spending equal amounts of time on the game as the survey would lower the amount of responses.

However, it is important to recognize that not all feedback would be equally valuable. Therefore, a critical and selective approach was required to prioritize feedback that would contribute more to the overall improvement of the game and project success. There were two occasions of playtests, each for a different iteration of the digital prototype. As mentioned before the group also conducted paper prototyping, which required gathering feedback by testing other users.

The participants who were selected and recruited were largely friends, family and classmates. Due to time restrictions and a need for flexibility in playtesting dates, this was the most effective option for finding and securing playtesters.

3.7 Timeplan

Even though the group had a clear project timeline established ahead of time, the actual work ended up deviating noteably from the original plan. The group had the intended goal of finishing an MVP at the end of study period 3, to start development of a first iteration during study period 4. However, it became apparent rather quickly that game development is a time consuming process. Since all members worked on different parts of the game, making sure that everything was compatible was a challenge that proved difficult.

Playtesting and receiving feedback was also an aspect of the project that consumed more time than initially expected. One playtesting session could go on for multiple hours, which was essential for receiving valuable insights to potential improvements for the game. Creating questionnaires and summarizing data to measure the success of the game was also something that took the group more time than expected, as research on the topic was rather scarce compared to other fields.

4

Process

This chapter describes the implementation process of Facterra. It covers the development steps taken based on the project plan, using Agile methods with iterative design, prototyping, and playtesting. The timeline and activities are supported by details from the project logbook.

4.1 Initial Steps and Setup

The project began in study period 3 with initial meetings to establish the team structure and working methods. By creating a schedule, the team could ensure regular collaboration, with the team meeting twice per week, once with the project supervisor and once independently. A group contract was drafted and finalized early, defining collaboration expectations. Simultaneously, preliminary research into suitable game engines was conducted, leading to the voting and selection of the Godot Engine. Alongside this, background research into the circular economy and analysis of relevant games like Factorio helped to inform early design decisions.

4.2 Paper Prototyping and Early Design

Following the setup phase, the group engaged in brainstorming sessions to gather ideas for the game concept, where concepts from other games were discussed and written down. As seen in Figure 4.1, this is what a result from a brainstorming session could look like. A central point was discussed on what makes games interesting with related topics linked. Where topics were highlighted to indicate what should be in Facterra. In the session, topics such as, feedback to the player, increasing complexity, and that the environment is a conflict were highlighted.

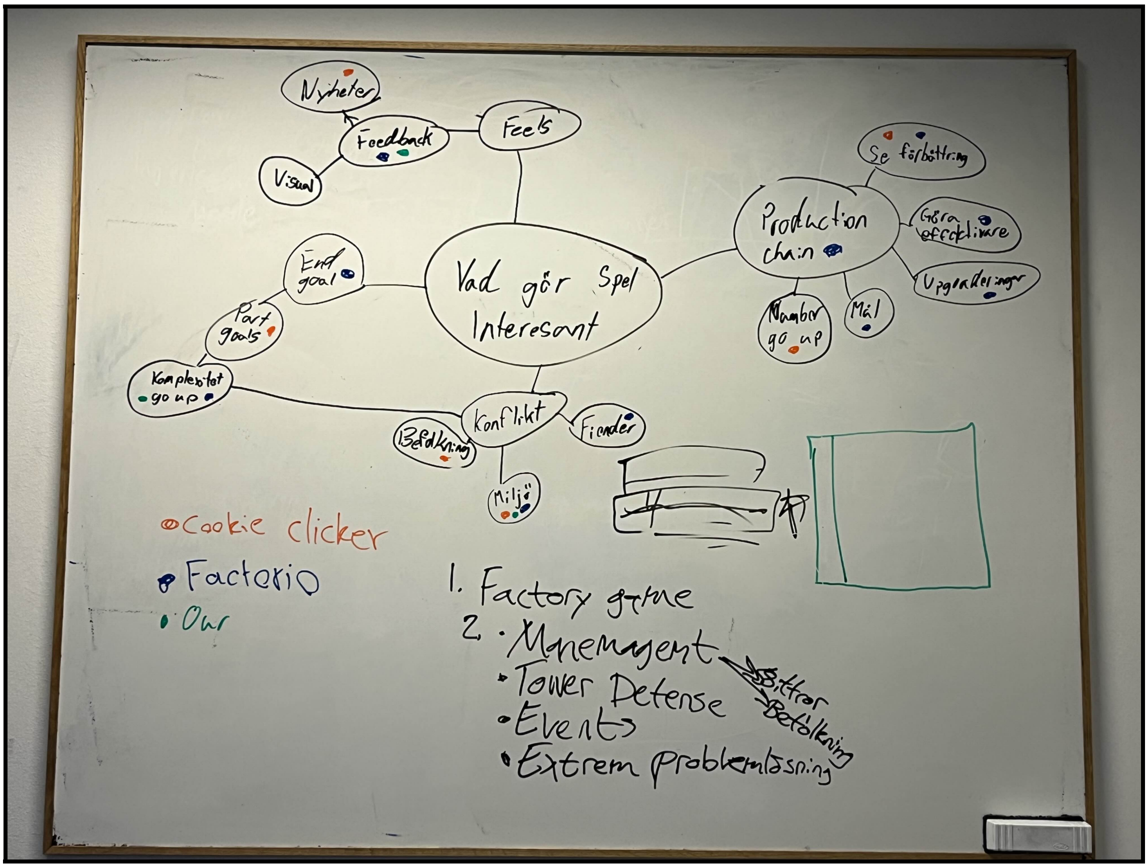


Figure 4.1: A mind map from a brainstorming session. This mindmap contains linked topics surrounding the central point of what makes games interesting.

Each team member created their own paper prototype to demonstrate their vision, which led to productive discussions about preferred mechanics and the desired direction for the game. Through this iterative process, two distinct paper prototypes were developed by different subgroups of the team. These two prototypes focused on alternative designs for the core gameplay loop.

These prototypes emphasized factory construction, resource management, and byproduct handling. The prototypes were tested internally and presented during meetings with the supervisor. Feedback from the supervisor and fellow students helped refine the design direction, focusing on balancing complexity with player accessibility. See Figure 4.2.

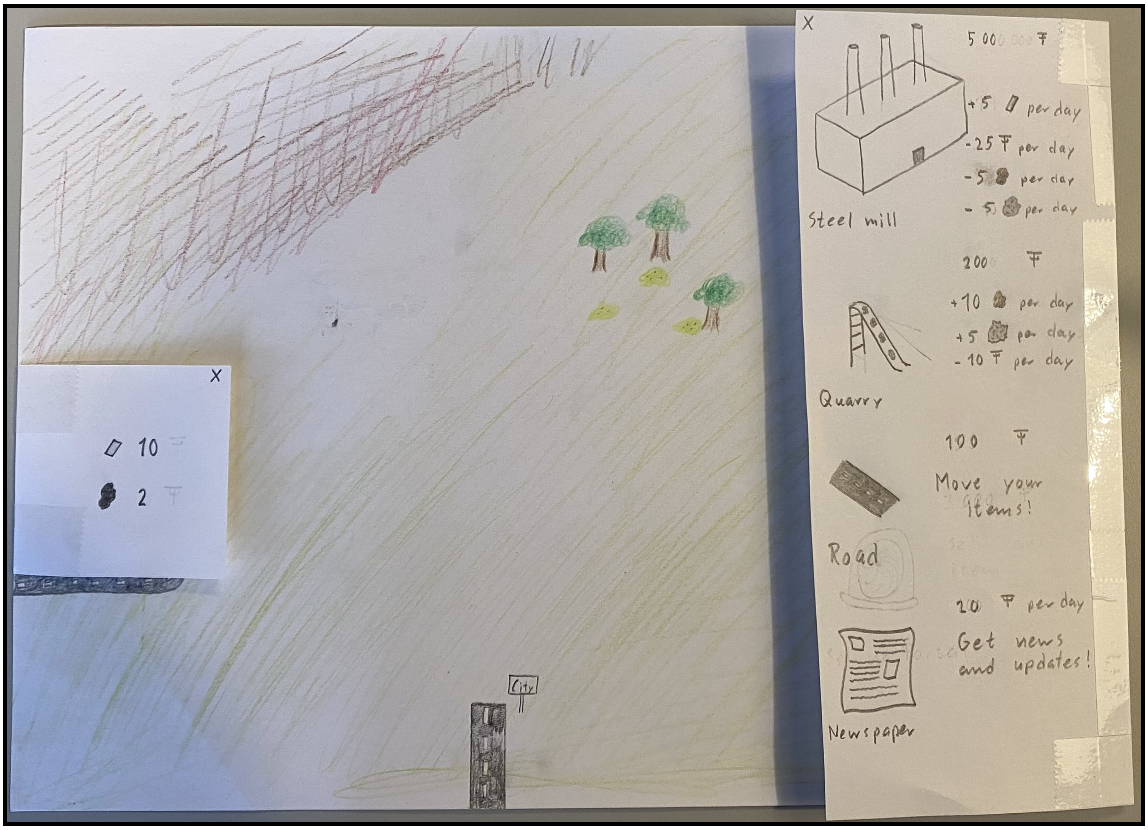


Figure 4.2: A Paper prototype that was used to gather feedback.

4.3 Early Development and Digital Prototyping

One month into the project, following the paper prototyping phase, development was reaching the end of the initial game design stage. This was done by organizing MoSCoW requirements into a game design document, as seen in Appendix B.1.

The initial concept for Facterra revolves around building and managing factories within a 2D top-down world, where players gather resources and produce goods. A core gameplay challenge lies in maintaining a balance between profitability and the environmental impact from factories. Several ideas were noted to support this balance, including the implementation of company production quotas, a city system whose needs can be influenced by player decisions, a research system for unlocking new buildings and upgrades, and an end goal to provide structure and progression.

While the game concept draws inspiration from existing factory simulation games such as *Factorio* and *Satisfactory*, Facterra should have some differences. Most significantly, environmental impact is a central game mechanic that should influence decision-making. In *Factorio*, environmental impact exists but functions mainly as a trigger for defensive gameplay, where pollution causes alien creatures to attack. By contrast, Facterra aims to ground its environmental impact system in the real-world, encouraging players to actively consider and mitigate the consequences of their industrial expansion through planning and sustainable choices.

Moreover, Facterra's production chains are designed to be relatively simple. Rather than constructing internal factory layouts, players are expected to focus on managing the broader input-output flow of factory buildings.

Additionally, unlike *Factorio* and *Satisfactory*, Facterra does not feature a controllable player; instead, the game is played entirely from a top-down view.

After the MoSCow requirements were set, the group transitioned to digital prototyping using Godot. A GitHub repository was set up for version control, adopting a feature-branch strategy to maintain an organized development workflow. Initial features implemented included basic tilemaps, a building placement system, and a basic resource economy.

As development progressed, team members organically specialized in different areas based on their skills and interests. This natural role selection led to a division of work on key subfeatures including asset creation, animation, core algorithm development, and UI implementation.

Parallel to programming, team members started creating basic assets for the game, such as sprites for buildings and resources. A modular system for buildings and resources was established early to allow for future expansion.

Internal playtesting of the paper prototype provided insights that were directly applied to digital development. Key lessons included the importance of clear resource feedback to the player and the need to simplify waste management systems without removing depth.

Having progressed two to three months into the project, the development focused on expanding core gameplay systems. Key implemented features included:

- **Production Buildings:** Buildings that take in resources and produce a good that can be output.
- **Storage Buildings:** Specialized structures to handle waste, biomass, and other resources.
- **Resources Nodes:** Resources nodes that are present on the map and are gatherable.
- **Gathering Buildings:** Buildings that gather and generate resources on resource nodes.
- **Currency System:** Tracking player income and expenses to introduce economic pressure.

- **Research System:** A research tree that allows players to unlock new technologies related to waste management and resource optimization.

- **Environmental Mechanics:** Systems to simulate environmental degradation, including landfills expanding, wildfires resulting from poor waste management, and trees being harmed by certain emissions.

- **Road and Transport Systems:** Road placement mechanics and infrastructure planning for resource transportation.

- **User Interface:** Development of panels for resource overviews, building management, and research navigation.

During this period, frequent internal testing and code reviews were conducted. Pull requests were used to maintain quality control, and regular feedback sessions helped adapt development priorities. In Figure 4.3 an iteration of the digital prototype is shown. Where there are resources on the map. Three distinct types of resources are visible; trees, coal, and iron. At the top a pause button is shown that allows the player to pause the game, a counter for the amount of currency available, and a button to show a list of buildings that can be placed alongside some of their information listed.

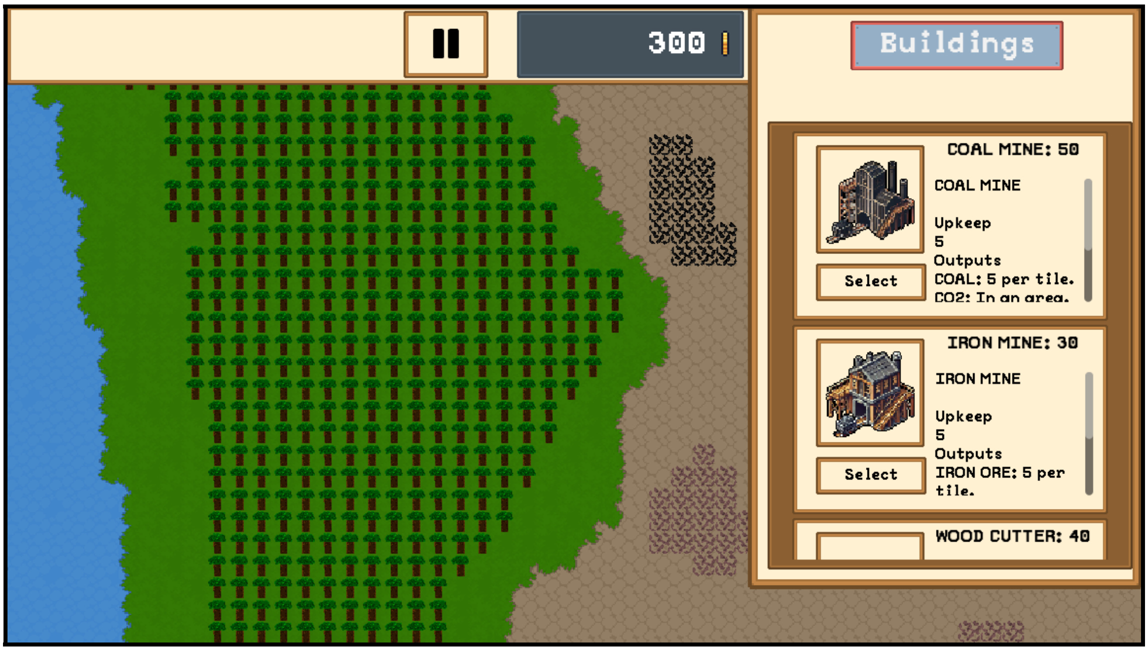


Figure 4.3: An iteration of the digital prototype. There are visible resources to gather, user interface for the pause button, currency and a list of buildings that can be selected.

4.3.1 Transport System

A functional road system was essential for simulating the circular economy, enabling resource transportation between factories. Initially, a single team member tackled this feature, but the implementation proved more complex than anticipated, particularly in handling dynamic connections between buildings. This prompted a second developer to join the effort and, through collaboration, the system was completed.

In the final design, roads operate similarly to other placeable buildings but with added connectivity logic. They automatically detect orthogonally adjacent roads and buildings, dynamically forming networks that visually display their connections. This allows players to both transport resources efficiently and intuitively understand the connections between their factories at a glance.

4.3.2 Game Art

At the beginning of the project, it quickly became clear that finding usable assets for the game would be difficult. Since the game uses a top-down 2D perspective with a pixel art style and includes many different, distinct buildings, existing asset packs did not meet the game's requirements.

As a result, custom assets were needed. To support this, ChatGPT's image generation tool was used. The process began with writing clear and detailed prompts that described the type of building required and the features it should include. It was established early on that the desired art style was 2D isometric pixel art. Multiple images were generated, and the prompts were refined through an iterative process. This involved adjusting descriptions, re-generating images, and testing which visual elements produced the best results. One of the main challenges was maintaining a consistent art style across different buildings. While the AI often produced visually appealing images of varying quality, it struggled to maintain a uniform style between different building types. As a result, some building sprites turned out better than others.

Once satisfied with an image, it was then saved and imported into Aseprite. There, images were painted over manually, adjusting the pixel resolution to match the game's style. The background was also cleaned up to make it transparent and added a solid black outline to each sprite for better clarity and visual consistency in-game.

This process allowed for a unique visual style to be created and tailored to the game's needs, even though it required extra effort to maintain consistency and quality.

4.3.3 Research Implementation

To progress in the game and ultimately achieve victory, research was implemented as a mechanic. With the help of a buildable research lab the player is able to increase production, unlock new buildings, and invest in sustainable methods. To implement this effectively, a straightforward and scalable approach was essential.

To that end, a new data type called research data was created, which is used by both the UI and the underlying game logic. Coupled with the global script "research manager" that manages and keeps track of already completed research, adding new research became an easy task. The process of creating new research entries would only require creating a new research data and pairing it to a duplicated entry in the UI. To customize research effects for individual buildings one would have to specify the effects in the script connected to the related building, by overriding the default function.

4.4 Playtesting and Feedback

Following the paper prototype phase, a continuous playtesting approach was adopted for digital development. Playtesting was integrated into the iterative workflow, with frequent informal tests and feedback sessions.

Feedback highlighted the need for better visual communication, playtesters claimed it was hard to understand where resources were stored at any given moment and that the environmental impact of the constructed buildings was not visible enough. Based on observations and player suggestions, several adjustments were made.

To address the concern with the environmental impact not being visible enough, multiple new features were added:

- The trees present on the playing field now shift between three states to indicate their health.
- A smog layer was added that grows thicker when emissions increase.
- Spontaneous wildfires start if the levels of certain emissions grow too high

The problem with stored resources being hard to track was sidestepped by implementing a multi selection system wherein the player could select multiple buildings at the same time. As a result of this tracking the resources was no longer as necessary since the player could, if needed, simply select all the buildings.

5

Results

In this chapter the results of the project will be shown, and it will include parts of the final product, the game, and the results of the final playtest.

5.1 Final Product

In this section, parts of Facterra will be described and shown. To play Facterra, see Appendix C.1.

5.1.1 Start Menu

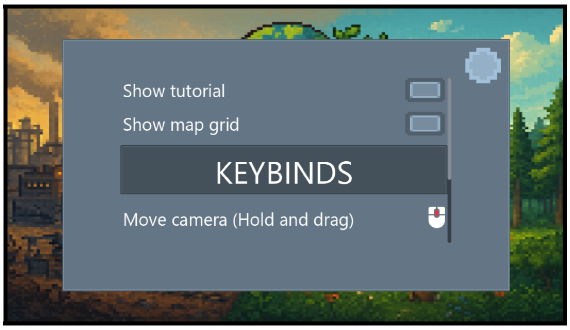
When the game starts, a start menu appears showing the game's title and three buttons: Start Game, Settings, and Exit Game.

- Start Game, begins a new game session, initiating the main gameplay.
- Settings, opens a menu with adjustable options.
- Exit Game, closes the game.

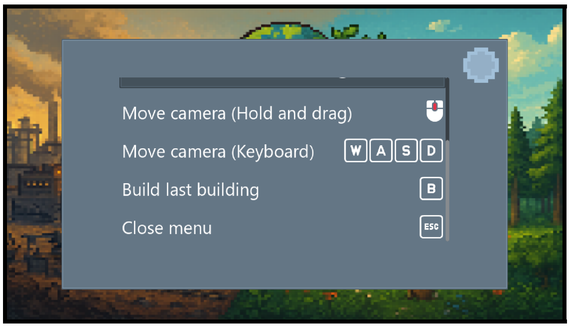
Figure 5.1: Start menu

5.1.2 Settings

A simple settings menu is presented in Figure 5.2. Some options are available such as enabling the tutorial, enabling a visible map grid and keybinds.



(a) Game options in settings

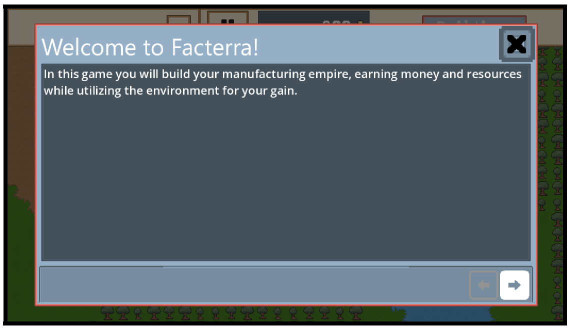


(b) Keybinds in settings

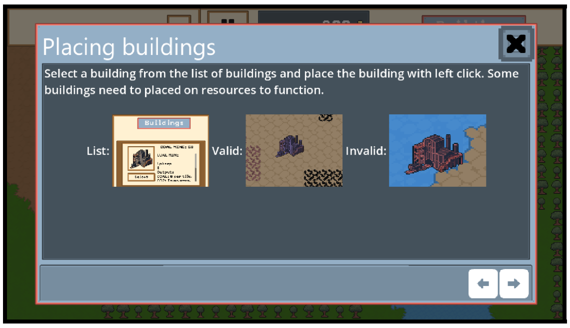
Figure 5.2: The settings menu. Showcasing keybinds and game options.

5.1.3 Tutorial

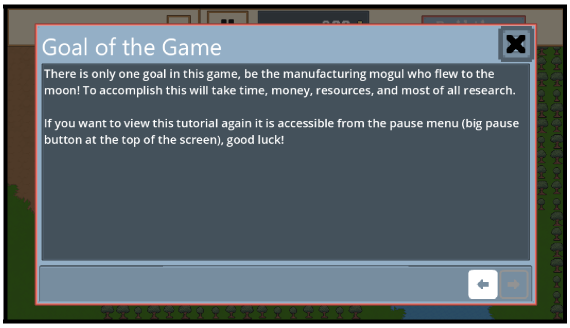
In Figure 5.3, a welcoming screen is displayed and designed to greet and engage the player by explaining the core premise of the game.



(a) First tutorial slide



(b) Second tutorial slide



(c) Last tutorial slide

Figure 5.3: Some of the tutorial slides

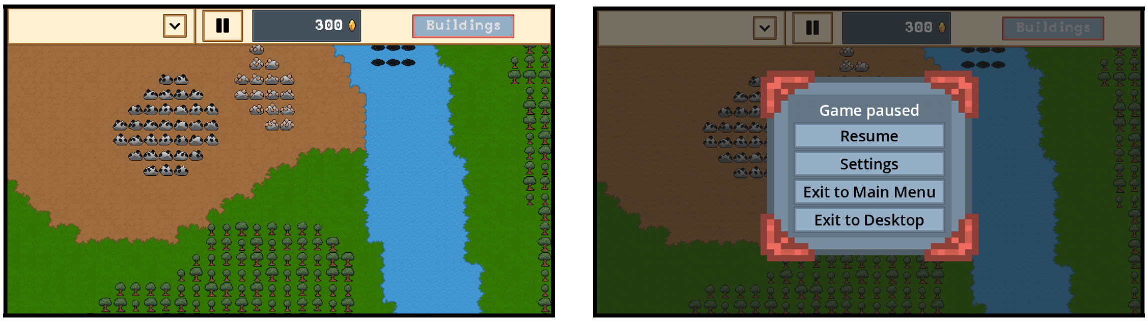
On the second tutorial slide in Figure 5.3b, an illustration of how to place buildings is shown. There are multiple slides similar to this explaining the different mechanics in the game. Then in the last tutorial slide in Figure 5.3c, there is a paragraph explaining what the goal of the game is and how to achieve it.

5.1.4 Game overview

The game is presented from a top-down, 2D perspective where the player can view the entire playable area, including different zones and resource locations, as seen in Figure 5.4a. At the top of the screen, the user interface displays important information such as the player's current money and resources. There are also three main buttons: a button to show more resources that are not visible, a pause button to pause the game, and a button to open the building menu.

Pressing the Pause button, the game stops and a pause menu appears. As seen in Figure 5.4b, this menu includes the following options:

- Resume – Continue playing the game
- Settings – Showing controls and tutorial
- Exit to Main Menu – Return to the start screen
- Exit to Desktop – Close the game



(a) An overview of the game when starting

(b) The pause menu with relevant actions

Figure 5.4: Game Start and Pause Menu

5.1.5 Resources

In Figure 5.5 several resources are shown including coal, iron, oil and trees. All these can be gathered in order to progress in the game. They have a limited quantity and will be depleted with time for buildings gathering on the resource.

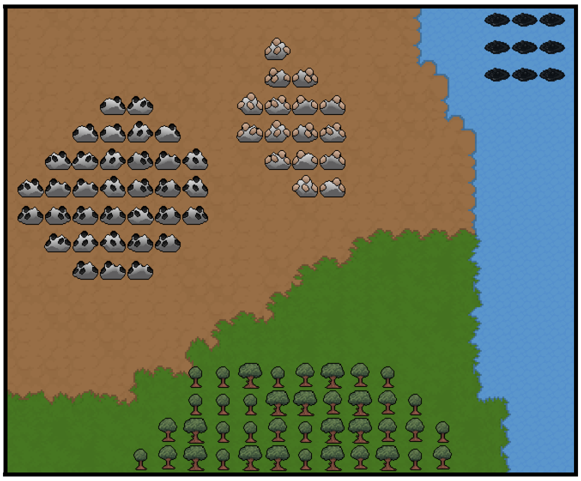
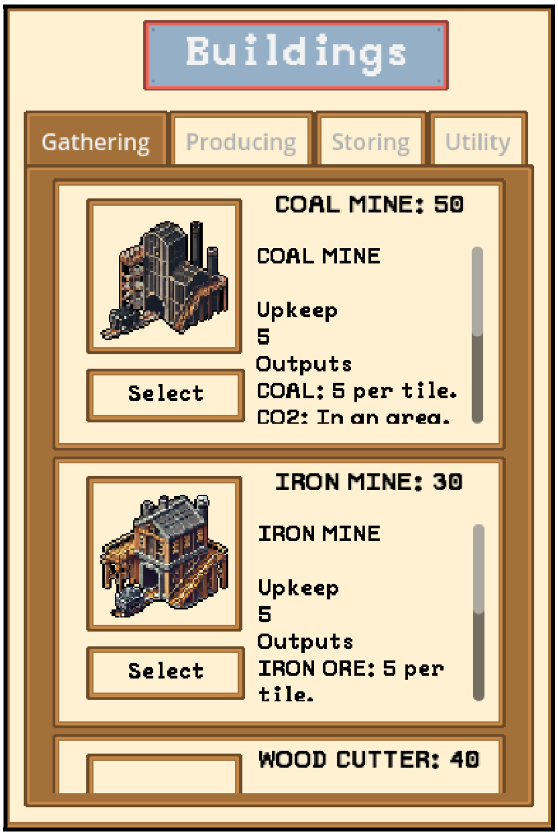


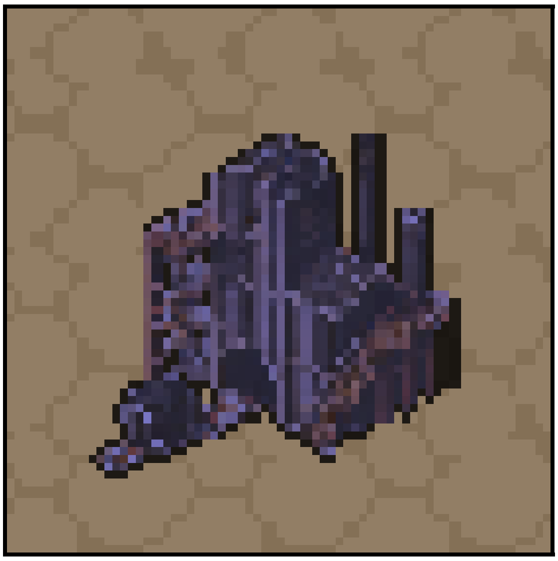
Figure 5.5: Some of the natural resources in the game

5.1.6 Buildings

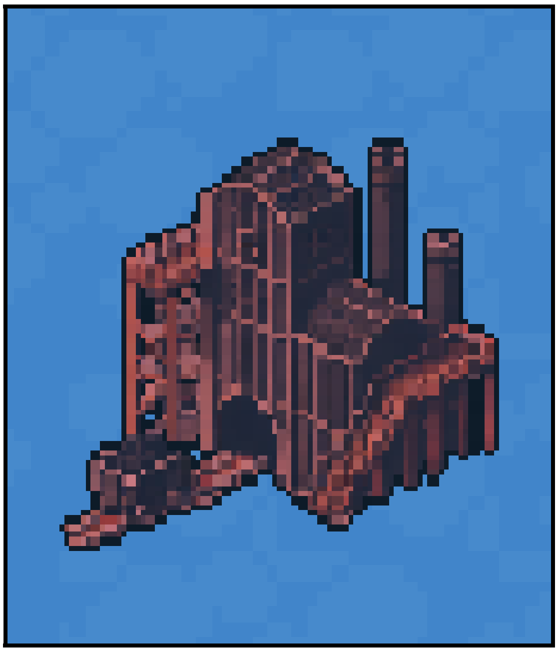
In the game, the player can place various buildings to expand and improve their industry. Buildings cost money to place and have ongoing upkeep costs. They are essential for progressing in the game, as they form a production chain by working together. There are several types of buildings, each with a specific role, including resource gathering, production, energy generation, storage, and utility, as seen in Figure 5.6. Some buildings must be placed directly on top of natural resources in order to gather them, while others require input materials to produce new items. Before placing a building, the user will see a blueprint preview showing where it can be built. Once a building is placed, it cannot be removed, so the player should choose carefully.



(a) Building list with available buildings



(b) Valid building placement



(c) Invalid tile placement

(d) Invalid to place buildings in other buildings

Figure 5.6: Selecting and Placing Buildings

In Figure 5.7 it is shown how placed buildings can be selected, to get more information and actions.

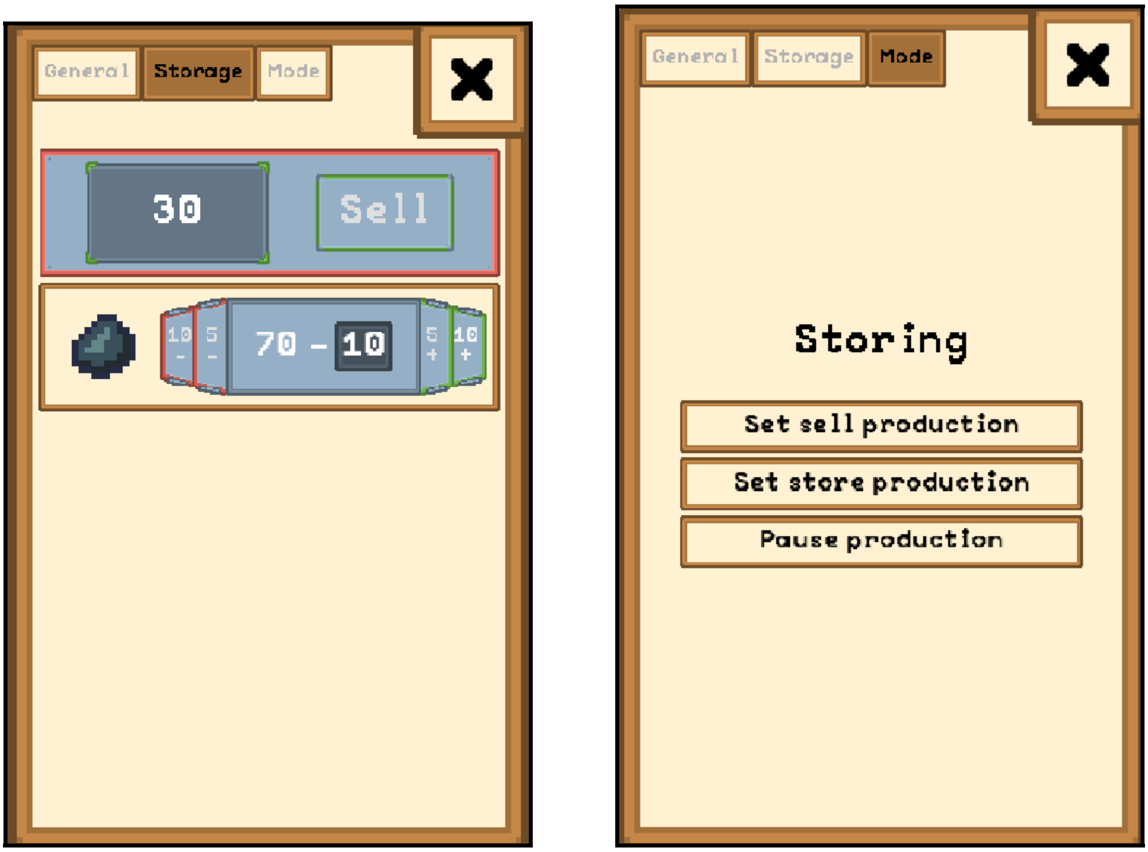
(a) Placed building is selected

(b) Multiple placed buildings are selected

(c) Building info for a placed building

Figure 5.7: Selecting and Inspecting Placed Buildings

For a selected building that is placed, their storage can be accessed, where resources can be sold for currency. Factories can also have their mode set, either for selling or storing their produced goods, and pausing their production. This can be seen in Figure 5.8.



(a) The storage for a placed building

(b) The different modes of a building

Figure 5.8: Building Storage and Modes

In Figure 5.9 a special type of building is shown, a wood cutter. The wood cutter has a gathering area that is highlighted when the player tries to place it. The gathering area shows what trees are in range for the wood cutter to gather. And to indicate it is producing, a chopping animation is shown to the tree that is being cut.

(a) Wood cutter being placed with highlighted area

(b) Woodcutter chopping a tree

Figure 5.9: The placement of a wood cutter and how it chops a tree.

5.1.7 Currency

The money the player acquires is the only global resource in the game that is accessible by all buildings regardless if they are connected by a road network or not. In addition to being required to purchase new buildings and research, money is used to keep production running through each individual building's upkeep cost.

5.1.8 Research

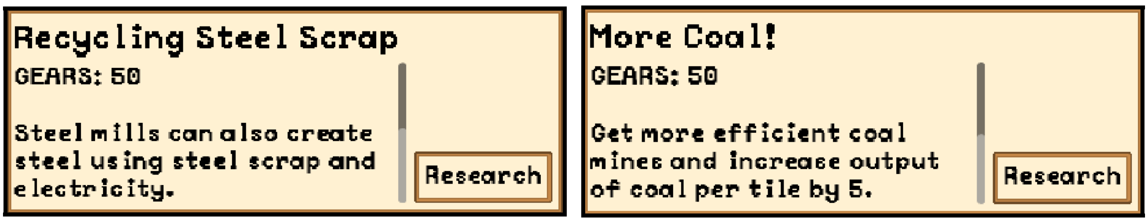
To progress and eventually win the game, there is research. In Figure 5.10 a placed research lab and the associated UI is featured. The UI contains multiple research entries, their cost and description.

Figure 5.10: Research UI when selecting a research lab

One of the more common types of research the player can pursue is in unlocking new buildings. One example of this, in figure 5.11, is one of the first unlockable production buildings, the steel mill.

Figure 5.11: Steel Mill unlock research

Beyond unlocking buildings, research is also capable of modifying or upgrading buildings. In Figure 5.12a, the sustainable research entry allowing recycling of steel scrap is featured. Giving the player the ability to make use of what was previously considered waste. In Figure 5.12b, a more traditional upgrade is featured, allowing the player to extract more coal per tile.



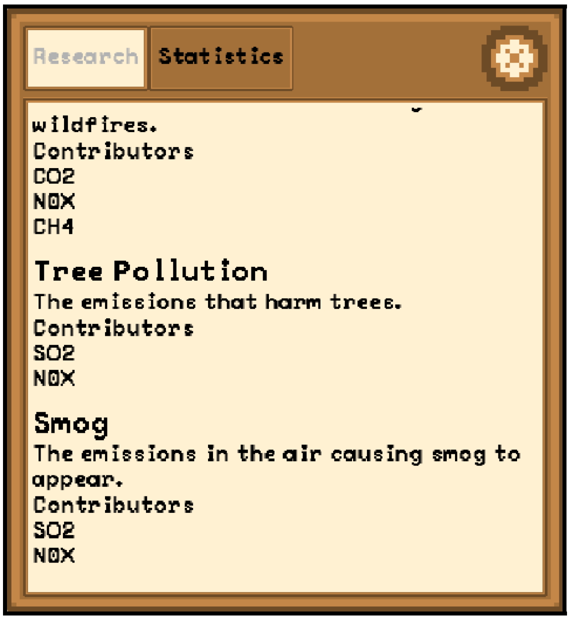
(a) Steel Mill recycling research

(b) Coal mine upgrade research

Figure 5.12: Building upgrades

As well as being a means of progression, the research lab also gives the player an insight into what emissions are contributing to different types of environmental hazards in a separate statistics page. Figure 5.13 shows the page, containing possible types of emissions, and which ones that are contributing to each type of hazard.

(a) First section of the statistics page



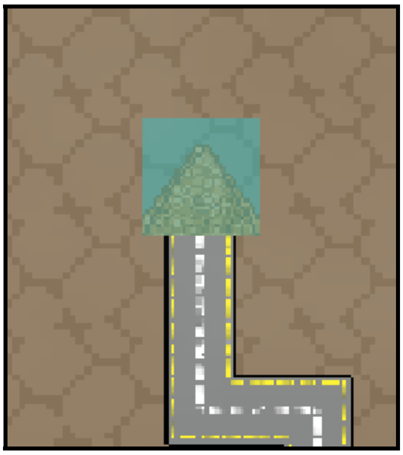
(b) Second section of the statistics page

Figure 5.13: The pollution statistics page, showing what possible emissions there are and what they contribute towards to.

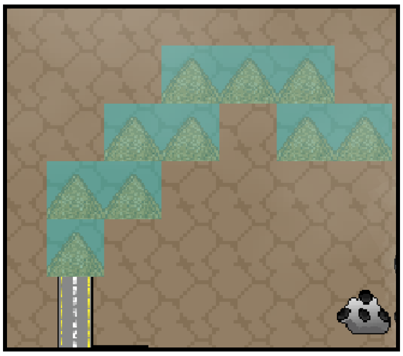
5.1.9 Environmental Impact

There are multiple ways the game shows the industries impact on the environment, all impacts are due to emissions such as NO_x, SO_2, CO_2, and CH_4, released from factories. The amount of emissions released in the air decay with time. Emissions can be absorbed by trees that are near the source of the emissions, in which some of the emissions can be harmful to trees.

There are also byproducts from factories such as steel scrap and biomass that can be stored in landfills, which expand and take more space on the map. The way a landfill expands is by choosing a valid tile type that is nearby and is not occupied by other buildings. The byproducts can be used through some buildings and upgrades through research. See Figure 5.14, for how a biomass landfill expands.



(a) Placed landfill

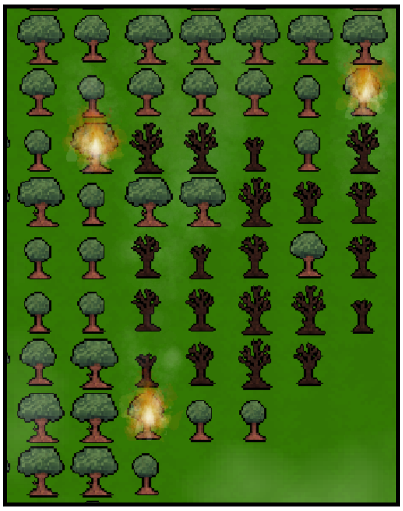


(b) Expanded landfill

Figure 5.14: Landfill expanding with byproducts stored

As seen in Figure 5.15. A wildfire can spawn on a random tree and spread to nearby trees. Where there is a probability for the spawn and spread of wildfires. The probability increases and decreases with the amount of emissions contributing to wildfires in the air. When a tree is fully burnt, it is dead and will not give wood if it is cut down.

(a) Indicator pointing the player towards an ongoing wildfire



(b) An ongoing wildfire that occured due to hightened CO_2, NO_x, and CH_4 emissions

Figure 5.15: Wildfire in the game

Certain emissions also contribute to smog visually appearing and moving in the game map. This can be seen in Figure 5.16.

Figure 5.16: Increasing smog levels caused by SO_2 and NO_x emissions

Additionally, the player can see the effect of emissions contributing towards polluting the trees, as seen in Figure 5.17. Where the trees change visually, and eventually die off by absorbing too much SO_2 and NO_x emissions.

Figure 5.17: Trees that have been polluted by SO_2 and NO_x emissions

5.1.10 Transportation

Transportation works through a network system, as seen in Figure 5.18. Buildings communicate their needs to the network they belong to, either requesting a resource or offering one. When a building requests a resource that another building in the same network offers, the resource is transferred between them.

A building or road, when placed by the player, is added to a network if it is orthogonally adjacent (i.e., directly above, below, left, or right) to another building or road already in that network. If a newly placed building or road connects two or more previously separate networks, those networks merge into one. If it is not orthogonally adjacent to any existing network elements, it starts a new network.

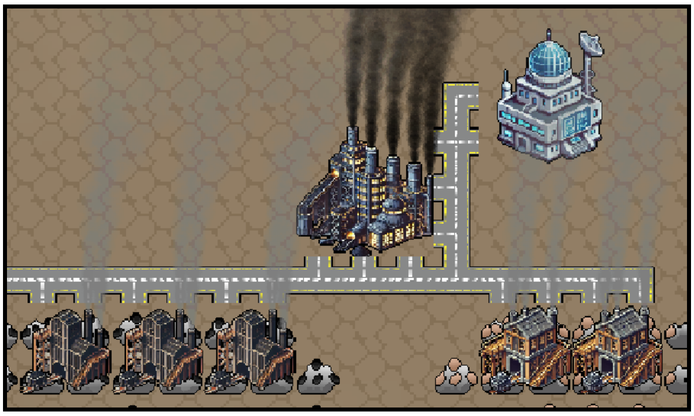


Figure 5.18: A road network connecting multiple buildings

5.1.11 Win Condition

To complete Facterra, a variety of resources needs to be gathered coupled with a strong income and key research upgrades. Once the player has progressed far enough, a rocket launch facility can be built to achieve victory, as seen in Figure 5.19.

Figure 5.19: The end screen for successfully beating the game

Although the game focuses on environmental awareness, launching a rocket is not meant to contradict that message. Instead, the rocket symbolizes humanity's curiosity and desire to explore, reaching beyond Earth and aiming for the stars. The game encourages the idea that humanity can pursue space exploration while also taking good care of the planet.

5.2 Final Playtest

The final playtest gathered data through a survey consisting of three parts. The first part collected demographic information about the testers. The second part was based on the GUESS questionnaire, and the third part included four open-ended questions aimed at determining whether the game raised awareness.

Understanding the demographic background of the testers allows for a more nuanced interpretation of the results. The survey included four demographic questions: age, gender, country of residence, and gamer type.

A total of 26 testers participated in the final survey. The tables below show the demographic of the playtesters.

Game version	
0.2.0	7
0.2.1	19
Age (%)	
15-19	7.7
20-24	76.9
25-29	7.7
30+	7.7
Gender (%)	
Male	73.1
Female	26.9
Country (%)	
Sweden	100
Time played (%)	
0-19 minutes	26.9
20-39 minutes	53.8
40-59 minutes	11.5
1 hour +	7.7
Type of gamer (%)	
Newbie	11.5
Casual	19.2
Midcore/core	42.3
Hardcore/expert	26.9
Previous knowledge (%)	
None	57,8
Factory game	19.2
Purpose and Goal	23.0

Table 5.1: Demographic distribution of the playtesters.

5.2.1 Player Satisfaction

The group selected 14 questions from the GUESS survey, specifically questions 8 through 21, see Appendix A.1. Each response was assigned a numerical value according to the following Likert scale. This can be seen in Table 5.2

Response	Numeric Value
Strongly disagree	1
Disagree	2
Somewhat disagree	3
Neither agree nor disagree	4
Somewhat agree	5
Agree	6
Strongly agree	7

Table 5.2: Range of responses, from 1 (strongly disagree) to 7 (strongly agree)

When the GUESS scale was developed, average scores for each question were reported based on feedback from players who generally had positive experiences with the games they rated [60]. Therefore, these averages serve as a useful benchmark. It can be reasonably assumed that higher scores reflect a more positive user experience. The questions the groups survey asked were from 4 different factors in GUESS, Usability/Playability, Play Engrossment , Enjoyment and Creative Freedom. For Usability/Playability and Play Engrossment there were 4 questions ask, for a possible max at 28. For Enjoyment and Creative Freedom there were 3 questions for possible max of 21.

	Usability	Engrossment	Enjoyment	Creativity	Total
Test Group Mean	4.71	4.38	5.11	5.00	4.76
GUESS Benchmark	5.79	5.00	6.36	5.28	5.58
Mean Difference	-1.08	-0.62	-1.25	-0.28	-0.82

Table 5.3: Comparison of mean scores within factors between this study and the original benchmark from the GUESS development study

	Usability	Engrossment	Enjoyment	Creativity	Total
Newbies/Novice	5.42	4.50	6.11	5.78	5.38
Casual	4.63	4.35	5.07	5.20	4.76
Midcore/Core	4.36	4.69	5.24	4.94	4.77
Hardcore/Expert	5.00	3.93	4.48	4.62	4.50
GUESS Benchmark	5.79	5.00	6.36	5.28	5.58

Table 5.4: Difference in mean scores within factors between each gamer type and the original GUESS benchmark

5.2.2 Awareness Raised

In the third part of the questionnaire, users were asked four open-ended questions divided into two pairs, specifically questions 22 through 25, see Appendix A.2. The first pair was intentionally phrased without any mention of environmental impact or circular economy, in order to assess whether players made connections to these aspects based on their play testing. The second pair of questions explicitly addressed environmental and circular economy aspects, aiming to evaluate reflections when prompted directly.

In response to the first two questions, *"By playing the game, what connections did you make to the real world?"* and *"What did you learn by playing the game?"*, 18 users (69.2%) made an independent connection to the environmental impact of their own actions during gameplay. One user, without any knowledge of the game's intended message, described how visual elements such as smoke rising from factories and burning trees brought climate change and its consequences to mind. It suggests that the game is capable of conveying the intended message without requiring explicit prompts. Only one player made an independent connection to circular economy, the user in question had previous knowledge of the purpose and goal of the project.

In response to the last two questions, *"What new insights did you gain about circular economy from playing the game?"* and *"What new insights did you gain about the environmental impact of factories from playing the game?"*, 9 users (34.6%) reported gaining insight about circular economy and 14 users (53.8%) reported gaining insight about the environmental impact of factories. Many users were not familiar with the concept of circular economy prior to playing the game, and a part of those who were did not report noticing its presence. The minority who did gain any insight mentioned aspects such as material reuse, system interdependence, and sustainable production. In regards to environmental impact, whilst a majority of players recognized the link between factory expansion and the deteriorating state of the surrounding areas, many others claimed that the game reinforced a basic understanding rather than offering any new insights. A prominent theme among those who gained any insights was the realization that resources are finite and decisions have lasting consequences.

In addition to the total statistics, responses were also categorized by gamer type. See Table 5.5.

	Environmental connection (%)	**Environmental insight (%)**	**Circular economy insight (%)**
Newbies/Novice	66.7	66.7	33.3
Casual	60.0	60.0	20.0
Midcore/Core	72.7	45.5	36.4
Hardcore/Expert	42.9	42.9	28.6

Table 5.5: Correlation between previous experience and educational effectiveness of the game

6

Discussion

This chapter reflects on the development and evaluation of the project. It explores how engaging the game was for different types of players, how well it achieved its educational goals, and what challenges the team encountered. Finally, it outlines lessons learned during the process and suggests possible improvements and problem statements for future development and research.

6.1 Player Engrossment

To get an understanding whether or not the game is fun or commercially viable the group decided to ask questions from GUESS. The people who answered GUESS benchmark during its development mainly did it on games they themselves found fun. This made the group see the mean rating for the different questions as an indicator on what is needed for a fun or successful game.

6.1.1 Demographic

Although the the questions are the same in both surveys the demographic is different and some of the questions asked about the playtesters is not comparable. The questions the group asked that is not comparable is time played and game version. They are important for the group to understand during what stage of the development the survey was answered and how long people want to play the game at that stage.

The age of the playtesters was gathered in ranges, such as age 20-24, this is different from the GUESS benchmark where they have more specific ages gathered. Although the way the group gather data on age is different it indicates similar age of the respondents, around early to mid 20s.

The respondents for the benchmark are assumingly mainly US citizens since the survey were distributed at US colleges. The respondents of the playtest were all from Sweden.

The distribution of gender and type of gamers is where interesting observations can be observed. The problem with looking at the difference between males and females on the groups data is that 6 out of 7 females classified themselves as casual or newbie. This would turn a comparison between males and females into a comparison between newbie and casual gamers compared to midcore and hardcore gamers. Therefore the significant observations between demographics can be between types of gamers among themselves and between types of gamers and GUESS benchmark.

6.1.2 Difference Between Types of Gamers

Among the 4 sections the newbies are at one of the extremes in 3 of them. Among them is Usability and they answered the highest among the different types of gamers. This looks weird since newbies should probably be the ones who find learning a new game the hardest. But there is an plausible explanation, they received extra help from the group to help learn the game. This is due to the group wanting them to not get stuck and feel like wanting to quit the game before giving it a proper chance. This probably made the playtesters believe it is easier to learn the game than it actually is.

For Enjoyment and Creativity newbies answered the most positively once again. This is probably because the standard newbies have is lower compared to more experienced gamers. Even if they have lower standards than more experienced gamers it is still positive that they find the game enjoying.

Looking at the Creativity section it shows a very clear trend. The more experienced the gamer was the less creative they believe the game is. This is possibly because the more experienced you are the easier it is to see patterns

6.1.3 Difference Between Facterra Scores and GUESS Benchmark

When looking at the mean of the mean scores a 4 represent neither agree nor disagree, therefore all scores above 4 indicate a positive response. The only section where the result is negative is Engrossment among Hardcore players. This indicates the game is not bad, it just is not as engaging as other games.

On average the playtesters of Facterra answered almost one step lower compared to the GUESS benchmark. This indicates there is room for improvement. Looking at the sections the one closest to the benchmark is creativity. Since the game is about building your own production chain creativity should be the games strong point. A big problem with versions 0.2.0 and 0.2.1 is that there is a lack of large number of production chains in the game and a plausible assumption is that adding more factories would improve the game.

Facterra had a mean difference of -0.62 on the engrossment section compared to the GUESS benchmark this is quite a promising result. If one takes that the benchmark was based on a game that the players enjoyed. This points towards that the players supposedly had more focus and attention to what happened in the gameplay and might be more recievable for information.

6.2 Educational Aspect

To determine whether Facterra successfully served as an educational game, play testers were asked open-ended questions about their experience. As stated by the theory in chapter 2, the impact a game has on its players depends on how engaging the game is and how well it is tailored to the target group.

The results varied. For new and casual players, GUESS scores on both engrossment and enjoyment coupled with overall insight gained and connections made was higher, suggesting the game was not as educationally effective for experienced players. With the lowest total GUESS score and among the lowest educational scores, a possible explanation is that the game's level of complexity was not challenging enough for them.

Overall, the game was not especially successful in educating players on the concept of circular economy. In part because users lacked previous knowledge, but even when prompted directly, fewer than 35% of players reported gaining any insight.

By contrast, the environmental aspect of the game was communicated rather well across all levels of skill. Since over half of all players reported gaining insight it is reasonable to claim that the game shows educational promise. Although the number of people claiming that the game only reinforced basic knowledge leaves room for this area to be improved as well.

Furthermore, in chapter 2 the theory also included visualization as a means of increasing awareness and reinforcing existing knowledge. Across all levels of previous gaming experience, almost 70% made note of the impact of their actions by visual cues such as smoke emerging from factories, burning trees and smog. This supports the theory that an emphasis on visual feedback is a key part of educational games and that Facterra satisfied this.

6.3 Challenges Encountered

Several challenges arose during the implementation of Facterra. One significant challenge was scope management. At the beginning of the project, the group was given a broad topic rather than a clearly defined project. This meant that part of the early work involved defining what the project and the goals should be. Initially, a larger and more ambitious goal was set for the game, imagining a broader set of mechanics and systems. However, as development progressed, it became clear that many of the planned features took significantly longer to implement than expected. Throughout development, balancing the ambition for feature-rich gameplay against the time and resources available remained a persistent struggle. As a result, some features originally planned had to be scaled back or removed to ensure the project remained manageable within the available timeframe.

Another challenge was the technical complexity involved. Learning the Godot Engine and its scripting language GDScript took considerable time. Implementing more advanced systems, such as the dual-grid logic for managing roads and buildings, required a deeper understanding of the engine's capabilities and limitations. While the team managed to overcome these obstacles, the initial learning curve slowed progress in the early stages.

Collaboration also presented challenges. With multiple developers contributing simultaneously, maintaining a coherent and functional codebase was critical. Establishing effective version control practices through Git and enforcing a system of code reviews helped mitigate potential conflicts, but communication and coordination still required continuous effort. Despite these challenges, the iterative and Agile-based development approach enabled the group to continuously refine the game based on playtesting feedback and internal evaluations.

Another notable challenge was sourcing suitable visual assets. Since the game is a 2D pixel art factory game with a wide variety of buildings and systems, it proved difficult to find existing assets that matched the specific style and functional diversity for what was required. Available asset packs often lacked the level of detail or type of structures required for a factory game. As a result, most assets were handmade using pixel art tools and AI-assisted generation. This approach gave more creative freedom, allowing the design of assets tailored to gameplay needs, but it was also time-consuming and required learning new tools and artistic workflows.

Developing a reliable transport system that balanced performance and dynamic functionality was challenging. The initial use of Godot's Path2D had limitations, leading to an attempted switch to AStarGridmap, which proved difficult due to limited knowledge and performance issues. Eventually, a custom solution was created to meet the project's specific needs. Coordinating the system across multiple scripts was a major hurdle, as many promising ideas turned out to be incompatible or too resource-intensive. This highlighted the complexity of pathfinding and the importance of code familiarity in collaborative development. In hindsight there could be several different ways to solve this issue but this was shown to be the most compatible with Facterra.

6.4 Lessons Learned

Several important lessons emerged over the course of the project. One major lesson was time management, which proved to be a crucial factor. Balancing the demands of the thesis writing and the development work required better prioritization. A clearer division of time between coding tasks and academic deliverables would have improved efficiency. Finally, stronger initial planning could have improved the early phases of development. While the team eventually adapted to Agile methods effectively, having a more detailed plan from the start regarding features, assets, and division of labor would have made the process smoother.

Another key insight was the importance of having an actively involved work leader. The group lacked someone in a leadership role who regularly checked progress, helped resolve blockers, or motivated the team when momentum slowed. This sometimes led to delays, uneven workload distribution, and a lack of direction during critical phases. In future projects, having a dedicated work leader who provides both guidance and encouragement could help maintain structure, ensure consistent progress, and keep team morale high.

6.5 Potential Improvements

If the project were to continue or be done again, several improvements could be made. Expanding the environmental mechanics to include more detailed simulation of pollution, ecosystem degradation, and player consequences could enhance the educational impact. For example, implementing a game over condition tied to severe environmental damage could raise the stakes and help emphasize the long-term consequences of poor sustainability decisions.

From a technical perspective, one improvement would be to develop the game on an isometric grid from the beginning. This was discovered too late in development to implement, but it would have allowed for more natural and appealing visuals while offering better flexibility in design. Likewise, the visual presentation would benefit from a clearer and more consistent art style. Formulating a defined visual theme early on and sticking to it would help unify the look and feel of the game.

The transport system could also be expanded to increase its complexity and better simulate real-world industrial systems. This could include power lines for energy distribution and visible transport vehicles such as trucks that move materials between buildings. These additions would help reinforce the concept of production chains and industrial symbiosis within a circular economy.

Narrative depth could be improved by incorporating a story and narrative feedback system. This would provide context for the player's actions and introduce meaningful goals and consequences, making the experience more personal and impactful. Feedback could come in the form of story events or newspaper headlines based on how sustainably or recklessly the player builds their factory network.

Testing also relied primarily on internal and conveniently available testers. In the future, a broader and more diverse group of testers would provide more representative feedback, especially in evaluating the game's ability to raise awareness across different demographics. Finally, adding a post-game reflection system that summarizes the player's environmental impact could help reinforce the intended educational message and encourage self-reflection.

6.6 Further Knowledge and Future Research

While this project demonstrated that games can raise awareness of environmental issues, several knowledge gaps and future opportunities were identified during development.

The long-term educational impact of the game remains unknown. Future research could investigate how repeated or extended play sessions influence players' understanding of sustainability and whether these insights translate into real-world behavioral changes. A valuable next step would be to conduct a longitudinal study tracking players over time to evaluate lasting learning effects.

Another area worth exploring is how multiplayer or cooperative gameplay might influence environmental learning. Industrial symbiosis in the real world often relies on collaboration between companies, something that could be mirrored in a multiplayer setting where players must negotiate, trade, or share resources sustainably.

While this project employed a *"show, don't tell"* approach, future research might involve the differences between this approach and an approach in which the player is more directly told of the goals of the game. Finding the differences between these two approaches can be highly useful for future developers of serious or educational games.

Lastly, cultural and demographic differences in how players perceive environmental messages remain largely unaddressed. Since all participants in this study were from Sweden, future studies should examine how different audiences across regions or backgrounds respond to similar gameplay experiences.

By addressing these areas, future research could expand the impact of serious games and contribute to more effective environmental education through interactive media.

7

Conclusion

Creating a game is fun and exciting, but it is more than meets the eye. Structuring and organizing a group, creating a reasonable scope, and listening to everyone's ideas whilst forming a clear vision of the finalized game is difficult but manageable. On top of that, the process revealed a crucial insight: making an entertaining game is hard, but making a game that is both entertaining and educational is even harder. Balancing gameplay enjoyment with meaningful content is a delicate challenge that demands careful design, iteration, and constant feedback.

There is a major problem with managing waste around the world. Educating and teaching about the circular economy is one step toward a healthy solution. Using games to raise awareness might not be the perfect method for everyone, but it offers an interactive and engaging way to approach complex issues. It encourages learning through doing and can reach audiences in ways that traditional methods may not.

The playtesting results showed that Facterra achieved its intended goals: it raised awareness about environmental issues and offered an engaging gameplay experience. While there is still room for improvement, especially in polish and depth, the game demonstrated that even a student-led project can deliver meaningful impact. By combining entertainment with awareness, games like Facterra could help make abstract issues more tangible and empower players to think critically about their role in the real-world economy.

Whilst the results show promise of raising awareness, Facterra might not have the biggest impact, but perhaps others will see games as an instrument to raise awareness for important issues. If the project inspires further development or discussion around serious games and sustainability, then it will have served a purpose beyond its original scope.

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A

Appendix 1

A.1 First external playtesting

These were the planned questions asked for the semi-structured interviews during the first external playtesting.

1. Version of the game?
2. What information did you have beforehand of the game?
3. Age?
4. Gender?
5. Country?
6. How long did you play?
7. Type of gamer? (Newbie, casual, midcore, hardcore)
8. What are your general thoughts of the game?
9. What is something positive about the game?
10. What is something negative about the game?
11. Was there anything you thought was confusing?
12. Did you find any bugs? And if yes, what.
13. Any input or setting you think is missing from the game?

A.2 Second external playtesting

These were the planned questions in the questionnaire during the second external playtesting.

1. Game version?
2. What did you know before you started playing the game?
3. What is your age?
4. What is your sex?
5. Country?
6. Play time? (Hour, Minute)
7. Type of video game player
8. I think it is easy to learn how to play the game.
9. I always know how to achieve my goals/objectives in the game.
10. I find the game's interface to be easy to navigate.
11. I think the information provided in the game (e.g., onscreen messages, help) is clear.
12. I feel detached from the outside world while playing the game.
13. Sometimes I lose track of time while playing the game.
14. I tend to spend more time playing the game than I have planned.
15. Whenever I stopped playing the game I could not wait to start playing it again.
16. I think the game is fun.
17. If given the chance, I want to play this game again.
18. I am likely to recommend this game to others.
19. I feel creative while playing the game.
20. I feel the game gives me enough freedom to act how I want.
21. I feel my curiosity is stimulated as a result of playing the game.
22. By playing the game, what connections did you make to the real world?
23. What did you learn by playing the game?
24. What new insights did you gain about circular economy from playing the game?
25. What new insights did you gain about the environmental impact of factories from playing the game?

B

Appendix 2

B.1 MoSCoW requirements

These are the MoSCoW requirements that were setup for Facterra after paper prototyping.

B.1.1 Must have

- Be able to place buildings.
  - Buildings can have an input and output.
  - Factory buildings that produce goods.
  - Buildings that generate power.
  - Storage buildings to store resources.
  - Some buildings are not placeable on water.
- Around ten buildings to build.
  - Woodcutter.
  - Sawmill.
  - Coal mine.
  - Iron mine.
  - Steel mill.
  - Gear factory.
  - Coal power plant.
  - Biomass power plant.
  - Warehouse.
  - Biomass landfill.
- Resource generation.
  - User interface to keep track of how much money and other resources you have.

  - Resource types such as coal, wood and iron ore.
- Environmental impact from factories.
  - Carbon dioxide.
  - Biomass.
- A way to reuse factory waste.
- Resource transport system.
  - Roads that can be placed on the map.
  - Resources are transported through the road network to other buildings that are connected.
- The player should be able to turn off a factory.
- A 2D world with a god-eye view perspective.
  - Grass.
  - Trees.
  - Water.
  - Be able to zoom.
  - Drag.
- Production chains.
  - At least four end products.
  - Wood to planks.
  - Iron ore and coal to steel.
  - Steel to gears.
  - Some buildings may use electricity when producing. Where electricity can come from power plants using coal or biomass.
- Be able to see different buildings.
- The game runs in real time.
- There should be a way for the player to pick what building to build.

B.1.2 Should have

- Advanced power system.
  - Power line system.
  - Solar.
  - Nuclear.
  - Water.
- More resources.
  - Copper

  - Other minerals
  - Stone?
  - Water? (pipe system?)
  - Food/Wheat?
- Possible ways to game over.
  - Environmental game over.
  - Economic game over.
  - Company deadline game over?
- Some end goal.
  - A machine that fixes everything.
  - A fusion reactor.
  - Launch a rocket to space.
- Company quotas.
  - Some company in the world.
  - Fill quotas by the company.
- People needs.
  - City or people in the world.
  - The people have some needs.
- Direct feedback.
  - Newspaper.
  - Sensors.
- Research system.
  - Tree with nodes.
  - Categories to research in.
  - New buildings to unlock.
  - Improve the efficiency of buildings.
  - Reduce environmental waste.
- A coherent visual design.
  - A coherent graphic style.
  - Light and shadows.
- Resource depletion.
  - It is possible for some resource nodes to go empty.
- Real-time.
  - The player should be able to control the speed of their factories through

a gauge or something similar.

- Different parts of the playing field should suit different factories.
- Balancing of the game.
- A tutorial.
- Menu.
  - Saving and loading the game.
  - Settings for audio, keybindings, resolution, and more.

B.1.3 Could have

- Graphical representation of resource transportation.
  - Trucks on roads.
- Advanced research, an in-depth tree.
- Accessibility options.
- A simple background story.

C

Appendix 3

C.1 Access Facterra

At: `https://github.com/linuskar/DATX11-DIT561-Bachelor-Project-Group-48` is where the GitHub repository for the project is located.

Follow the instructions in the README file for the repository on how to download a version of Facterra. Select the latest version of Facterra to download, that is the highest version number. Note that the game has been exported with support only for Windows.