Fosa Kettunen

Prototyping a Tactile Interface for Spatial Visualisation

Metropolia University of Applied Sciences
Bachelor of Culture and Arts
Degree Program in Design
Thesis
May, 2025

Abstract

Author(s):	Fosa Kettunen
Title:	Prototyping a Tactile Interface for Spatial Visualisation
Number of Pages:	28 pages
Date:	22 May 2025
Degree:	Bachelor of Culture and Arts
Degree Programme:	Design
Specialisation option:	XR Design
Supervisor:	Markku Luotonen, Senior Lecturer

Tactile interfaces are physical objects that allow a person to manipulate and control digital objects. The increase in digitalisation of our environment to 3D has revealed that editing digital objects is complicated and time consuming. This thesis aims to determine if a good, intuitive interface can be built to enable people to edit 3D models using tactile interfaces. A prototype using a tactile interface for spatial visualisation was developed. The system utilises the Unity game engine, 3D printing, cameras, and AR software. A literature review is performed on “Review: Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application.” The review paper contains a compilation of tactile interfaces categorised into technologies and applications. These are used to study the requirements needed to build a prototype for this project. The prototype is used to discuss potential use cases for artists, designers, and companies. The thesis identified ARToolkit as a technology for machine vision applications in game engines. The prototype identified technological limitations with camera capabilities, such as the high resolution needed for accurate tracking in scaled virtual space. User and company feedback highlighted interest in the concept, and further ideas and use cases were gathered.

Keywords: Prototyping, Tangible user interface

Tiivistelmä

Tekijä(t):	Fosa Kettunen
Otsikko:	Taktiilisen käyttöliittymän prototyypin kehittäminen tilan visualisoimiseen
Sivumäärä:	28 sivua
Aika:	2.5.2025
Tutkinto:	Muotoilija AMK
Tutkinto-ohjelma:	Muotoilun tutkinto-ohjelma
Pääaine:	XR Design
Ohjaaja(t):	Lehtori Markku Luotonen

Taktiiliset käyttöliittymät ovat fyysisiä esineitä, jotka mahdollistavat henkilön muokata ja ohjata digitaalisia esineitä. 3D digitalisoituminen meidän ympäristössämme on tuonut esille, että digitaalisten esineiden muokkaus on monimutkaista ja aikaa vievää. Tämän opinnäytetyön tavoitteena on selvittä, että voidaanko hyvä ja intuitiivinen käyttöliittymä, joka avustaa ihmisiä 3D esineiden muokkaamiseen taktiilisia käyttöliittymillä rakentaa. Prototyyppi, joka käyttää taktiilista käyttöliittymää tilavisualisointiin rakennettiin tässä opinnäytetyössä. Prototyyppi hyödyntää Unity-pelimoottoria, 3D-tulostinta, kameroita ja AR ohjelmaa. Kirjallisuuskatsaus suoritetaan artikkeliin "Review: Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application". Kirjallisuuspaperi kokoaa yhteenvedon taktiilisista käyttöliittymistä ja luokittelee ne teknologioiden ja käyttökohteiden mukaan. Kirjallisuuden aineistoa käytettiin tutkimaan millaisia vaatimuksia prototyyppi tarvitsisi. Prototyyppiä käytetään keskustelemaan mahdollisista käyttötapauksista artisteille, suunnittelijoille ja yrityksille. Opinnäytetyö löysi ARToolkit toimivaksi teknologiaksi konenäkö sovelluksiin pelimoottorissa. Prototyypin avulla havaittiin teknologisia rajoitteita kameran kyvyissä. Esimerkiksi tarkkaan skaalattuun virtuaalitilaan tarvitaan korkea kamera resoluutio. Käyttäjiltä ja yrityksiltä saadun palautteen perusteella prototyyppi herätti kinostusta ja sen pohjalta kerättiin uusia ideoita ja käyttötarkoituksia prototyypille.

Avainsanat: Prototyyppi, Taktiili käyttöliittymä

Opinnäytetyön alkuperä on tarkastettu Turnitin Originality Check -ohjelmalla.

Contents

1 Introduction

Digital visualisation is prominent in various fields, from advertisement to game design to architectural planning. Digitalisation allows us to simulate and replicate real-world objects in a digital space from which we can create animations, music and artistic effects.

As of 2024, the latest phones and software have made creating 3D models more effortless and accessible to artists and designers. Multiple phone applications enable people to generate 3D models suitable for publications and commercial use by capturing a series of images with their phones. This increased accessibility of 3D models has driven a growing demand for refining models to meet the specific requirements of various digital mediums, such as websites, video production, and gaming.

The flexibility of 3D models has caused multiple fields to have specialised software to handle and visualise 3D data to fill its unique requirements. Professional tools and specialised software often require at least tens of hours of learning to understand the basics of control and editing. All the while, the interfaces are not intuitive to first-time users. This has created difficulties for artists and designers who are not proficient in computer-based 3D model editing. They have 3D models but do not have the required skills or creative freedom to work or create content with them.

One area that has emerged to solve this problem is tactile interfaces. Tactile interfaces use touch as an interactive medium and project information to digital windows. These interfaces seek to improve accessibility and create better spatial comprehension using intuitive real-world touch.

This thesis tries find a suitable solution for visualising 3D world using tactile interface. This thesis reviews a paper with list of published tactical interface solutions. In those solutions, technologies and functionality are examined. A prototype is built to show one possible solution. Ideas about the prototype are discussed, commented and then gathered to find possible future expansions.

2 Literature Review - Tangible User Interfaces Paper

The purpose of this literature review is to analyse the article “Review: Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application” (Krestanova, Cerny, & Augustynek, 2021). The reviewed paper examines various functional tactile interface solutions between 2010 and 2020. The review paper categorises existing solutions by application areas and different technologies used. This categorisation works as a platform for developing a prototype, defining a scope and generating ideas for discussion points in interview conversations.

The literature review paper explores multiple real-world tangible user interfaces or “TUIs” TUIs connect real-world objects to the virtual world through physical objects or materials that can be moved or rotated. An example could be a 3D-printed cube or sand that is tracked by a camera and displayed on a screen. The paper describes each project's use, technical solutions, and resulting demos and analyses the technical solutions that influence the project’s functionality. The authors in the paper categorised projects into ten major application groups:

1. teaching
2. medicine and psychology
3. programming and controlling robots
4. database development
5. music and arts
6. modelling of 3D objects

7. modelling in architecture

8. literature and storytelling

9. adjustable TUI solutions

10. commercial TUI smart toys.

The Tangible User Interfaces paper highlights that TUIs provide a more interactive and engaging experience than regular graphical user interfaces (GUIs) like buttons or touchscreens. TUI technologies significantly impact functionality in practical projects by delivering fast and intuitive feedback and enhancing user interaction by integrating physical and digital environments. The authors of the literature review highlight the importance of selecting the right technical solutions to improve effectiveness and user engagement.

For this thesis, the focus is on the different solutions and how they help design a prototype. Examples are collected from the literature review paper. Subjects include: modelling 3D objects, modelling in architecture and literature, and storytelling.

2.1 Research Questions

Given the thesis author's experience in cultural projects, this thesis review of the paper focuses on finding value for small businesses, hobbyists, and individuals with their existing creative materials, such as 3D models, art, animation, and music. To this end, the following research questions are proposed:

- In what ways could the paper’s solutions add value to existing creative materials?
- What use cases are there when building a prototype?

Part of this thesis also involves building a prototype, which requires finding easily re-creatable technology from the paper. The prototype is designed as a flexible foundation for users to build upon and explore ideas. Building a prototype takes time, so technology that allows for easy additions and expansions is valuable in keeping the scope manageable. To capture these requirements, the following questions are considered:

- Are there ready projects that could be expanded upon?
- What technologies could be used to build a demo?

2.2 Analysis

This section addresses each research question by finding themes in papers that are part of the literature reviewed paper's solutions, and presenting findings. Solutions from the paper are used as examples and examined to see how they would work in a prototype.

2.2.1 Value for Created Material

In the author's experience, customers, companies, and artists have ready-made material that they want to use. A material can be any creative product, including pictures, videos, places or sounds. This section, "Value for Material", examines the benefits and drawbacks of incorporating technology and explores possible ways to create additional value for the material, as points of interest for people. How could the projects in "Review: Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application solutions" add value to existing creative materials?

In the paper on tangible user interfaces, particularly suitable solutions to this thesis are those aimed at children and education. Educational tools require measurable outcomes to evaluate effectiveness. At the same time, technology designed for children prioritises simplicity and durability as children are more likely to engage in highly active play that may result in device misuse or damage. Therefore, the paper's solutions for children and education are made accessible and appropriate for studying this thesis prototype.

One solution in the tangible user interfaces paper utilised Augmented Reality (AR) and TUIs. The University of Madeira Interactive Technologies Institute (Campos, Pessanha, & Jorge, 2010) developed a game and learning solution that can be seen in the drawn image in Figure 1. The solution consists of four elements. The Main elements are the surfaces and backgrounds which are physically present with a person. The background features images of butterfly habitats and a movable tracker with a picture of a butterfly that can be positioned at each location. A camera streams the location of the tracked surface in relation to the platform into a virtual window. As the tracked surface is moved to the correct habitat, a detailed virtual butterfly is shown in a virtual window.

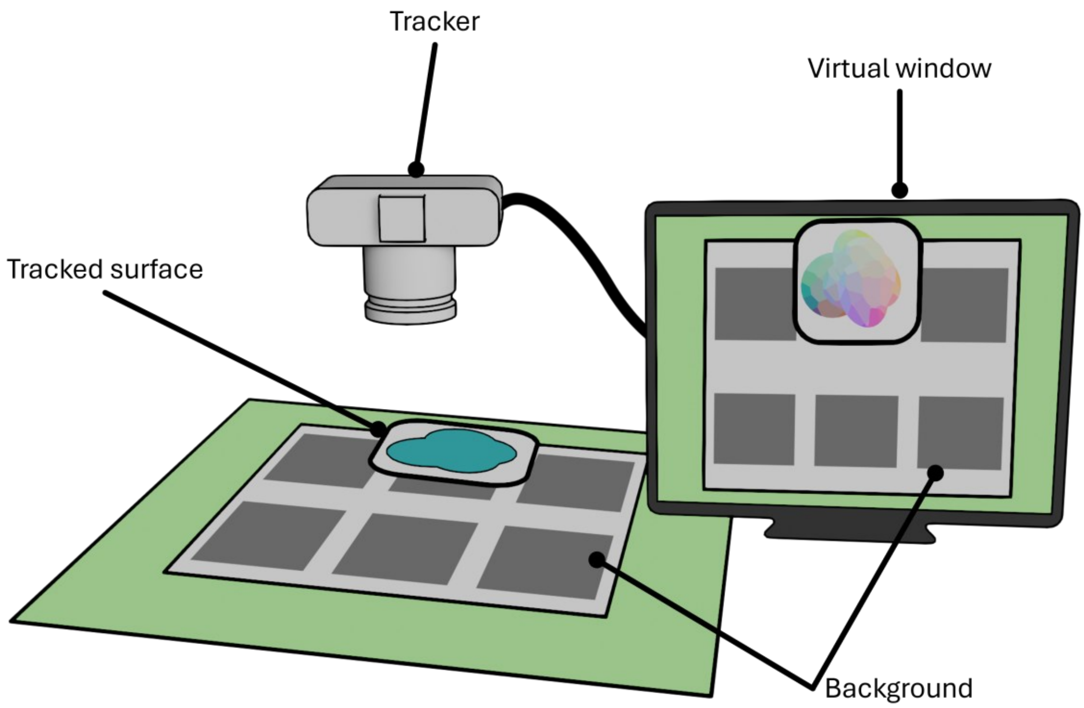

Figure 1 - Children's AR game

According to one of the literature review's solution papers, adding virtual elements increased children's engagement and interest. Added value came with the novelty of moving the digital twin and interactivity. The solution is based on tracking real pictures instead of markers, making the project much more fail-safe than other literature review paper solutions that used abstract shapes for markers. If the tracking or technology failed, there were still the images to look at, retaining functional value. The example showed an effective way to add visual value to a working project (Campos, Pessanha, & Jorge, 2010.)

When studying solutions in the tangible user interface paper, TUIs seem to add value in two ways: they bring benefits to the virtual world and allow easy interactivity. For example, adjustable knob allows a wide range of inputs, location, rotation and position of the object and adjustment of the knob. Those simple inputs enable solutions to add value by creating storytelling through relations and actions, as seen in the previous children’s AR game example, where matching the butterfly's location to its habitat location could serve as a trigger. The game’s inputs are processed by a computer capable of generating and displaying virtual elements, such as digital twins, videos, animations, or sounds. This flexibility expands the range of potential applications. The addition of virtual windows benefits an artist's material by enabling the visualisation of dynamic and engaging digital content that responds interactively to user inputs.

2.2.2 Use Cases for Prototype

The literature review paper identified solutions that fit into eight application areas. Because TUI is an interface that connects technologies together, it has a wide range of applications as an intermediary technology. This section of the thesis explores what use cases would fit the thesis prototype.

In the literature review paper’s section “3.1. TUI as a Method for Learning”, there is an example of an exhibit demonstrating the global distribution of plankton in the world's oceans through an interactive multi-touch table (Ma, Sindorf, Liao, & Frazier, 2015). In the exhibit, visitors used movable physical rings to explore the types, shapes, and scales of plankton in oceanic regions. A drawing is shown in Figure 2. This solution features a large table that accommodates multiple users. The basic use case of this idea is to explore and reveal information that has multiple data layers. A wide range of simple or zoomed-out data can be displayed in the table, and with interactive nubs, a person can focus on finer details. This demonstrates the potential to utilise physical knobs to navigate complex data and make it more visually simple. A knob could allow the movement of the camera to navigate three-dimensional digitally recorded caves. Cubes and shapes could represent housing when planning on a small scale (Nations, 2023).

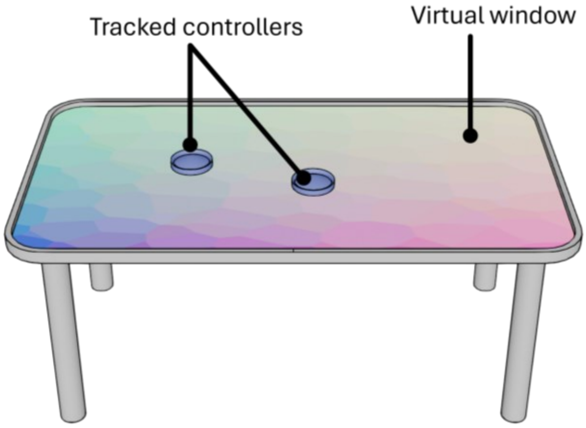

Figure 2 - Museum's digital table

In the review literature paper solution, one solution developed a modular synthesiser called Spyractable. It is a translucent round table for art culture solutions (Potidis & Spyrou, 2014). Users created sound by moving objects around the projected table, a wide sound synthesiser. Each object on the table produced its own effect. Different effects interacted with each other. This solution builds on one of the strengths of interactive TUIs by making something new from existing materials and tools. Spyractable offers more content by allowing people to create their own content. The table technology could help people utilise it for practical applications, such as planning, creating new music, or visual effects.

2.2.3 What Technologies Are Available

Building a TUI requires a computer to sift through raw data to create parameters that can later be interpreted by software. This software displays the digital elements and ties those elements to the tracking technology's filtered input. There is ready-made software and different types of technologies. In this section, “What Technologies Are Available,” the author examines the technologies featured in this thesis literature review study. The goal is to find easily modifiable tech which could be later used in this thesis prototype.

Three types of virtual windows tended to occur in the literature review paper’s solutions: projectors, displays, and screens. Displays and screens often serve as indicators or visual aids and have a wider range of applications than projectors. Screens have been successfully implemented in various solutions, such as TUI applications in medicine and psychology, likely due to the affordability, accessibility, and durability of current touchpads and screens. Projectors are a convenient solution for large projects or those requiring depth, as they can project onto large surface areas, such as walls or floors. However, from images and test cases, it is apparent that projectors have multiple weaknesses. Projectors require a low-light condition to be visually functional or to operate effectively. This means the room needs to be darkened by closing the windows and turning off the room lights. Projectors are also more expensive and often require a line of sight to the surface. If the projector’s surface is not much larger than a large screen, the screens tend to be cheaper.

In some tangible user interface papers, the software is part of the hardware and cannot be accessed unless purchased with the product. Manufacturers create programs to interface with their devices, but presumably, they are not incentivised to share or make editable code, as the audience is smaller and does not correlate with higher product sales. When access to code is lacking in software or is non-existent, developing, innovating, or improving a prototype is impossible in this thesis, as it restricts the ability to integrate new technologies. These limitations are not evident in the two other open-source software programs that are also present in multiple literature review papers solutions. OpenCV and ARToolKit are software libraries specialising in computer vision and are community-built and maintained. Given their extensive documentation, numerous features, and up-to-date maintenance, these are considered for the prototype build in this thesis.

In conclusion, building a tangible user interface prototype requires software and hardware which are not tightly coupled. Screens and displays are accessible because they are widely used and cheaper, making them ideal for fast prototyping in projects that lack a clear direction. A projector or more expensive solutions, such as LED screens, are beneficial when the project has grown. A proprietary software tied to hardware in many papers' solutions limits creative flexibility and innovation. To mitigate this, adaptable open-source libraries OpenCV and ARToolKit are used as the foundation for developing an accessible and modifiable prototype for this thesis.

2.3 Implications and Conclusion

In the reviewed paper, “Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application” multiple example solutions demonstrate that Tangible User Interfaces (TUIs) can provide intuitive and interactive experiences for museums or designers. Tactile interfaces work with a wide range of people and are accessible technology. Examples ranged from individual solutions to multi-person tables. Tactile features allow for bridging the physical and digital worlds. This holds promise for building prototypes with broad application purposes, enabling the creation of a platform that can be later utilised in other projects.

In this thesis, the review paper “Review: Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application,” published in 2021. Later MR, AR and VR technologies have become more relevant. It is sensible to find new papers about TUIs that consider the changes in the MR and AR landscapes since 2021, as the field has new technological advances yearly. It is reasonable to consider that TUIs could incorporate and be part of new evolving XR technologies. The paper has an impressive 64 examples, categorised by the technology used and applications. However, the tangible user interfaces paper lacks information on whether solutions are repeatable or testable, and how easy it is to build upon these technologies.

In the literature review paper’s examples, there is a wide range of applications where design considerations for usability are important in selecting the right combination of hardware, such as projectors, screens, and physical input knobs. Designers have to consider factors such as lighting conditions, software, hardware, and interaction. Freely available computer vision libraries, such as OpenCV and ARToolKit, offer ready-made solutions that make it easy to start and test prototypes for this thesis project. They are recognised as good software from which to begin creating prototypes. In the paper's reviews, basic computer display solutions were popular and sufficient to make a working project. Overall, the literature review suggests that well-built TUI elements can add long-term value to various projects, benefiting creators and designers. The literature on TUIs shows the possibility of connecting the virtual and physical worlds, allowing for multiple accessible interfaces. In this thesis, versatile and reliable prototypes are created without starting from scratch.

3 Designing a Prototype

Part of the design process is conceptualising a product's requirements. The thesis first discusses initial requirements and ideas about what the design should accomplish, scoping it down. Then, technologies are compared and used to build a prototype using the author's capabilities.

3.1 The Design Concept

This thesis prototype is scoped for a single-person project. The project is focusing on building a working demo first. The section below sets goals and uses the scope of the project to clear objectives, making sure that the development is finished with the available resources and time

3.1.1 Goals

The goal is to create a prototype that serves as a proof of concept, allowing end users to experience its functionality and potential applications. A practical example highlights the possibilities in the tactile interface area and may encourage other developers or companies to build upon this concept. To achieve a wide range of freedom for the developer and any other person who wants to use the prototype further, one goal is to make this prototype accessible by choosing software and hardware that are not limited by restrictive licenses or expensive components. The prototype should also be modular to make it easy to build upon.

When new technology is introduced, there is an initial novelty of unique and innovative new things and technologies. This can be seen in the literature review paper solutions. However, a longer-term project needs to add some functional value that a previous material did not have, in order to retain usability after the “wow” factor has worn off or the technology has become more commonly known. This thesis prototype should also have functional value.

The literature review shows that TUIs have a wide range of applications. This thesis prototype ideally would allow each person to test each use case and application, but the prototype can not be expanded that widely. Given the development time of this thesis, in this thesis section “User Feedback” discussion with people in different industries shows more about the project's path.

3.1.2 Use

In Europe there is increasing interest in flexible room planning because of a rising demand for hybrid office environments. Open office concepts work as holistic and adaptable spaces, featuring rentable meeting areas and movable furniture such as chairs and tables. Tactile interface is a promising platform for exploring potential solutions, as it can interact and modify spaces. This thesis prototype focuses on specific solutions by trying to maintain a modular and expandable project, ensuring the prototype’s ability for wider use. Prototype theme is room and space planning that uses 3D-printing to produce TUIs physical objects for testing purposes. Utilising movable physical components makes the interface accessible to diverse users. Using a virtual display makes it possible to visualise and plan multiple configurations for the same space. For example, spaces can be modified to reflect different times of day, wall colours, floor materials, shapes, or arrangements of furniture, allowing for a wide range of design and rendering options.

3.1.3 Final Concept

For the final concept, this thesis is going for a tactile user interface for spatial planning. Five basic components are required to make a prototype effective for room planning. First, there is a physical object that serves as the controller, such as a plastic cube. Physical controller enables a person to interact with a virtual space by allowing different position rotations and design configurations to be reflected within it. The object's shape is scaled to the dimensions of the real-life version it imitates, as this helps users perceive it as a scale model that allows users to understand spatial relationships and proportions more accurately.

Second, an object tracker or other machine vision technology is needed to track the changes made to the physical models. This could be a simple camera. The system would interpret the user's adjustments by capturing real-time visual data. Third and fourth, a computer platform and software are needed to process the data collected by the machine vision system and then translate it into virtual space. The software could be on a phone, in the cloud, or on a local computer, interpreting the data for visualisations.

Finally, a display system is needed to show visualisations that a chosen platform generates. A display could be a screen, a projector, or another virtual window. This display translates the processed data into a detailed and accurate representation of the proposed room configuration, enabling users to visualise the outcome of their interaction. The final drawing of the proposed concept is seen in Figure 3.

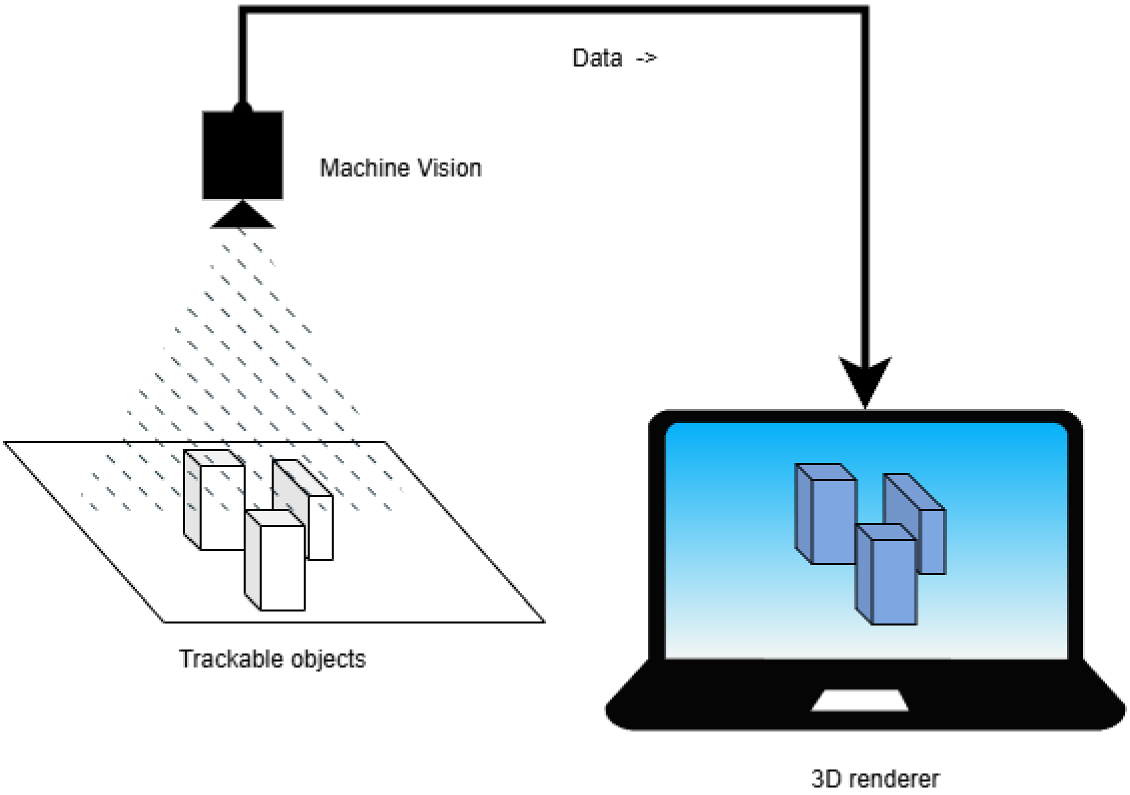

Figure 3. Concept visualisation

Users can actively design and visualise room layouts by shifting physical objects. On the screen, a person sees a digitised counterpart that combines each component: movable physical items, machine vision, data processing, and display.

3.2 Technology

The next goal is to build the prototype. This thesis prototype needs suitable technology for each concept feature, including machine vision, platform, and tracker technology. Each component and its limitations are examined to ensure that they align with the scope of the author's skills and available time.

3.2.1 Platform and Software

Software is required for this thesis prototype to render the 3D model and track changes in 3D space. Unity's game engine can build lightweight applications for desktop and Android platforms, making it an excellent solution for prototyping. The Unity game engine includes image tracking software AR-Foundation, which only builds for mobile platforms (Unity-Technologies, 2024). For a more flexible image-tracking SDK, the prototype utilises ARToolkit (ARToolKit, 2024). ARToolkit is an open-source tracking library that can calculate real-world camera transforms to virtual space from physical markers. Software that can be integrated into desktop applications is more flexible and enables enhanced performance when paired with more powerful hardware.

3.2.2 Camera and Accuracy

For machine vision, a camera is needed. In optimal situations, the camera would create clear, large, and sharp images at least 30 times every second (Meshroom-Contributors, 2021). Cameras have orthographic distortion that needs to be corrected on a camera basis. (Weng, Cohen, & Herniou, 1992) (opencv.org, 2024). The number of pixels the camera produces in the area affects the accuracy of virtual recreation. When tracking smaller physical objects and scaling them to match real-life measurements in virtual scenes, minor errors are made more significant in the virtual scene. Due to the camera's finite resolution, virtual objects often exhibit some jittering as they can exist in an invisible range between two adjacent pixels. This can be less noticeable with software. A simple equation “Equation 1” was made for this thesis to roughly map the accuracy by calculating the range of units that an object could exist in. For example, a 250mm wide platform with a 1080-pixel resolution camera and a 1:20 scale conversion would result in a 0.23 mm/pixel loss of accuracy in the virtual scenes, or over 4.6 mm. The accuracy is inversely proportional to the pixel count on one side and directly proportional to the length of the platform, as shown below. Virtual accuracy is multiplied by the proportion to which it is scaled. For example, a 100x100mm platform representing a 10x10m room would have a scale of 1:100.

$$\text{Real world accuracy} = \frac{\text{Visual area side length}}{\text{Pixels in length}}$$

$$\text{Virtual world accuracy} = \frac{\text{Visual area side length} * \text{Scale}}{\text{Pixels in length}}$$

Equation 1 accuracy relations

From equations, a table of data examples is deduced. The following table (Table 1) has error rates for two small 250mm and 500mm platforms.

Table 1. Platform size relation to camera resolution

Platform size (mm)	**Camera resolution (pixels)**	**Error Rate in the real world (mm)**	**Error Rate in the virtual world with 1:20 ratio (mm)**
250x250	1080x1080	0,23	4,63
250x250	2160x2160	0,12	2,31
250x250	4320x4320	0,06	1,16
250x250	8640x8640	0,03	0,58
500x500	1080x1080	0,46	9,26
500x500	2160x2160	0,23	4,63
500x500	4320x4320	0,12	2,31
500x500	8640x8640	0,06	1,16

A small 50cm platform requires a good resolution camera to keep the virtual error rate low. More significant error rates are more likely to cause jittering and make stacking objects vertically near each other more difficult in the virtual world, as the gap they experience can be anywhere between the error rates. To maximise the quality of the prototype, the error rate would be unperceivable to the human eye, meaning at least 1mm of virtual world accuracy. This means a small platform of 25x25cm with a 4k side length or around a 28-megapixel camera.

3.2.3 Trackers

When tracking a physical object, three types of data points need to be tracked: type, position and rotation. There are solutions for object and image tracking. This thesis prototype utilises barcodes provided with ARToolkit's "Barcode Sample" demo. An example of barcodes is shown in Figure 4. Bar codes are small black boxes with distinct features. Barcodes can be printed and applied to real-life objects, which are then captured by the camera, recording their transformation data. It calculates the position and rotation of each unique marker. Transformation data can create a digital double in a virtual world.

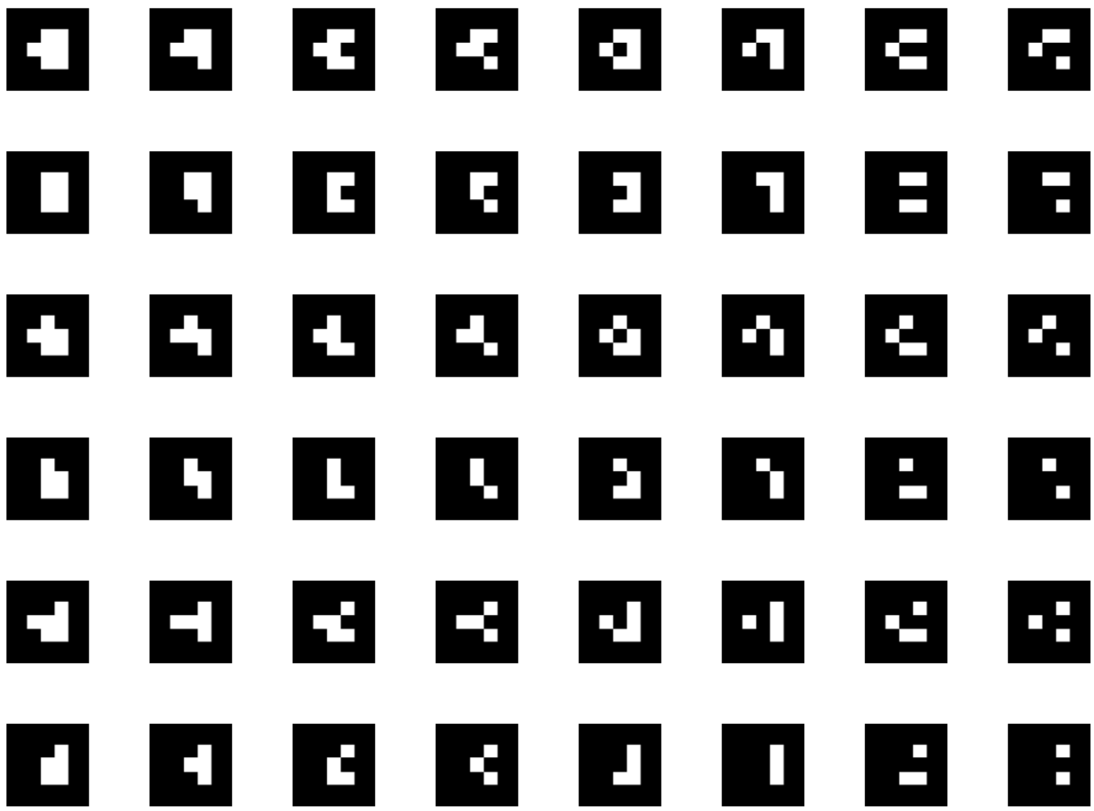

Figure 4 ARToolkit bar-codes

In this thesis prototype markers are put on simple miniatures. They were first modelled with 3D software and then printed with a 3D printer. 3D modelling took around 10 minutes per item per item. 3D printing took from 30 minutes to two hours with Ultimaker2, depending on the size of the printed object and print settings. The largest is a sofa with dimensions of 3.9 x 10.75 x 3.2 cm.

Barcode tracking works well on flat, large surfaces such as chairs or tables, as they have an easy line of sight to a camera. But thin walls can have some problems because, depending on the orientation of a wall, sides can be easily occluded. Additionally, smaller objects, such as rocks, are impossible to track as the barcodes would become too small and exhibit more noticeable error jittering due to noticeable error rates. In the future, more sophisticated object tracking, utilising the object's appearance and shape, would be a suitable fit for the project. For example, OpenCV multiple object tracking (Petrovicheva, 2020). Barcode tracking allows the fast addition of new objects, but the slowness of 3D printers makes the additions harder. 3D printing and modelling a new detailed 3D model takes several hours, and doing that for every piece makes the process long.

3.3 Prototype

In this thesis prototype’s platform, objects should be easily moved with hands while the construct should still fit in a table. The average house in the EU and US is around 100 square metres (Wilson, 2022). A 50cm platform makes a rough scale conversion rate of 1:20.

For a final prototype, the following components are used: one camera, Nikon 700, four 3D-printed objects, and Unity HDRP. From Figure 5Figure 5, the prototype can be seen in action. In Figure 5Figure 5, Camera (C) feeds a live image feed to the computer via cable. Objects (B) are tracked in the Unity project and displayed on the computer screen (A). In Figure 6, close-ups of the 3D-printed models are shown. The bar codes are placed high on flat surfaces to minimise occlusion.

Figure 5. Image of a prototype. (A) computer (B) Printer models (C) Camera

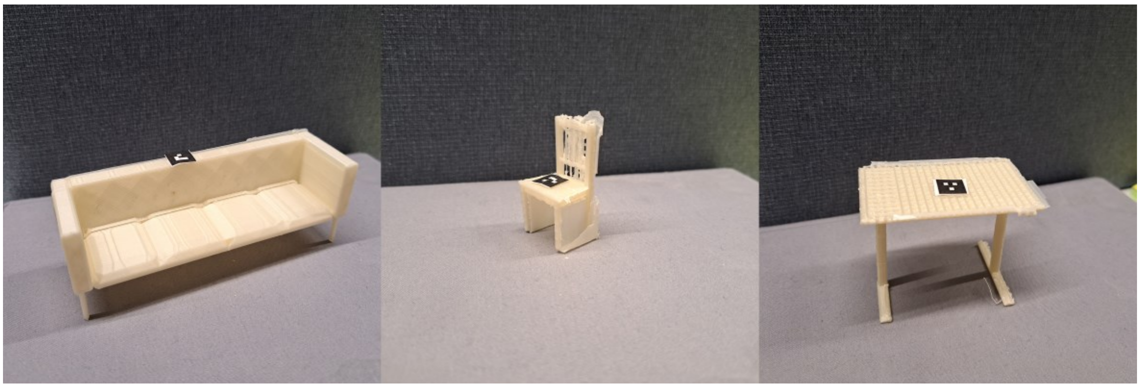

Figure 6. Closeup on 3D printed models

4 User Feedback

The finished prototype is presented to individuals as a concept they can explore. The purpose is to map and identify the ideas people project onto the demo for potential future applications. Interviews were gathered from people at the MatchXR 2024 event and around the Aalto University campus. In a conversational tone, eleven people are interviewed. Their occupations and the question, “What uses could you see for this?” are posed to provoke ideas from participants. Four of the questions from people are chosen in this thesis. Questions that are answered are chosen by the most creative and useful ideas. For each question, the author offers their opinions and insights regarding how the prototype developed for this thesis can address this issue.

A person with the role of event organisation and supervisor asked a question: “Would this be good for vendors when planning venues for Christmas events?” Thesis author: The thesis prototype can be easily used to plan venues. However, this could already be managed with simpler technology by printing 2D floor plan and precut shapes that could be moved around the floor plan. Utilising a scale model of the area could be a valuable approach to creating commercial materials for advertisements. Once complete, the scale model could be used on-site as a miniature map to help people navigate the area. The prototype does not need much modification. Each table could be represented with a small cube that can be printed quickly in large quantities, and a rough size and layout could be modelled or scanned with the phone.

A family of four is moving into a new apartment, and they asked, “Would this (the prototype) be good for planning when we move in?” They are interested in planning the placement of heavy furniture before moving in. Author: While a small-scale project may appear beneficial, the process of designing, printing, and modelling multiple 3D objects that fit the specific dimensions of the furniture might be too much work and effort for such a small one-time application. Fitting new furniture in a differently shaped house is a problem that can be solved with a ruler and a piece of paper. With measured furniture, a person can cut paper shapes into the correct sizes and use them as a guide. For a museum or theatre with large spaces and multiple objects to move, where users will use the prototype more than once, the prototype would be valuable and worth developing.

Could this be a game that helps people learn on the Aalto University campus by replicating areas with blocks?” Author: Implementing the prototype in multiple places would be expensive and hard to add, as each place would need its own screen, and fixing and maintaining them most likely would be too much work. Current physical 2d maps of the campus are widely used and appear to be effective. But the idea of making a game would be a fun implementation in one place. This could be a stop for new students on the orientation day, where they get to try and play with it. At the same time, it could be something visitors or children could enjoy.

“Could this help set picture paintings around the gallery?” Author: Changing the prototype to work with walls instead of the floor is possible. The prototype area could be created using miniature 3D printed walls. With multiple cameras for tracking, occlusion would not be a problem. The paintings could be small rectangular approximations which are magnetically attachable to the walls. Visualising an art gallery would greatly benefit from the digital visualisation part. The atmosphere of the gallery could be more easily planned with interactive real-time visualisations. The light and paintings could be easily changed.

In conclusion, the people interviewed in this thesis had interest and curiosity to the thesis prototype. It has potential to work in many applications and could work as a versatile tool for spatial visualisation and planning. However, in the author’s mind, the project is more suited to active and wider use. While some use cases, such as arranging household furniture, might be more efficiently accomplished with traditional non-digital solutions, venue layout planning for events or the arrangement of art in museums are more specific and work on a larger scale. They would benefit more from digitalisation. For the prototype, a campus-wide learning game concept highlights this thesis project’s potential as an engaging and interactive work. The idea of adapting the prototype to plan art displays in galleries demonstrates that the prototype’s utility can extend beyond simple flat surfaces, making its flexibility a successful feature.

5 Conclusions

This thesis investigated the potential of tangible user interfaces (TUIs) as a possibility to bridge physical and digital reality, aiming to add to the usability, flexibility, and reach of virtual assets and creative materials. By examining the review paper “Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application”, this research identified a range of TUI applications and ideas. These included educational tools, museum exhibits, and other designing platforms integrating real-world objects with virtual elements. A prototype was designed and used to test a functional TUI demo, and later, additional use cases were discussed.

The literature review findings showed that TUIs can add value to creative material by creating intuitive interactions and displaying novel digital visualisations. The reviewed examples showed that TUI technologies can increase engagement, make spatial planning more intuitive, and enhance storytelling. The existing TUI solutions can be adapted to add value to creative materials by making them interactive and contextually rich.

When constructing the prototype, it became evident that open-source software and available hardware components can form a workable foundation for other people to build TUIs, which allows customisation and development of TUIs further to individual needs. This study’s prototype explored layout planning using a game engine and machine vision from the open-source ARToolkit tool. The prototype demonstrated the possibility of constructing a simple TUI platform that could be expanded on. Limitations emerged in marker resolution requirements, jittering in digital elements, and difficulties scaling down certain objects or applying the system to smaller sizes. For future development, this thesis prototype would likely be part of a large-scale project focusing on a single use case to assess how these limitations impact full applications.

In conclusion, this research showed that TUIs are accessible and modifiable systems that offer a platform for making better creative solutions and spatial plans. As technologies evolve, TUIs will most likely continue to expand their role in the VR and AR scene and continue bridging the gap between the digital and physical worlds.

References

artoolkitx. (2024). *github.com*. Retrieved 2024, from https://github.com/artoolkitx/arunityx

Campos, P., Pessanha, S., & Jorge, J. (2010, November). Fostering Collaboration in Kindergarten through an Augmented Reality Game. *International Journal of Virtual Reality, 10*, 33–39. doi:10.20870/IJVR.2011.10.3.2819

Jenkinson , J., & Watson, N. (2024). *Top 10 Office Design Trends for 2024*. Retrieved December 3, 2024, from Top 10 Office Design Trends for 2024: https://officeprinciples.com/insights/office-design-trends-for-2024

Krestanova, A., Cerny, M., & Augustynek, M. (2021). Review: Development and Technical Design of Tangible User Interfaces in Wide-Field Areas of Application. *Sensors, 21*. doi:10.3390/s21134258

Ma, J., Sindorf, L., Liao, I., & Frazier, J. (2015). Using a Tangible Versus a Multi-touch Graphical User Interface to Support Data Exploration at a Museum Exhibit. *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 33–40). New York, NY, USA: Association for Computing Machinery. doi:10.1145/2677199.2680555

Matteo, S., Martina, B., & Enrique, F. M. (2024). Telework by region and the impact of COVID-19 pandemic: An occupational analysis. European Commission. Retrieved 2024, from https://publications.jrc.ec.europa.eu/repository/handle/JRC137946

Meshroom-Contributors. (2021). *meshroom-manual.* Retrieved 2024, from https://meshroom-manual.readthedocs.io/en/latest/tutorials/sketchfab/sketchfab.html

Nations, U. (2023, October). *Building Blocks of a Better City: Minecraft's Role in Urban Development*. Retrieved December 11, 2024, from Building Blocks of a Better City: Minecraft's Role in Urban Development: https://unric.org/en/building-blocks-of-a-better-city-minecrafts-role-in-urban-development/

opencv.org. (2024). *docs.opencv.org.* Retrieved 2024, from https://docs.opencv.org/4.x/dc/dbb/tutorial_py_calibration.html

Petrovicheva, A. (2020). Multiple Object Tracking in Realtime. Retrieved 2024, from https://opencv.org/blog/multiple-object-tracking-in-realtime/

Potidis, S., & Spyrou, T. (2014). *Spyractable: A tangible user interface modular synthesizer.*

Unity-Technologies. (2024). AR development in Unity. Retrieved 2024, from https://docs.unity3d.com/Manual/AROverview.html

Vaz, R. I., Fernandes, P. O., & Veiga, A. C. (2016). Proposal of a Tangible User Interface to Enhance Accessibility in Geological Exhibitions and the Experience of Museum Visitors. *Procedia Computer Science, 100*, 832-839. doi:https://doi.org/10.1016/j.procs.2016.09.232

Weng, J., Cohen, P., & Herniou, M. (1992). Camera calibration with distortion models and accuracy evaluation. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 14*, 965-980. doi:10.1109/34.159901

Wilson, L. (2022, July). *How Big is a House? Average House Size by Country - 2024*. Retrieved November 30, 2024, from How Big is a House? Average House Size by Country - 2024: https://shrinkthatfootprint.com/how-big-is-a-house/