Digital E-Guestbook with Tangible Embodied Interfaces: An Interactive Tree Visualization for Public Spaces

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Abstract

This report delineates the conceptualization, prototype development, and subsequent discussion of a digital e-guestbook that incorporates tangible embodied interfaces (TEI). Intended for public spaces such as libraries, museums, or educational institutions, the e-guestbook features an interactive tree visualization that dynamically grows with each visitor's contribution. The project seeks to foster community engagement, instill a sense of belonging among visitors, and facilitate social interactions within these public spaces. The TEI provides users with a custom leaf-shaped keyboard, enabling them to append unique leaves to the growing tree, signifying their presence and engagement within the space. Developed using Unity, the e-guestbook utilizes innovative visualization and user interaction design techniques to create an immersive and captivating experience.

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Chapter 1

Introduction

In recent years, public spaces, including libraries, educational institutions, and museums, have sought innovative methods to augment visitor engagement and social interaction. Traditional paper-based guestbooks, which have functioned as a medium for visitors to express their impressions and exchange experiences, are progressively becoming obsolete and underutilized owing to the growing dependence on digital technology and shifting user preferences.

Tangible Embodied Interfaces (TEI) are systems that bridge the physical and digital worlds, typically involving physical objects that can be touched and manipulated to control digital information. This project leverages the potential of TEI to address the challenge of underutilized traditional guestbooks. The central question we aim to answer is: How can modern technology, specifically TEI, revitalize traditional guestbooks, thereby making them more appealing and engaging for contemporary audiences?

The primary objective of this project is to foster community engagement and social interactions in public spaces. We plan to achieve this by developing a TEI-based e-guestbook that provides a captivating interactive experience. This unique and innovative approach allows users to leave their mark, attracting more visitors to engage and interact, thereby enhancing the social atmosphere and engagement within public spaces.

The e-guestbook's implementation utilizes the Unity game engine in conjunction with an Arduino-based leaf-shaped keyboard as the tangible input. This combination effectively captures user inputs and transmits the data seamlessly to Unity, integrating user-generated content into the interactive tree visualization. Each individual can contribute their own customized leaf to the tree, representing their presence and personal connection to the space. The growing contributions from visitors are showcased, intertwining tangible input hardware with engaging digital visualization, fostering a unique and novel experience.

This report is structured as follows: a literature review, ideation process, prototype development, discussion. Each section respectively explores relevant research and theoretical background, details the design concept's evolution and refinement, presents the prototype implementation, and summarizes findings, outcomes, future opportunities and conclusion.

Chapter 2

Literature Review

This literature review presents the essential background and methodological principles informing the development of the project. As an evolving interdisciplinary field, tangible and embodied interactions have been garnering increased attention within the research community. The body of work explored in this section offers a focused exploration of these topics and their relevance to the e-guestbook project. This section is organized around three primary themes: 1) TEI and Physicality, 2) Design Challenges and Prototyping, and 3) Design Principles and User Experience.

2.1 TEI and Physicality

The intrinsic physicality of Tangible Embodied Interactions (TEI) encourages a more immediate and engaging involvement with the world through the interaction with computational objects incorporated into the physical environment. This viewpoint is underscored in the article by Hornecker (2011), which was published in the Interactions magazine.

Embodied interaction refers to the idea that our understanding and interaction with the world are fundamentally shaped by our physical bodies and the environment. Hornecker (2011) emphasizes that TEIs incorporate an expansive variety of systems that utilize this concept, merging body movement, tangible manipulation, and physical data embodiment. Further emphasizing the critical role of this integration, Hornecker (2011) underscores the necessity of merging digital and physical elements in designing interactions that resonate with our natural abilities. Moreover, the article posits that the evolution of TEI inherently demands an interdisciplinary approach, which in turn opens up novel opportunities for interaction. It's suggested that collaboration across diverse disciplines is crucial for the development of innovative and effective TEI solutions. Embracing this interdisciplinary essence, our project brings together insights from diverse domains such as Human-Computer Interaction (HCI), computing, product design, and interactive arts.

Building on the value of tangible elements, Hulusic et al. (2023) delves into the efficacy of Tangible User Interfaces (TUIs). Specifically, their research examines how TUIs can augment user experience and immersion in virtual reality applications, with a particular focus on the cultural heritage sector. The study implemented physical counterparts to virtual objects of a School House Virtual Museum (SHVM) and argued that this approach can heighten users' sense of presence and facilitate a more robust cognitive mapping of the virtual environment. This principle, known as Substitutional Reality, accentuates the importance of harmonizing virtual and physical environments within the realm of virtual reality applications. Notably, Hulusic et al. (2023)' findings suggest that even low-fidelity proxies exhibiting minimal or moderate inconsistencies can induce positive effects on the user experience.

Upon considering these insights, it becomes evident that employing TUIs in interaction scenarios presents a promising avenue for enriching user engagement and immersion. The evidence presented in this study concurs with Hornecker (2011)'s findings on the significance of incorporating tangible components into interactive systems.

2.2 Design Challenges and Prototyping

The creation of tangible components for interactive systems necessitates a complex, multidisciplinary approach. Zuckerman et al. (2016) introduce a prototype TEI, termed 'DataSpoon', specifically designed to assess movement kinematics during self-feeding in children afflicted with motor disorders, including cerebral palsy. This innovatively instrumented spoon generates invaluable quantitative data that aids professional caregivers in formulating more efficacious treatment strategies. The design process of DataSpoon presented distinct challenges, particularly in reconciling user, technical, and safety requirements that could potentially conflict.

Extending the discussion to the involvement of stakeholders in the design process, Zuckerman et al. (2016) highlight the significance of incorporating perspectives from a diverse array of stakeholders, including professional caregivers, safety experts, and the children themselves. This inclusive approach caters to the needs of both caregivers and children, culminating in a design that is both effective and user-friendly. A recognized limitation of this study is the small number of participants - only two - involved in the validation process. Despite this limitation, the study provides valuable guidelines for designers of assistive technologies catering to children with disabilities. These guidelines emphasize preserving the direct interaction between caregivers and children, and the development of assistive technologies that mimic familiar tools and artifacts. This accentuates the potential of TEIs in improving the quality of life for individuals with disabilities, contributing significant insights to the field of assistive technology development.

Progressing from the theoretical foundations of Tangible Embodied Interactions (TEI), Visschedijk et al. (2022) investigate its practical implementations, introducing ClipWidgets, an innovative system of modular tangible User Interface (UI) extensions for smartphones. The system, crafted using 3D printing technology, encompasses a suite of components including widgets, a custom phone case, markers, and recognition software. There are three thoughtfully designed widgets: button, dial, and slider. Each of these widgets includes a movable interaction component coupled with a mechanism that transcribes this motion into marker rotation.

The ingenuity of ClipWidgets lies in its ability to sense multiple input types concurrently, without the need for specialized or external hardware. The 3D-printed phone case serves a dual purpose - it not only facilitates the attachment of modular widgets but also assists in the process of computer-vision-based interaction detection. The markers, small coloured objects on each widget, rotate in a preset manner during user interaction. This rotation enables the computer vision software to discern the status of the widget. Visschedijk et al. (2022) illustrates the versatility and functionality of ClipWidgets through its applications as a game controller, a music interface, and an interactive graph tool. This research on ClipWidgets unveils the potential of multi-modal input and modular design, revealing how these facets can appreciably augment the versatility and adaptability of TEIs. In a practical application of these principles, our custom keyboard, equipped with buttons, sliders, and dial elements, exemplifies the concepts and design methodologies underscored in the research.

The other methodologies employed in the **?** study, including the use of 3D printing technology and computer vision-based interaction detection, which present valuable strategies for the e-guestbook project. These methodologies pave the way for rapid prototyping and customization, aligning seamlessly with the iterative design approach emphasized in the previous paper by **?**. This congruence not only underscores the relevance of the ClipWidgets research to the e-guestbook project but also bolsters its academic foundation, demonstrating the project's grounding in cutting-edge research.

Moreover, the methodologies deployed in the Visschedijk et al. (2022) study, which include the utilization of 3D printing technology and computer vision-based interaction detection, furnish beneficial strategies for the e-guestbook project. These methodologies herald the possibility for rapid prototyping and customization, aligning perfectly with the iterative design approach emphasized previously by **?**.

2.3 Design Principles and User Experience

Crafting compelling user experiences often entails harnessing elements inspired by nature within interactive designs. The integration of natural phenomena into interaction design, as explored by Ossevoort and Bruns (2023), presents a pioneering approach that offers a unique perspective on the relationship between technology and the environment. They brought forward the notion of incorporating natural phenomena as a potent design element in interactions, as illustrated by their creation, Flare – a silk dress that responds to wind currents. Such an approach not only amplifies sensory experiences but also cultivates a profound bond with nature. By treating nature as an integral contributor in the design process, one can create interactions that intrigue users on both physical and emotional dimensions.

It's evident that integrating nature-inspired elements into interactive systems constitutes a promising strategy, as it induces a sense of balance and cohesion, thereby enriching the user experience. For instance, trees symbolize growth and resilience, serving as prominent and influential emblems of nature. The incorporation of tree-inspired features or other natural elements into interactive systems cultivates a more profound connection between users and their environment. In the context of the e-guestbook project, the integration of tree can motify markedly enhances the user experience. By aligning the project with the natural world, sensations of familiarity and comfort could be evoked, thereby mitigating the divide between the digital and physical realms.

Beyond the tangible hardware in TEIs, the transformation of data into meaningful, physicalized representations also holds a pivotal role. van Koningsbruggen et al. (2022)'s seminal study illuminates the influence of data physicalisation on the comprehension and interpretation of data. The researchers present an inventive approach termed 'Data Diaries', a sequence of tasks transitioning from data visualisation to physicalisation, illustrating the capacity of tangible interactions to augment data understanding.

The findings indicate that participants encountered difficulties while utilising materiality to communicate data. However, overcoming these challenges led to a deeper understanding of the data itself. Interestingly, van Koningsbruggen et al. (2022) also observed that the tangible nature of the data representations make data physicalisations focus not only on efficiency and accuracy but also on the story of the data.

These conclusions accentuate data physicalisation's potential in forging more engaging and meaningful tangible interactions. The 'Data Diaries' approach underlines the importance of storytelling in data physicalization. It emphasizes the need to frame data in a way that resonates with users on a personal level, rather than merely showcasing quantitative metrics.

Inspired by van Koningsbruggen et al. (2022) study, our project seeks to apply data physicalisation principles to accentuate the distinctive story of the tree and its visitor interactions. By incorporating personal and contextual elements into the data visualisation, we aspire to craft an immersive and intuitive experience that encourages user engagement with the tree and contributions to its growth and evolution. This strategy cultivates a deeper connection between users and the tree, leveraging innovative TEI-based solutions to bring the story of the tree to life.

The integration of interactive tables within domestic settings, while promoting home engagement, presents a novel research direction as explored by zum Hoff et al. (2022). This research delves into the potential role of digital support for domestic interactive tables, traditionally perceived as 'social interfaces' within homes. The researchers highlight a prevalent gap in the design of such interactive systems for home settings, given that most existing designs cater predominantly to public interactions, collaborative work, and educational environments. They attribute this gap to a lack of understanding and appropriate applications for designing interactive tables within the domestic context. In their attempt to bridge this gap, zum Hoff et al. (2022) conducted a study proposing four design principles—Sociality, Flexibility, Distinctiveness, and Homeyness—as guiding pillars for future interactive table designs for domestic use. Their conclusion postulates that digitally augmented tables can serve as social hubs within homes, linking the physical and digital activities of household members, thereby facilitating more satisfying communication practices while delineating boundaries between private and work-related activities.

While the study by zum Hoff et al. (2022) offers insightful contributions, it is not without limitations. Concerns remain about the representativeness of the survey sample and the generalizability of the findings to other populations. There might also exist unexplored alternative perspectives on designing interactive tables for domestic settings. Nevertheless, the study provides valuable insights into the potential of interactive tables to augment social experiences within home environments. The design principles proposed—Sociality, Flexibility, Distinctiveness, and Homeyness—establish a pragmatic framework for designing interactive systems that aim to boost social engagement and cultivate connections.

These principles can be extended to this project to ensure effective facilitation of user interaction and fostering community spirit. For instance, the principle of Sociality can guide the design of the e-guestbook to stimulate interaction and engagement within public spaces. Flexibility can be ingrained by accommodating diverse user preferences, needs, and modes of system engagement. The principle of Distinctiveness can assist the e-guestbook in providing unique and customizable experiences, distinguishing it from traditional guestbook or mobile applications. Lastly, the principle of Homeyness can be used to create a warm and inviting atmosphere that appeals to users on a personal level and fosters a sense of belonging among visitors.

2.4 Conclusion

This literature review has explored some key articles in the fields of tangible and embodied interaction. The review serves to provide methodological guidance and inspiration across various aspects of the e-guestbook project, ensuring its development is rooted in a strong academic foundation. The studies analyzed in this review not only demonstrate the feasibility and practical value of this project but also highlight the innovative potential of integrating interdisciplinary approaches and concepts.

Chapter 3

Ideation Process

The ideation process, a critical and creative journey, is integral to the Design Thinking methodology. This stage centers on the generation, exploration, and evolution of concepts, aiming to craft innovative solutions. In the context of this project, the ideation process is tasked with transforming the traditional notion of guestbooks by leveraging modern technology, specifically Tangible Embodied Interfaces (TEI) and interactive displays.

3.1 Motivation and Conceptual Framework

The motivation for this project stems from the need to modernize the traditional concept of guestbooks. In today's digital age, when thinking about the act of signing a guestbook, the most intuitive idea that often arises may be that of simply scanning a QR code and filling the form with our smartphones. Although efficient, this often lacks meaningful engagement and personal connection, functioning merely as an empty formality. Individuals remain oblivious to their impact on and belonging within the shared space.

This project seeks to reimagine this interaction by developing an interactive digital guestbook. Rather than logging attendance as a superficial formality, the guestbook aims to showcase visitors' unique contributions to the shared space. The envisioned experience extends beyond efficiency and practicality alone. It strives to cultivate community and amplify visitors' sense of belonging. Aligning with broader trends toward interactive and immersive digital experiences, the guestbook addresses the impersonal nature of many digital tools by infusing them with physicality and personal touch.

The conceptual framework holds potential to reshape how we interact in and engage with public spaces. An interactive platform for creative expression, the digital guestbook could become a focal point where inclusivity is engendered and community is built.

Visitors are transformed from passive occupants of a space into active contributors and participants, forging personal connections with the space and each other.

By leveraging technologies like TEIs and interactive displays, this reconceptualized guestbook logs more than just an individual's attendance. It showcases their unique creative expressions, reflections, and stories. Although visitors may remain anonymous, their accumulated contributions develop a rich tapestry, weaving together the character and spirit of the community. What emerges is a collaborative, creative work—one that did not exist before the interactions and continues to grow and transform with every new visitor and entry.

This project envisions the potential for technology to amplify human experience rather than diminish it. Tools are developed not for efficiency alone but to cultivate meaningful interactions and a shared sense of purpose. By design, the digital guestbook fosters an environment where strangers can create and build together, transcending physical and social barriers through the collaborative act of adding their voice.

3.2 Framing "How Might We" (HMW) Questions

As emphasized by Rikke Friis Dam (2021), "How Might We" (HMW) questions serve as an influential instrument for sparking innovative ideas and potential solutions during the ideation phase of a design challenge. These broad and open-ended questions allow for exploration of a wide range of solutions while keeping the focus on the project's objectives and user needs. HMW questions are conceived by reformulating the primary problem statement or Point of View (POV) into an investigative inquiry. This transformation fosters innovative thinking and directs the ideation process.

For this project, the following HMW questions are formulated:

1. "How might we make the guestbook more interactive for public spaces?"
2. "How might we embody user's responses in tangible interfaces?"
3. "How might we visualize the responses in a way that symbolizes the guests as part of the building's ecosystem?"

These questions serve two key purposes in the ideation process. Firstly, they catalyze creativity during brainstorming sessions, stimulating a wealth of diverse ideas. Second, they help keep the ideation process centered on the previously identified core insights.

3.3 Initial Ideas and Brainstorming

The initial concept is inspired by the rendering pipeline in computer graphics. This pipeline involves vertex processing (points), primitive assembly (lines), and rasterization (faces). Drawing from this concept, a tangible interaction model is proposed in which users place pins onto a felt board and connect them using lines to create shapes as shown in the figure below. To digitize these shapes, a camera setup captures an image of the felt board. The captured image is then analyzed using computer vision techniques to reconstruct the created shapes.

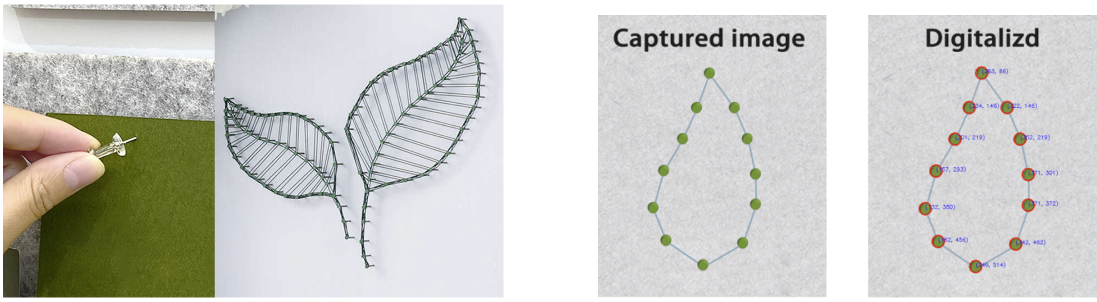

Figure 3.1: Proposed physical element and digitization process[1]

However, the idea did not stop there. Through brainstorming and iterative design, the concept evolved into its current state, incorporating various elements. The brainstorming outcomes are presented in Figure 3.2.

The Figure 3.2 illustrates the brainstorming map, delineating the diverse components and pertinent considerations within the scope of the e-guestbook. The map is segmented into four principal categories:

1. **Hardware Components:** This section outlines the different physical elements under consideration for the project. It comprises a range of potential components, such as an Arduino-powered keyboard, an image capturing camera setup, and numerous interactive elements.

2. **Software Components:** Moving to the software side, this section segment into an array of software tools and methodologies under contemplation. It spans various software solutions, incorporating real-time interactive platforms, 3D modeling utilities, and computer vision methodologies.

3. **User Engagement:** Pivoting focus towards the user, this category underscores strategies tailored to augment user interaction and personalization. It covers a broad spectrum of potential strategies, from real-time response mechanisms and user-driven experiences to social interaction catalysts and gamification.

4. **Visualization of User Responses:** The final segment discusses the visual representation of user responses. It includes a range of potential visualization techniques, primarily centered around a tree-like structure that dynamically evolves in response to user activity.

[1]Image source: https://www.pinterest.com/pin/868350371882373811/

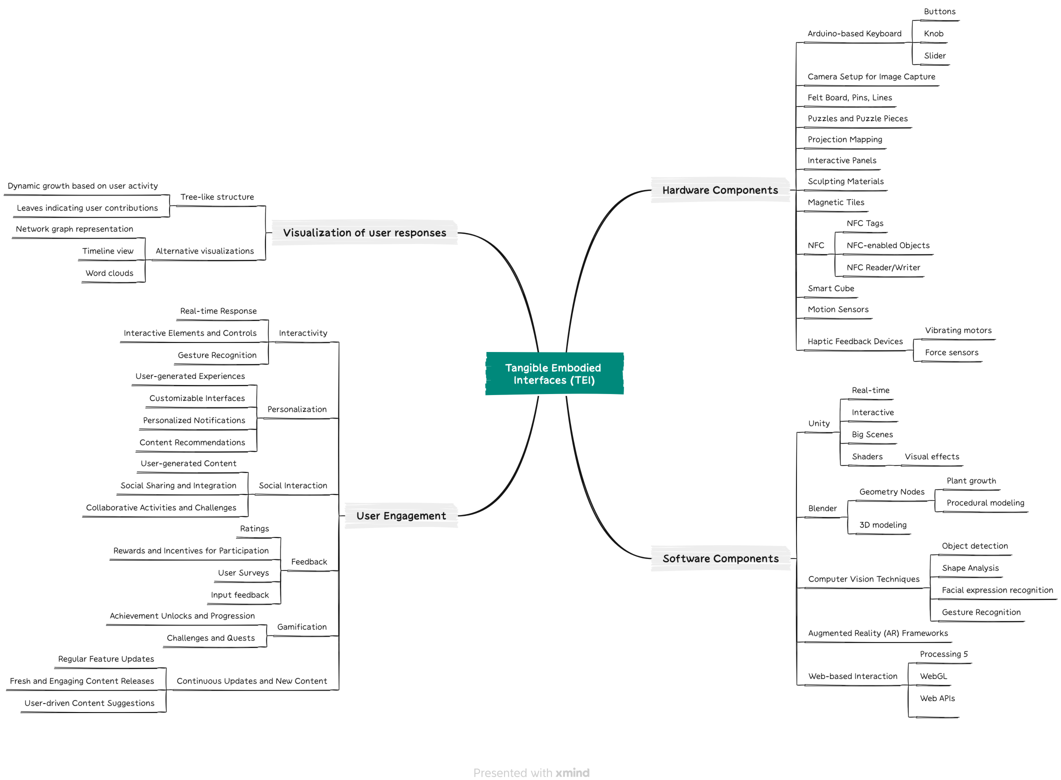

Figure 3.2: Brainstorming map

3.4 Symbolism of the Tree

The third HMW question and the outcomes of the brainstorming session collectively inspired the selection of a tree as the central motif. This decision was not arbitrary; rather, it carries profound symbolism.

3.4.1 Symbolic Significance of the Tree

Universally, trees symbolize growth, strength, and interconnectedness. They represent the life cycle, with each new leaf metaphorically symbolizing a new message or memory inscribed into the e-guestbook. This representation enables users to visualize their contributions as integral components of a larger, growing entity, thereby nurturing a sense of community and shared experience.

3.4.2 Inspiration from a Shrub

Figure 3.3: Moving shrub[2]

A key source of inspiration for this project was the sight of a shrub meticulously sculpted to become an integral part of the architectural landscape (as shown in Figure 3.3). The pruned part of the shrub, conforming to its surroundings, reflected the static nature of the building, while the outward-growing branches, asserting their vitality, symbolized dynamic growth and evolution. The idea of representing people as these vibrant leaves, stretching beyond the pruned structure and adding their unique flair to the overall form, emerged. This observation led to the concept of our e-guestbook, where each visitor's input is a new leaf on an ever-evolving digital tree, together forming a vibrant ecosystem that mirrors the community within the building.

[2]Image captured by Dr. Anne Ozdowska.

3.4.3 Inspiration from Literature

Ossevoort and Bruns (2023)'s paper also influenced the tree's selection. This paper emphasizes the potential of embedding natural phenomena into interactive system design, positing that this approach can bolster reconnection between humans and nature. By integrating tree-inspired features into the e-guestbook, a deeper connection between users and their surroundings can be forged, effectively bridging the gap between the digital and physical realms.

3.4.4 Alignment with Project Goals and User Interaction

Moreover, the dynamic growth of a tree aligns with the project's objective to construct an interactive and evolving visual display. As users append their messages, the tree expands and transforms, mirroring the community's continuous participation and engagement. This visual metaphor also offers an intuitive and engaging interface to users, encouraging interaction and exploration.

3.5 Prototyping and Iteration

Adopting the concept of rapid prototyping, this study draws inspiration from the DataSpoon study by Zuckerman et al. (2016). To refine and validate ideas, quick hardware prototyping and testing are conducted using Arduino. This phase involves the creation of multiple prototype versions to examine different facets of the e-guestbook design, allowing for the exploration of various tangible interaction models. Further details are covered in the subsequent Prototyping Development section.

3.6 Final Concept

Hardware Components: An Arduino-based leaf-shaped keyboard with buttons, knobs, and sliders for user input.

Software Components: Unity game engine and Blender are deployed for real-time interaction and 3D modeling respectively.

Visualization: The e-guestbook incorporates an interactive tree visualization as its focal point, which dynamically grows and evolves in response to user contributions and activities.

Users interact with the e-guestbook by employing the leaf-shaped keyboard's buttons to contribute new leaves, each of which can be uniquely customized by pressing buttons again. The slider adjusts the camera position within the visualization, enabling users to examine various angles and perspectives of the evolving tree. By manipulating the knob, users can trace the tree's growth and evolution over a specific timeframe, offering insight into its progression over time.

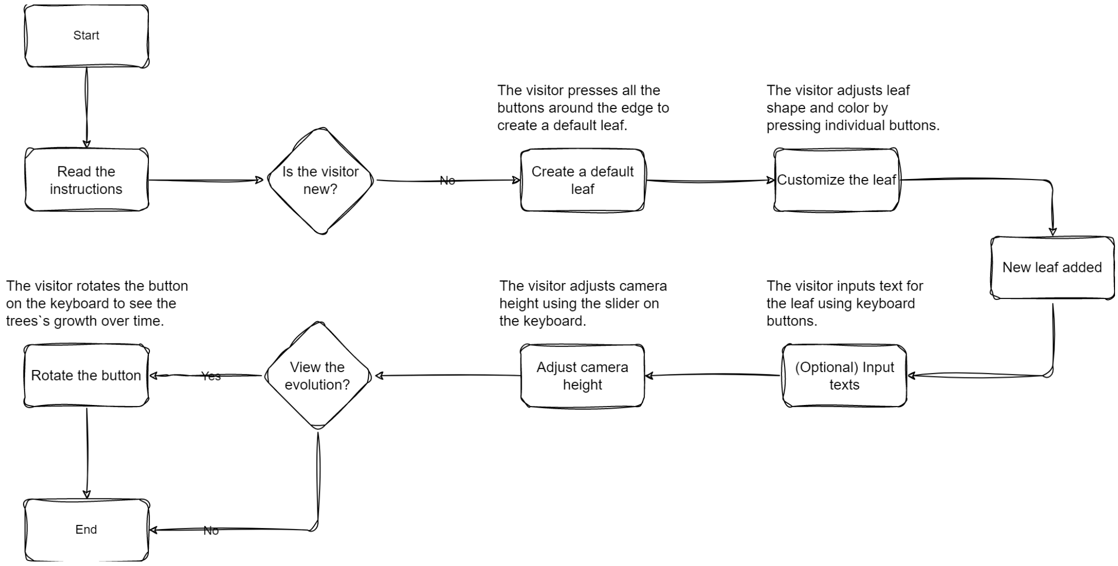

Figure 3.4: UserFlow chart

Chapter 4

Prototype Development

For more demonstrations of this project, please visit the GitHub repository at https://github.com/crzaycatseven/TEI-Guestbook-Tree.

4.1 Hardware Prototyping

4.1.1 Hardware Components

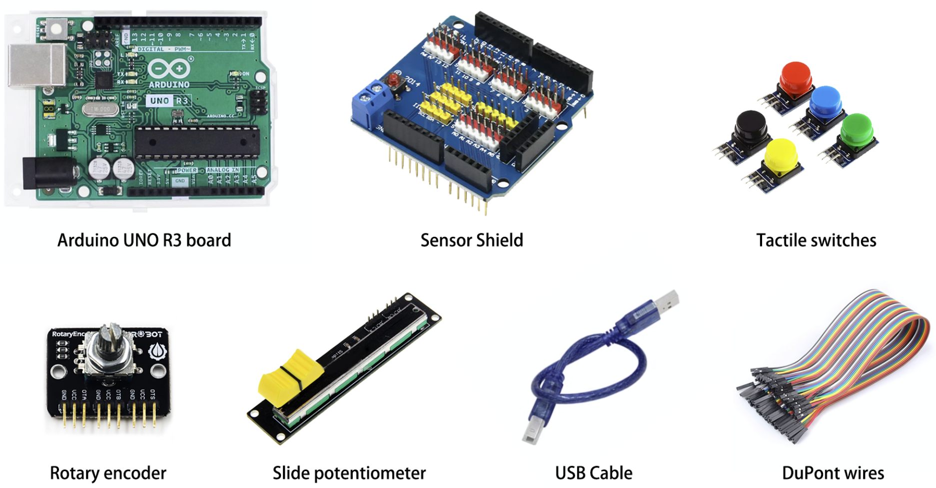

Figure 4.1: Hardware Components[1]

[1] Image source: Online shop, https://shop225003950.taobao.com/

The e-guestbook hardware prototype uses Arduino-based components, including the following:

- **Arduino UNO R3 board:** This serves as the central processing unit of the project, controlling all input and output devices. Within the prototype, it is utilized to interpret user inputs and relay this information to the Unity game engine for processing.
- **Arduino UNO R3 Sensor Shield:** This component is mounted on the Arduino board, facilitating the connection of various sensors. In the prototype, it is used to connect the tactile switches, rotary encoder, and slide potentiometer.
- **Tactile switches:** These switches are part of a leaf-shaped keyboard that serves as the user's input device. In the prototype, users contribute a new leaf and customize it by pressing these switches.
- **Rotary encoder module (with a built-in switch):** This module is also part of the leaf-shaped keyboard. In the prototype, users view the growth and evolution of the tree over a specific period by rotating this encoder.
- **Slide potentiometer module:** This module, another component of the leaf-shaped keyboard, serves as an input device for the user. In the prototype, users control the camera position within the visualization by sliding this potentiometer, allowing them to explore the evolving tree from different angles and perspectives.
- **Wires:** The DuPont wires are specifically used to connect the sensors to the Sensor Shield, while an USB Type A to Type B cable is specifically used to connect the Arduino board to the computer for code uploading and debugging.

4.1.2 Prototype Assembly

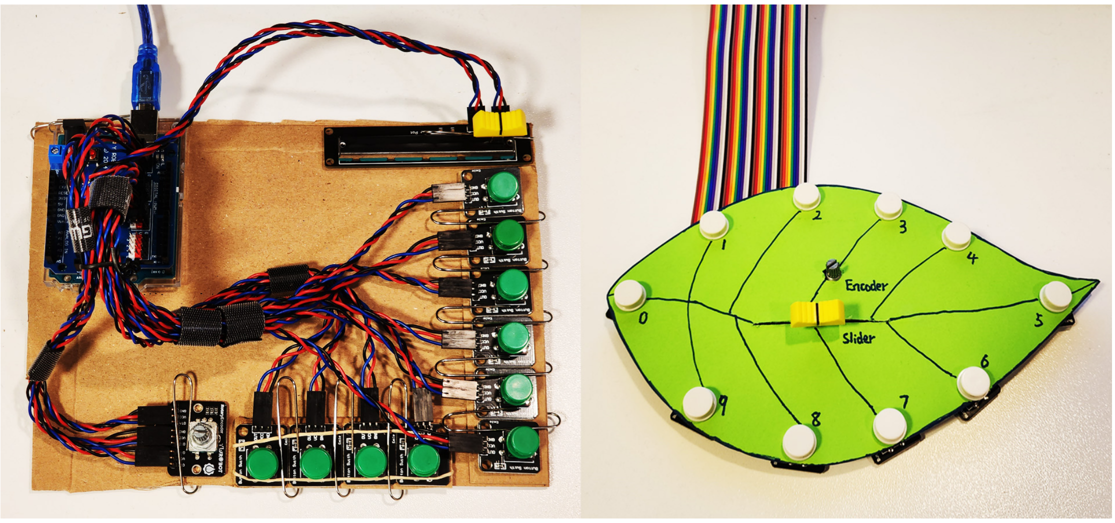

Figure 4.2: The Assembled Prototype: The left-hand side depicts the basic assembly, while the right-hand side presents the assembly with a tree-shaped keyboard crafted from cardboard.

During the prototyping process, soldering was not used, to make the process easier to repeat and modify. The Sensor Shield was mounted on top of the Arduino board, and the sensors, including the tactile switches, rotary encoder, and slide potentiometer, were connected to the Sensor Shield using DuPont wires. Figure 4.2 provides a visual representation of the fully assembled prototype.

4.2 Software Prototyping

Software prototyping holds a pivotal position in actualizing the interactive and visual components of the e-guestbook project. During this phase, the conceptual ideas were transformed into tangible interfaces, offering an early insight into the final product. This transition was realized through the development of interaction interfaces, data processing management, and exploration of how user inputs could be integrated into the dynamically evolving visual display.

4.2.1 Tree Modeling

The visual embodiment of the e-guestbook project takes the form of a growing tree, which serves as the foundation for all other functionalities. The tree modeling process consisted of twointegral components: establishing the tree's framework and rendering its mesh. Nonetheless, this process presented an array of challenges necessitating creative problem-solving and repeated iterations. To address the issues and refine the outcomes, three distinct strategies were sequentially implemented.

First Approach: Procedural Generation

The preliminary strategy employed procedural generation via a C# script, where a key parameter—`Growth Factor`, ranging from 0 to 1, modulated the tree's growth. Relying on this parameter, algorithms and random number generation fashioned the tree's framework vertices (points), subsequently utilized in mesh generation. Nevertheless, this method fell short of yielding satisfactory outcomes. The unpredictability resulting from the randomization rendered several aspects of tree growth uncontrollable. Consequently, the generated tree exhibited a mechanical and unnatural appearance. The method also struggled with accurately reflecting the variation in trunk and branch thickness during growth, compromising its natural aspect. Besides, this strategy was computationally demanding and more suited for small, simplistic trees. For larger, intricate trees, considerable processing was required, which impeded real-time interactivity.

Second Approach: Pre-modeling and Shader

The secondary strategy entailed constructing a complete 3D tree model in Blender, an open-source 3D computer graphics software toolset. Once the model was created, its UV mapping was manually adjusted to a specific layout. The model was subsequently imported into Unity, where a custom shader facilitated the tree's growth control. However, manually adjusting the UV mapping proved extremely time-consuming. Furthermore, the growth animation is similar to the layer-by-layer output of a 3D printer and unnatural, which left a persistent horizontal cross-section.

Final Approach: Combination of Procedural and Pre-modeling

The final strategy introduces a novel method of initially constructing the tree's skeleton in Blender, encapsulating only the essential vertex data (location, normal, vertex radius). This method, both swift and fully customizable, enables the formation of any envisaged tree-structured framework.

A custom plugin, coded in Python, was developed for Blender. The plugin's first function sets 'vertex groups' for the framework we developed. These groups are essentially selections of vertices corresponding to specific parts of the tree model, such as the Trunk, a primary branch, or a secondary branch (branches sprouting from the primary branches). We manually select these vertices and group them. The primary motive of setting these vertex groups lies in controlling and facilitating the growth of different tree parts separately in subsequent stages.

After the framework's structure is fully defined with these vertex groups, the plugin exports this data to a text file. This file contains the structured and categorized vertex data, primed for import into Unity for further processing.

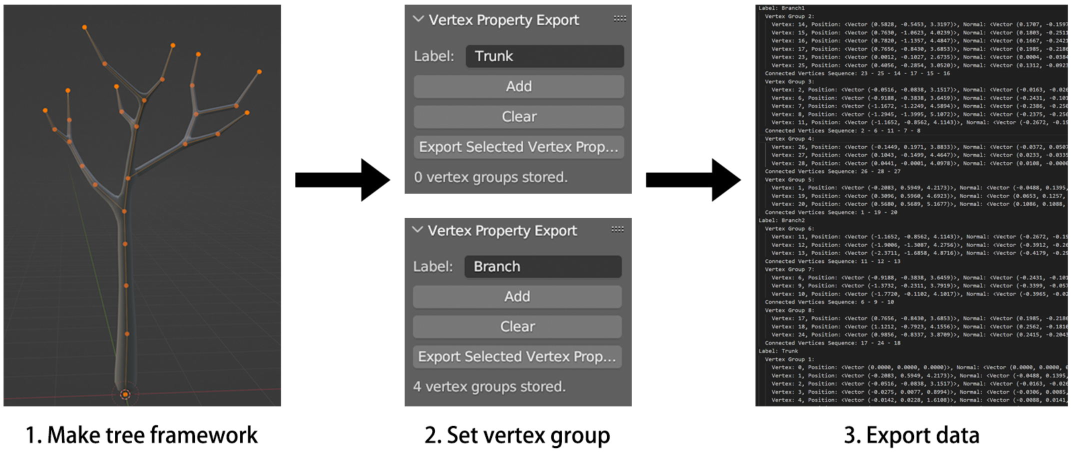

Figure 4.3: Pipeline in Blender

Custom Unity Package

In Unity, a custom package is developed to import the processed text file from Blender and generate the interactive tree model. The package consists of several C# script files, main files are described in the following table:

Table 4.1: Overview of Custom Unity Package Main Script Files

Script File	**Functionality Description**
TreeFromSkeleton.cs	(Main) Generate a tree with a trunk, branches and leaves, updates the tree model, and manages the UI.
Branch.cs	Defines the Branch class, representing the tree branches and their respective properties and methods.
BranchParser.cs	Parses the branch vertex data from the text file and returns a list of Branch objects.
Leaf.cs	Defines the Leaf class, representing the tree leaves and their respective properties and methods.
LeafUtils.cs	Provides utility methods for handling tree leaf generation and position calculation.
MeshGenerator.cs	Generates Mesh (3D object) for the tree trunk, branches, and leaves based on input data.
TreeVertex.cs	Defines the TreeVertex class, representing tree vertices and their respective properties and methods.
TrunkParser.cs	Parses the trunk vertex data from the text file and returns a list of TreeVertex objects.

These scripts are designed to work seamlessly together to achieve the following workflow:

1. Utilize **BranchParser** and **TrunkParser** to parse the text file data and construct **Branch** and **TreeVertex** objects.
2. Invoke **TreeFromSkeleton** to form and update the tree structure based on the aforementioned objects.
3. Employ **MeshGenerator** to create 3D models (Mesh objects) for the tree trunk, branches (as shown in Figure 4.4), and leaves.
4. Update the tree growth and add new leaves in real-time based on the growth factor (as shown in Figure 4.5), using the **LeafUtils** and **TreeFromSkeleton** scripts.

Figure 4.4: Different generated full-grown tree models in Unity (Leaves not displayed)

Figure 4.5: Tree grows (Leaves not displayed)

4.2.2 Interactive Features

Integrating Arduino with Unity

A central element of our project entails the fusion of Arduino and Unity, achieved via a Unity package titled Uduino. This package is purposefully made to bridge the gap between the digital world of Unity and the physical world of Arduino. It allows for real-time communication between the two platforms, translating physical inputs into digital responses.

Within our framework, Uduino oversees the signals transmitted from the keyboard. Each key press triggers a specific event within the Unity environment, enabling real-time interaction. A separate script inside Unity is dedicated to handling these inputs and the corresponding triggered events.

Implementing Custom Leaf

To incorporate personalization and interactivity, a script called CustomLeaf was developed, enabling users to generate distinctive leaves based on their inputs. Each keystroke corresponds to an alteration of the leaf's style, affecting elements like vertex position offset, thickness, scaling, and color.

Initially, the CustomLeaf script establishes a default green leaf. Upon receiving specific key inputs, the script dynamically modifies the leaf's shape and color. Consequently, each leaf embodies a unique manifestation of user interaction, constructing an endlessly diverse tree enriched by contributions from multiple users.

Through this implementation, users can create custom leaves that add a personal touch to the tree, as depicted in the illustration below:

Figure 4.6: Different styles of leaves achieved by adjusting parameters. From left to right: Default Leaf, Wide Leaf, Narrow Leaf, Low Scale Leaf, Yellow Hue Leaf, 0 Brightness Leaf, High Saturation Red Hue Leaf.

Adding Leaves and Camera Movement

The incorporation of new leaves into the tree entails an interactive procedure, commencing with the AddLeaf event, which is activated by a user's input. Nevertheless, leaves can only be appended if there exists an available slot on the tree. In the absence of open slots, the tree's growth factor is automatically increased, prompting the tree to grow and reveal new slots for additional leaves.

To visualize the tree's expansion and inclusion of new leaves, a camera script has been incorporated. This script dictates the camera's position and motion within the Unity scene. As a new leaf slot emerges, the camera seamlessly shifts, magnifying its focus on the new leaf's position as shown in Figure 4.7. Concurrently, the recently appended leaf becomes progressively apparent, symbolizing the user's contribution to the tree. Ultimately, this sequence cultivates a captivating visual experience for users, making their interaction with the e-guestbook uniquely personal and memorable.

Figure 4.7: When a new leaf is to be added, the camera will zoom in and focus on the corresponding position.

Forest

1. **Tree Generation:** The e-guestbook project is engineered to develop and adapt alongside the community it represents. Consequently, it is crucial to cater to a growing volume of user contributions. Given the finite capacity a single tree has for supporting leaves, for example, a hundred leaves, a new tree is produced when this limit on the existing tree is reached. This strategy guarantees the system's scalability and signifies the continuous development and evolution of the community. Each emerging tree signifies a new chapter in the communal narrative, nurturing a sense of anticipation and enthusiasm. This procedure is overseen by a Unity script named 'Forest Manager', which observes the current tree's state and triggers the generation of a new tree when required.
2. **Forest Perspective:** The e-guestbook project encompasses more than individual contributions; it aims to nurture a sense of community and shared experiences. The system incorporates a feature that modifies the camera's perspective based on user engagement, enabling users to appreciate the communal contribution to the forest's growth. Upon detecting user activity on the slider sensor, the system adjusts the Y-coordinate of the camera position, facilitating a shift in perspective from an individual tree to the entire forest as shown in Figure 4.8. This provides a more expansive, comprehensive perspective of the forest, epitomizing the collective contributions of all users. It serves as a visual symbol that each visitor's interaction is part of a larger narrative, contributing to the community's shared story.

Figure 4.8: Camera in the air

3. **Temporal Navigation:** A unique aspect of this system is its ability to render the evolution of the forest over time. The system transitions into 'Temporal Navigation' mode upon the rotation of the Rotary Encoder. In this mode, the "current time" is adjusted based on the input from the Rotary Encoder, effectively showcasing the forest's state at various points in time. To facilitate this feature, each tree within the forest is associated with a growth log that records the timestamps of each added leaf. When in 'Temporal Navigation' mode, the system consults this growth log to determine the leaves present at the calculated 'current time', subsequently modifying the tree's appearance. This process results in a dynamic representation of the forest's evolution, mirroring the cumulative interactions of the users.

4.2.3 Implementation Challenges

Smooth Natural Tree Growth

A primary challenge in this project was the simulation of smooth, natural tree growth. The construction of a tree's structure, or skeleton, only involves defining vertices in 3D space. These vertices, however, do not inherently possess continuity, which is crucial for portraying smooth growth in the tree. A solution to this challenge is found in a technique commonly utilized in the 3D field known as subdivision. But here it's more an interpolation.

Interpolation refers to the process of estimating values situated between two established values. Within the parameters of our project, we employed interpolation to engender a smoother transition between vertices, thereby simulating the continuous growth characteristic of a tree.

Outlined below are the critical steps involved in our code implementation:

1. **Vertex Identification:** The initial step requires the identification of the final actual vertex and the subsequent vertex from the array of vertices. The final vertex

represents the tree's current endpoint, whereas the subsequent vertex denotes the point towards which the tree will expand.

2. **Interpolation Factor Computation:** Subsequently, the interpolation factor is calculated. This factor is a ratio denoting the present stage of growth between the final and subsequent vertices.

3. **Execution of Interpolation:** The interpolated vertex's position and radius are determined using the calculated interpolation factor. The interpolated position denotes a point along the line between the final and subsequent vertices, suitably adjusted to correspond to the current growth phase. Likewise, the radius is interpolated to enable a fluid transition in the tree's thickness, resulting in a more natural, seamless visual effect as the tree seems to grow progressively from one vertex to the subsequent one.

Dynamic Orientation of Mesh Growth

In the early development phase of our Mesh Generator, the growth direction for all faces defaulted to the vertical axis. Consequently, this resulted in a uniform orientation for face normals and UVs, irrespective of the mesh's local geometry or curvature. While efficient and straightforward, this strategy resulted in visual anomalies and inaccurate lighting calculations, particularly apparent in complex, non-linear mesh structures.

A face normal represents a vector perpendicular to a polygon's surface. For tree trunks or branches, where the mesh geometry may twist and turn, a uniformly oriented face normal can lead to incorrect lighting effects and visual discrepancies. Correspondingly, UV coordinates, which map the two-dimensional texture onto the three-dimensional mesh, when applied uniformly, may cause texture stretching or distortion, negatively impacting the tree's visual aesthetics.

To address this challenge, the growth direction for each face ought to be dynamically computed based on the local geometry. In the refined script, the growth direction (referred to as 'upDirection') is recalculated for each vertex predicated on its position in relation to the next vertex in the list. The local right and forward directions are subsequently computed using the cross product of the up direction with the global forward and right directions, respectively. This approach ensures that each face's orientation and its corresponding UVs accurately echo the mesh's local geometry. The following are some of the utilized formulas:

For vertex calculation:

$$
\begin{aligned}
\text{upDirection} &= \text{normalize}(\text{nextVertex} - \text{currentVertex}) \\
\text{rightDirection} &= \text{normalize}(\text{cross}(\text{upDirection}, (0, 0, 1))) \\
\text{forwardDirection} &= \text{normalize}(\text{cross}(\text{rightDirection}, \text{upDirection})) \\
\text{angle} &= \frac{2\pi \times \text{radialSegmentIndex}}{\text{radialSegments}} \\
x &= \text{trunkRadius} \times \cos(\text{angle}) \\
z &= \text{trunkRadius} \times \sin(\text{angle}) \\
\text{vertexOffset} &= \text{rightDirection} \times x + \text{forwardDirection} \times z \\
\text{vertices} &= \text{trunkVertices} + \text{vertexOffset}
\end{aligned}
$$

For UV calculation:

$$
\begin{aligned}
\text{uv.x} &= \frac{\text{radialSegmentIndex}}{\text{radialSegments}} \\
\text{uv.y} &= \frac{\text{currentVertexIndex}}{\text{vertexCount} - 1}
\end{aligned}
$$

4.2.4 Prototype Testing

Hardware Components Testing: The evaluation of hardware components involved confirming their operational accuracy and consistency. This was done by monitoring the sensor output in the Serial Monitor of the Arduino Integrated Development Environment. Based on the results, necessary calibrations were made to enhance sensor stability and responsiveness.

Tree Visualization Testing: The testing process of the tree visualization was iterative, necessitating considerable trial and error. To confirm that the visualization could accurately portray user inputs and grow dynamically as intended, we tested it under various conditions. This involved testing diverse user input scenarios, modifying visualization parameters, and refining the algorithms used for tree generation. All issues identified during this process were rectified through iterative debugging and refinement of the visualization code, ensuring that the final tree visualization precisely reflected user inputs and provided an intuitive user experience.

Chapter 5

Discussion

Despite appearing to be a simple reimagining of a traditional guestbook, the e-guestbook project has a deeper significance. It is a synthesis of technology and tradition, a link between the digital and physical realms, and an opportunity to enhance social interactions in public spaces.

Reimagining Interaction At its core, this project is an exploration of the potential of tangible and embodied interaction (TEI) in transforming our experiences and interactions. It is a testament to the power of technology in enhancing our connection with the community or even the world. The project's significance lies in its potential to reimagine one of the ways we interact with public spaces.

In the digital age, traditional guestbooks using pen and paper may only be used when necessary. While people are accustomed to scanning QR codes or using NFC tap as common forms of interaction, these methods may offer little in terms of engagement. They are often transactional and lack the depth and richness that can only be achieved through more innovative forms of interaction. Our implemented project, however, transcends these limitations by integrating multidisciplinary technology like interactive displays into the interaction process, thereby inviting visitors not just to leave their mark, but to become a part of a growing, evolving entity. This way goes beyond the conventional methods, thereby redefining the way we interact with technology.

Interdisciplinary Collaboration Drawing on expertise from various fields such as Human-Computer Interaction (HCI), computer graphics, computing, product design, and interactive arts, the e-guestbook project showcases the richness and diversity of TEIs. The project's design, for instance, incorporates HCI principles to ensure user-friendly interactions, while its visual elements draw from the field of interactive arts to create an aesthetically pleasing and engaging interface. The underlying technology, including the use of computer graphics and computing, enables the realization of these design concepts into a functional system.

Moreover, the project's iterative design process reflects the product design methodology, which emphasizes continuous refinement. By integrating knowledge and methodologies from these diverse disciplines, it is more efficient to address complex design challenges and create a more comprehensive and novel solution. It also represents a broader trend in the field of TEI, highlighting the importance of diverse perspectives.

Challenges and Limiataions The e-guestbook project, while presenting exciting prospects, also faced numerous challenges during its development and currently bears several limitations.

The primary challenge lay in the realization of dynamic tree visualization, which incorporated the creation of the tree model, the formulation of a growth algorithm, and the management of the tree leaves' data. After multiple iterations, a hybrid solution emerged by merging two distinct methodologies: pre-construction of the tree model in Blender and utilizing a self-fashioned Unity package to regulate the tree's growth and leaf information. This combination of methods allowed for a more efficient and effective management of the tree visualization process. Furthermore, this strategy proffers a swift and efficient way to generate a variety of tree types, thereby enhancing its adaptability for future expansions.

An additional challenge resided in the simulation of seamless, natural tree growth, which required continuity in the tree's structure. Subdivision method in 3D area provided a concept for addressing this challenge, employing interpolation to estimate values between known points and adding extra vertices between defined ones. Consequently, a more realistic, continuous tree structure was realized.

As for the limitations, the absence of user testing emerged as a notable issue. Despite the project's design, which considered user interaction, it has yet to undergo practical testing with actual users in a real-world environment. User testing is vital for uncovering usability concerns and discerning how users interface with the system. Another limitation is the real-time performance issue. With the continuous increase in leaf count, real-time rendering becomes increasingly challenging. Each leaf in the tree is an individual object that needs to be processed and rendered, thereby exerting substantial strain on the system. As the tree grows, the computational requirements increase, potentially leading to performance issues such as slower response times or, in extreme scenarios, system crashes.

Enhancing Social Interactions The e-guestbook initiative is designed to bolster social interactions within public spaces such as libraries, museums, or educational institutions. Its primary aim is to cultivate community engagement, instil a sense of belonging among visitors, and enable social interactions.

Imagine a scenario where a visitor steps into a library equipped with the e-guestbook system. The interactive display, featuring a vibrant tree populated with numerous distinctive leaves, captivates the visitor. Intrigued, the visitor approaches the display and discovers a leaf-shaped keyboard. Through the interaction with the keyboard, the visitor realizes that each keystroke contributes to the formation of a unique leaf on the tree. The visitor proceeds to create a unique leaf, infusing their personal essence into the tree. As the leaf is added to the tree, the visitor feels a sense of contribution and belonging. Other visitors, witnessing this interaction, are encouraged to participate, leading to a ripple effect of engagement and interaction.

In a subsequent visit, the visitor observes the emergence of new trees. Yet, by manipulating a knob on the keyboard, they can navigate through the library's past, revisiting trees from previous days. This functionality provides not only a sense of continuity and historical richness but also enables visitors to revisit their past interactions. Encountering their distinct leaves still adorning the trees, visitors are reminded of their contributions to the growing forest of the library. This experience instills a sense of pride and ownership, making them feel more connected to the public space. Recognizing that the expansion of this digital forest is a result to their collective endeavours, the visitors are further motivated to make recurrent visits. Consequently, the e-guestbook transcends the enhancement of social interactions to foster a sense of unity and community within public spaces.

Future Directions In considering the trajectory of the e-guestbook, several promising directions for its future evolution present themselves:

- **User Testing**: As mentioned earlier, despite the project's user-centered design, empirical testing involving actual users within a real-world environment is yet to be conducted. Undertaking user testing could yield crucial insights into user-system interaction patterns, detect potential usability issues, and subsequently inform refinements to the system's design and functionality.
- **Performance Optimization**: Given the progressively increasing leaf count, real-time rendering poses an escalating challenge. Future work could pivot towards constructing a new tree data structure, refining the growth algorithm, and deploying the project using WebGL. This would empower the system to operate across different platforms within a browser, thereby augmenting compatibility while minimizing reliance on high-performance hardware.
- **Enhanced Interactivity**: Broadening the project scope to incorporate additional interactive elements is another viable path. For example, the system could enable users to individualize their leaves further, permitting the addition of personal messages or application of diverse shaders for unique leaf effects, thereby enriching user experience personalization.
- **Expansion to Other Public Spaces**: The adaptability of the e-guestbook system lends itself to potential implementation within various public spaces, including

parks, community centers, or city squares. Each locale could introduce unique interaction methodologies, influenced by its distinctive features. Such an expansion would extend the project's reach, amplifying community engagement impact.

- **Visual Artistry**: The e-guestbook's aesthetic appeal and user engagement can be significantly elevated by emphasizing visual enhancement in future developments:
  - ***Dynamic Backgrounds***: The development of dynamic backgrounds for the tree is one prospect. For instance, the interactive scene could change according to the time, weather conditions, or season of the public space where the e-guestbook is located.
  - ***Local Landmarks***: Incorporating iconic buildings or landmarks from the public space in the background, making the digital experience feel more grounded and relevant to the physical location.
  - ***Animations and Special Effects***: Infusion of animations or visually striking effects onto the tree can enhance the visual appeal.

Conclusion To conclude, the e-guestbook project is an exploration in the field of tangible and embodied interaction. It reconceptualizes the manner in which we engage with public spaces, transforming the traditional concept of a guestbook into a symbol of growth, community, and collective memory. It shows the potential of interdisciplinary collaboration in addressing complex design challenges and the importance of diverse perspectives in creating comprehensive and innovative solutions. I believe that the this project represents a promising step towards creating more engaging and meaningful interactions in public spaces.

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