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Expansion of Architectural Heritage Conservation through Digital Interactions and Gamification: A Case Study of Singapore Thian Hock Keng

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Abstract

The research aims to overcome the limitations of physical conservations of architectural heritage using digital interactions and gamification. Physical conservation is limited by practical factors like materials availability or durability of the originally used materials. On the other hand, digital 3D interactive models do not face all these constraints. Therefore, this project demonstrates how an ancient heritage temple, the Thian Hock Keng in Singapore, benefits from this expanded version of digital interactions and gamification. Digital Heritage (DH) methods, such as the generation of 3d point clouds and construction of 3D polygonal models, are used to create a hyper realistic scan of the heritage site. On top of a 3d walkthrough of the heritage space, classical narrative storytelling technique is used to keep the player engaged in the gameplay with a 3-act structured story plot. The outcome not only covers wider perspectives of the history of this space, but it also gains the advantage in its presentation through gaming, where the audience is fully immersed in the virtual temple space as a first-person player. The gamification of the 3D Thian Hock Keng temple serves as a case study to support further research on expansions of digital heritage conservations through interactions.

1. Introduction

Built in 1839 by the local Hokkien community to worship Mazu, the Goddess of the Sea, the Singapore Thian Hock Keng (THK) temple has undergone at least four phases of constructions and restorations, both minor and major (*Guardian of the South Seas: Thian Hock Keng and Singapore Hokkien Huay Kuan.*, 2006). In 1973, the temple was gazetted as a national monument by the Singapore government. According to the Urban Redevelopment Authority's (URA) conservation guidelines— known as the '3Rs' (maximum retention, sensitive restoration, and careful repair)— the temple must comply with these standards (Yeo, 2020). In addition to adhering to regulations set by government agencies, THK's architectural heritage conservation efforts have also been challenged by physical constraints such as the lack of original materials and traditional craftsmanship (杨茳善 Yeo Kang Shua, 2010).

Between 1994 and 2001, James Ferrie & Partners Architects was engaged to restore the heritage site which pillar structures were heavily invested by termites. This was the first major restoration project that THK had embarked on since 1906. The restoration is to abide to the following guidelines:

- To retain the architectural style
- To retain the quality of the architectural structures
- To retain the methods and techniques used in the architectural structures
- To import the materials from its origins
- Under special circumstance, non-original materials are allowed (e.g. for lighting and termites prevention), with the sole purpose to enhance durability

The project was conducted in three stages: pitching and report preparation (1994-1997), selection of companies (1998-2000) and restoration work (2000-2001) (南海明珠: 天福宫, 2010). The extensive restoration project was awarded excellence in the UNESCO Asia Pacific Cultural Heritage Building in 2001.

The physical conservation guidelines set by the authorities ensured that the restoration process retained the exterior appearances, the materials originality and also the exact craftsmanship used on the heritage building. The conservation process is complex and costly, which is often also limited by the sustainability of the building structure (e.g. prevention from termites' invasion under high humidity environment), the availability of the original materials (e.g. ceramic tiles imported from the West) and also the availability of the craftsmen' workmanship (e.g. craftsmen trained in Min Nan style architecture).

This research aims to overcome the limitations of physical heritage conservations by converting the heritage site to a Digital Heritage (DH) through the construction of 3D interactive models. With the use of gameplay elements and compelling storytelling techniques, the digital material will better engage and educate the user to understand the cultural content of the heritage site.

2. Literature Review

The UNESCO defined DH as unique human resources which are significant and worth preserving for future generations, either "born digital" or converted from existing analogue resources ("Charter on the Preservation of the Digital Heritage," 2003). It

encompasses not only cultural resources, but also administrative, scientific, educational, medical, legal, technical and all other forms of resources.

Specifically, the 3D DH of a heritage site or monument is generated with the collection of 3D data such as polygonal mesh models and point clouds (Grilli & Remondino, 2019). The data then went through segmentation (the process of grouping meshes or point clouds) and classification (pixel or point labeling). This 3D digitalisation of the heritage site or monument should also be standardised and pegged to high accuracy and precisions in measurements, with careful planning in the digitalisation process, considering the level of radiation penetration on during the recording process, overcoming the challenges during the data acquisition process, and determining complexity of the digitalisation process (Argyridou et al., 2023).

There is a demand on creating more meaningful cultural heritage experiences from the younger generation (Bugeja & Grech, 2020). Given the current advancement and easy access to immersive technologies such as augmented reality (AR), virtual reality (VR) and mixed reality (MR), it is no longer sufficient to just present the user with a digital 3D walkthrough of the heritage site. To better engage and enhance the user experience in understanding the heritage site, gamification should be used in the design process. Recent study has proven that gamification helped to improve knowledge acquisition and enhance the visitor's engagement when viewing virtual museums (Yolthasart et al., 2024).

Gamification is defined as "the use of game design elements in non-game context" (Deterding et al., 2011). Alike to Serious Games (SG), the purpose of the use of game design elements in gamification is different from an entertainment game. SG is are games that have an intended purpose to inform, train and educate the user, and not just for amusement (Michael & Chen, 2006). But this does not mean that SG should not, or are not entertaining to play with (Abt, 1987). In the context of DH, different types of SG can be classified by answering the following set of questions (Paliokas, 2019):

1. What is this game for?
2. Who is playing the game?
3. What players have to do (to complete the game)?
4. How playing this game feels?
5. What equipment do people need to play the game?

Werbach and Hunter identified the three levels of game element hierarchy as Components, Mechanics and Dynamics (Werbach & Hunter, 2012). Components, which is at the bottom of the hierarchy, consisted of game elements that motivate the player such as Points, Badges and Leaderboards (PBLs). The PBLs trio is a good starting point for a gamified system, but it not sufficient to push the action forward. Second on the hierarchy is Mechanics, such as challenges and competition which help to engage the player and move things ahead. Dynamics is the highest level of abstraction consists of elements such as emotions and narrative. In this three levels hierarchy, the game elements in Components is connected to one or more of the higher-level elements, while each element in Mechanic helps to achieve one or more intention in the Dynamics. It is also worth noting that a single game would never use all of the game elements at each category.

3. 3D Construction of Digital Heritage

Digital Heritage (DH) offers a powerful conservation tool that breaks through the limitations of traditional architectural preservation. While conventional efforts are constrained by material decay, environmental damage, and restoration costs, DH introduces new ways to preserve and experience cultural spaces through immersive 3D technologies. To reconstruct an object in 3D, it involves two collection processes -- 3D scanning (3D mesh) and picture acquisition (texture) (Bruno et al., 2010). The DH of THK is reconstructed using light detection and ranging (LiDAR) technology, which sends out laser signals to gather information and generate point clouds, creating hyper-realistic 3d models. LiDAR, where information is gathered via bouncing light off an object, has a history of more than 60 years (McManamon, 2015). After the texture mapping of the mesh and texture is done, the 3D model is then cleaned up into lightweight models which are conducive for a real-time game engine.

Digital reconstruction of Thian Hock Keng (THK) requires a combination of LiDAR 3D scanning technique and thoughtful artistic refinement to convert raw data into a real-time interactive experience. This process is not merely technical, but interpretive: blending heritage documentation with game-ready optimisation. While the initial scans captured the physical geometry of the temple in partial low to high detail, the raw assets presented challenges for real-time use. Fragmented meshes, baked-in shadows, and non-uniform topology has to be cleaned, rebuilt, or replaced with new models. The goal is to retain most historical fidelity to a certain extent while creating a stable foundation for gameplay, or to be utilised in other formats of representation.

3.1 Checking and Scaling of LiDAR mesh

The THK management provided the team with a GLB (GL Transmission Format Binary) file that contains the 3D mesh and baked textures of the THK temple. The scan is hyper-realistic in some areas, with a baked-in 2D texture that includes real-world shadows captured during the photographic process. However, as is often the case with mid to lower-tier 3D scans, the distribution of detail is inconsistent. The areas of visual importance often lack in resolution, while less relevant regions are oversaturated with geometry. This imbalance in polygon density made the scan unsuitable for direct use in a real-time engine and required further processing. Key issues identified include:

- Fragmented mesh geometry, resulting in disconnected faces and inconsistent polygon flow
- Inconsistent mesh scale and ground plane, requiring normalization to align with Unreal Engine's world coordinates
- Baked-in lighting artefacts, such as shadow information embedded in the textures, which limited flexibility for dynamic lighting setups
- Non-optimised topology, making the mesh inefficient for interaction due to overly high poly counts and poor edge loop structures

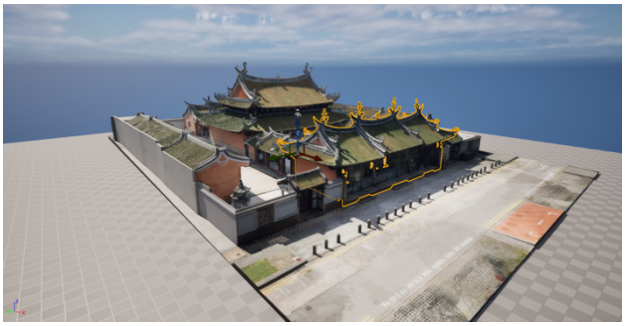

Figure 1. LiDAR scan of THK provided by the Management Committee of THK

3.2 Retopology and 3D Reconstruction using Maya and Houdini

The first step is to assess which parts of the scanned data could be salvaged and which needed reconstruction. Basic transforms are applied to align the model’s scale and orientation with the Unreal Engine scene. Mesh cleanup is initiated in software such as Maya and Houdini, with Houdini’s auto quad-remesh tool used for preliminary topology corrections. Challenges include manual retopology and re-modelling of 3D models, as illustrated below.

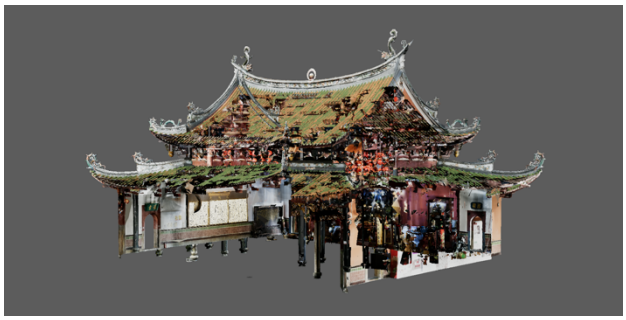

Figure 2. The mesh of the LiDAR scan is too fragmented

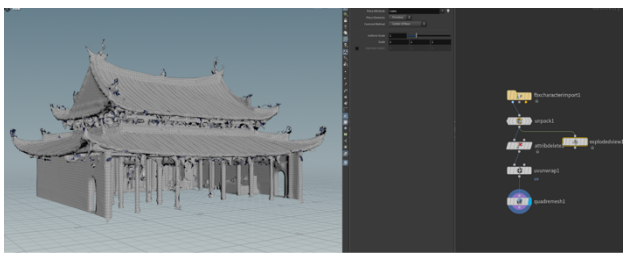

Figure 3. Attempt to clean up the topology using Houdini auto quad-remesh tool

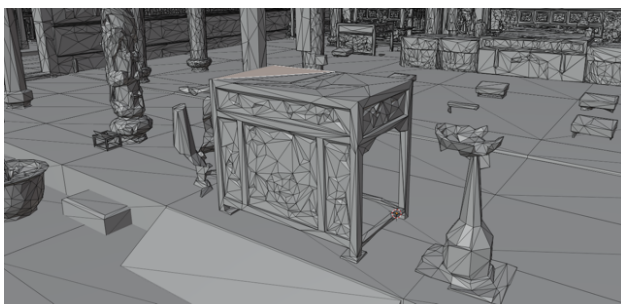

Figure 4. The topology of the mesh is not suitable for real-time interactions for gameplay

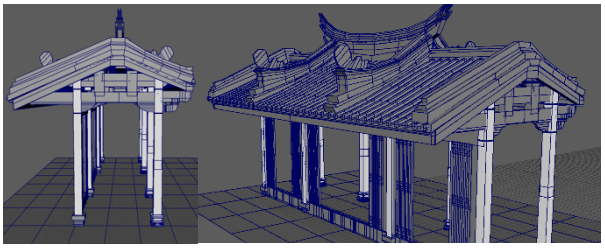

Figure 5. Manual remodelling of the temple entrance

The team also evaluated whether to preserve certain assets as-is, rebuild from scratch, or use hybrid techniques (e.g., retopo + projected textures). This decision was made based on gameplay relevance, visual importance, and performance impact. For example, high-detail structures like dragon pillars and rooftop carvings were remodelled manually.

3.3 Real-time Walkthrough in Unreal 5.4

To transform the 3D model of THK from a static representation into an immersive digital experience, the team implemented a real-time walkthrough using Unreal Engine 5.4. This approach was not merely chosen to showcase the environment, but to enable embodied spatial interaction—allowing users to walk through, pause, examine details, and interact with the temple space as if physically present.

Unlike video documentation or passive 3D viewers (e.g., Sketchfab, Autodesk Viewer), a real-time walkthrough provides agency, presence, and interactivity. In the context of cultural heritage, the visitor becomes an active participant who can explore at their own pace, unlocking details and experiences that deepen their understanding of the space. The use of a first-person camera enhances this sense of embodiment and encourages intuitive exploration.

Figure 6. Screenshots from early 3D walkthrough render tests in Unreal Engine 5.4

Unreal Engine 5.4 is selected for its advanced rendering capabilities, particularly its ability to handle complex LiDAR-generated architecture. The use of Nanite, Unreal's virtualised geometry system, allows high-resolution assets, like the ornate dragon pillars and tiled rooftops, to be rendered in real-time without sacrificing performance, even on mid-tier hardware. Traditional engines would have required aggressive mesh decimation, which risks stripping away culturally important details.

During early testing, the engine was able to handle unoptimised scanned meshes with relative ease. This gave the team valuable flexibility, enabling them to experiment with how far they could push the visuals before needing to invest time in more complex

manual retopology or remodelling. It was a pragmatic balance between visual quality and production time.

Unreal's Lumen global illumination system contributed significantly to the sense of atmosphere, dynamically simulating how light behaves inside and outside the temple—sunlight filtering through wooden eaves, soft glow from lanterns, and shadows cast across stone and ceramic surfaces. These subtle lighting interactions helped ground the experience in realism and enhanced emotional resonance.

Finally, Unreal's modular and scalable framework made it an ideal choice for ongoing development. Beyond just exploration, the engine supports layered interactivity such as storytelling sequences, cultural puzzles, and symbolic encounters, all powered by Blueprint visual scripting. This made it possible for the team to iteratively build upon the experience, each addition enhancing both the design fidelity and cultural understanding. As the project evolved, so did the developers' appreciation of the temple's historical significance, forming a feedback loop where building the game became a form of immersive research itself. This increased appreciation is aligned with the objective of the THK gameplay, which is to educate the player with THK's architectural and cultural content.

4. Digital Interactions through Meaningful Gamification and Classical Narrative Storytelling

Meaningful gamification is when the player finds something meaningful out of the gameplay (Nicholson, 2015). Using Werbach and Hunter's game elements hierarchy as a guide, instead of providing rewards (Components) as a form of gaming motivation, the gameplay uses a 3-act story structure (Mechanics) to keep the player engaged in the story plot (Dynamics). Storytelling is a great tool to convey cultural messages and better engage the audience for cultural heritage (Paolini & Di Blas, 2014).

Classical narrative storytelling uses a formulised story structure as, portraying the protagonist going through conflicts while trying to achieve his goal. The 3-act structure or three-act model is made up of three acts, which serves as the paradigm of dramatic structure: Beginning (or setup), Middle (or confrontation), End (or resolution) (Field, 2005). Each act ends with a "plotpoint", or turning point which is a crucial event that changed the direction of the story (Thompson, 1999).

4.1 Gameplay Design Process

Using Paliokas's set of questions to categorise Serious Games in Digital Heritage (Paliokas, 2019) , our THK gameplay is:

A single-player game designed to allow visual art students to navigate in a simulated environment using a personal computer (PC) with keyboard in order to learn and appreciate about the architectural structure and heritage design of Thian Hock Keng temple.

The objective of the gameplay is to allow appreciation and generate genuine interests on the heritage site. Specifically, visual art students who might gain knowledge of Chinese design elements and get inspirations from the architectural structures. The THK gameplay follows Werbach and Hunter's three levels of game element hierarchy to keep the player engaged and motivated to complete the game.

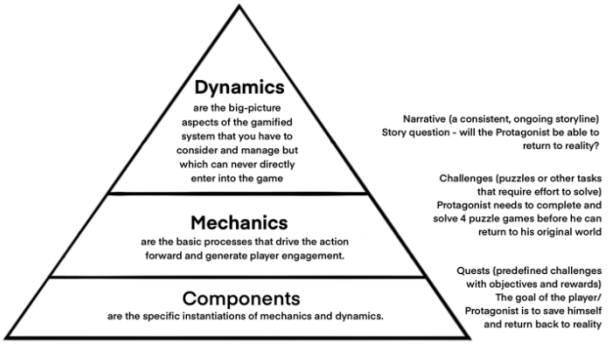

Figure 7. Game elements hierarchy for THK gameplay

The mapping of the gameplay loop design ensures that the player moves through the game in a forward action. When the player is stuck, hints and prompts are generated to help the player get to the next point. Challenging game puzzles and compelling story plot points are designed to keep the player engaged with the gameplay.

Figure 8. Gameplay loop design for THK gameplay

4.2 Storytelling using Three-Act Structure

A three-act story structure with plot points are designed and written for the THK gameplay. A typical story starts with Act One introducing the protagonist in his day-to-day environment (setup), with the establishment of a character goal. Until one day a crucial event happened (Inciting Incident), which triggers the start of a series of conflicts and radically changed the direction of his current route (McKee, 1997). Plot Point 1 is introduced before the end of Act One. Act Two is the lengthy middle which shows the protagonist going through a series of challenges and conflict (confrontation) which prevents him from achieving his goal, where more information about the conflict in and introduction is revealed at Midpoint and Plot Point 2. In Act Three, it is when the story reaches ¾ of the structure and the Climax takes place.

During the Climax, the story question got answered (the audience knows if the protagonist manages to achieve his goal or not) and leads to the end of the story (resolution).

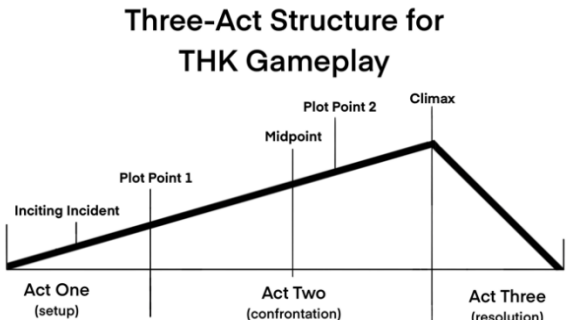

Figure 9. Three-act structure of THK gameplay

In the THK Gameplay *Legend of Thian Hock Keng*, the protagonist is a Singapore teen who is from a family lineage of heritage restorers. As a child, he spent most of his time at the temple waiting for his father to end work and play with him. The character goal of the protagonist is to get attention and love from his father. However, his father's busy work schedule became the main conflict of the story and made it challenging for the protagonist to achieve his goal.

Story Plot Point	Description
Introduction	Growing up, Protagonist feels neglected by his Father who is a temple restorer at THK.
Inciting Incident	Protagonist destroyed multiple temple artefacts after his Father missed his graduation ceremony due to temple restoration work.
Plot Point 1	Deity Mazu appeared and thrust Protagonist into an unknown timeline. Mazu tasked Protagonist to restore all the artefacts in order to return to his original world. His first task was to solve the cast iron gate game puzzle.
Midpoint	After completing the first game puzzle, Protagonist has to restore the dragon pillar by completing the game puzzle.
Plot Point 2	Protagonist is still not done with restoring the artefacts. His next task is to solve the lantern puzzle.
Climax	Protagonist reached the final game puzzle – light reflection puzzle at the incense burner. After much struggle, he finally managed to solve the puzzle and Mazu re-appeared and sent him home.
End	Protagonist returned to his original world and realised that his Father has been watching him over the years. Protagonist and Father reconciled.

Table 1. Story structure for *Legend of Thian Hock Keng*

Figure 10. Screenshot of 2D animated cut scene from *Legend of Thian Hock Keng*

Figure 11. Screenshot of first-person player view from *Legend of Thian Hock Keng*

Through first-person gameplay, players experience the story and environment from the perspective of the protagonist. Without physically stepping into a religious site, they can appreciate the beauty of Min Nan-style architectural, the intricate Chinese ornamental designs of a Hokkien temple, and Western-influenced elements such as the floor tiles and iron casted gates.

5. Results and Discussions

The results from this study can be discussed from two aspects: the workflow of creating a Digital Heritage (DH) with an interactive gameplay component, and the player's gameplay experience with *Legend of Thian Hock Keng.*

From the aspect of creating a Digital Heritage (DH), the technological advancements in LiDAR technology and photogrammetry, coupled with the real-time game engine Unreal Engine, have allowed the digitalisation of a heritage site to be done quickly and productively. Upon receiving the point cloud data, the team can quickly generate a 3D walkthrough of the THK temple in basic daylight to test the limitations of the scan. Some limitations include fragmented meshes, unwanted shadows embedded in the scan, and lowly defined structures, which will be used for the interactive component. To overcome the problem, the 3D artists manually re-topo and edited the meshes. In some cases, the asset is being modelled and textured from scratch. The main challenge of our project is designing and creating an interactive gameplay which is engaging and motivating for the user.

The creation of the THK gameplay is divided into two phases: preproduction and production. The preproduction stage involves the design of the characters, writing of the story plot, design of the gameplay loop design, floor plan and visual development of the 2D cutscenes. The production stage involves the retopology of the LiDAR models, 3D modelling and texturing of selected

assets, creation of gameplay in Unreal Engine, and the animating of the 2D cutscenes.

The project is done over two school semester breaks by nine art and design undergraduate students. The team consisted of three game artists, three 3D assets artists, two 2D artists, one programmer and one UIUX designer. The 3D assets team started the project, then the interactive game team joined in and worked parallelly. Both teams work closely together under the coordination of the project manager (research associate).

Figure 12. Screenshot of title slate in Chinese inspired designs from *Legend of Thian Hock Keng*

Figure 13. Screenshot of gameplay start menu from *Legend of Thian Hock Keng*

Our early pilot test received positive responses from players. The storytelling is clear, and participants are eager to find out what happens at the end. Future user testing—comparing a basic DH 3D walkthrough with the player experience in *Legends of Thian Hock Keng*—will help us determine whether the gamification of DH is effective. The target test group includes visual art students as well as members of the general public. However, we have not been able to conduct these user tests and collect detailed data, as the team is still refining the game during the semester break.

The use of extended reality tools is a possible expansion of the current THK gameplay. Instead of confining to the personal computer (PC) and keyboard navigation player experience, the use of a wearable device provides an immersive user experience. The three specific forms under external reality are namely—virtual reality (VR), augmented reality (AR) and mixed reality (MR) (Mudička & Kapica, 2023). Unreal Engine 5.4 supports the use of wearable device and the team did a basic walkthrough test with Oculus Meta quest 3 (wired). The connection for a VR preview and 3D walkthrough is straightforward. However, user interface and player experience needs to be re-designed and configured if the THK gameplay is to be converted to a VR game.

Figure 14. VR walkthrough test using Oculus Meta quest 3

In this paper, we provided a detailed account of the creation of a Digital Heritage (DH) project with an interactive gameplay component, combining LiDAR technology and manual 3D modelling to produce the 3D assets. The focus was on the gamification of a 3D walkthrough— specifically, how the team designed the gameplay and structured the story's plot points to make the experience engaging and motivating for users. This project serves as a case study to support future research on gamifying DH 3D walkthroughs to enhance user engagement.

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