

DIGITAL VISUAL TRANSFORMATION OF MONGOLIAN OX-HORN BOW CRAFTSMANSHIP BASED ON UNITY GAME DESIGN*

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Abstract

Mongolian ox-horn bow craftsmanship embodies the material wisdom, mechanical knowledge, and cultural memory of nomadic society. However, modernization and the decline of traditional transmission have weakened its inheritance. This study aims to interpret the cultural origins, structural features, and production process of the Mongolian ox-horn bow and to transform its core visual elements into a digital design language suitable for Unity-based game development. A mixed-methods approach was adopted, combining literature review, field investigation, interviews with inheritors, expert evaluation, and questionnaire analysis of 196 valid responses using SPSS. Based on these findings, a Unity-based design practice was conducted, including 3D modeling, scene construction, interactive programming, and iterative optimization. The study established a digital visual transformation framework integrating cultural analysis, craft reconstruction, digital modeling, interactive design, and user verification. The Unity game system reconstructed the bow's structure, production process, and

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cultural context through immersive scenes and physics-based archery simulation. User evaluation showed an overall satisfaction rate of 89.3% and a craft cognition improvement rate of 76%, indicating that game-based design can effectively support the digital preservation and dissemination of traditional ethnic craftsmanship.

Keywords: Mongolian ox-horn bow, production technology, visual design

Introduction

Mongolian ox-horn bow craftsmanship is a precious form of intangible cultural heritage of northern nomadic peoples, embodying thousands of years of material wisdom, cultural beliefs, and aesthetic values. However, modernization and industrialization have brought serious challenges, including the aging of inheritors, broken transmission chains, and limited channels of communication. Traditional teaching methods and two-dimensional displays are no longer sufficient to preserve and transmit such delicate techniques effectively, resulting in the gradual marginalization of this traditional craft. Therefore, digital technology is urgently needed for systematic protection, three-dimensional restoration, and interactive communication.

The digital transformation of traditional craftsmanship has become a major direction in cultural heritage preservation. The Unity game engine offers an efficient approach to the visual presentation of complex crafts due to its strong rendering capabilities, convenient interaction design, and cross-platform performance. It supports 3D modeling, dynamic process simulation, and interactive system development. At present, however, the digital preservation of intangible cultural heritage often remains limited to static display, lacking immersive and interactive design for Mongolian ox-horn bow craftsmanship. Unity-based visual transformation can convert abstract techniques into operable

digital content and provide a new medium for cultural inheritance (Bellotti et al., 2013).

This study has both theoretical and practical significance. Theoretically, it integrates interdisciplinary knowledge and contributes to the research system of intangible cultural heritage digitalization. Practically, it enables long-term preservation and dynamic restoration of craftsmanship, enhances public understanding—especially among young people—and promotes the innovative development of nomadic culture. The research also provides a replicable technical scheme for the digital transformation of similar traditional handicrafts.

Objectives

1. To systematically interpret the cultural origins, historical background, manufacturing techniques, structural characteristics, and cultural symbolism of Mongolian ox-horn bows and arrows, clarify their cultural connotations, accurately extract transformable core visual elements, and establish a design language suitable for digital presentation.

2. To realize the digital visual transformation of Mongolian ox-horn bow craftsmanship in the Unity game environment, build a complete visual design system and technical specifications for digital scenarios, and promote the in-depth integration and coordinated adaptation of visual design with game mechanics and gameplay.

Literature Review

In recent years, serious games have been increasingly recognized as effective tools for engaging the public and enhancing learning in cultural heritage. Early research by Bellotti et al. (2013) established a foundational model for cultural heritage serious games, emphasizing the integration of historical authenticity, educational goals, and interactive gameplay. Mortara et al. (2014)

further demonstrated that well-designed serious games improve knowledge acquisition and public engagement by creating immersive and visually compelling environments. Subsequent studies have focused educational design evaluation: Malegiannaki and Daradoumis (2017) reviewed spatial games heritage education and highlighted their positive effects on contextual understanding and spatial cognition, while Tsita and Satratzemi (2019) proposed systematic design assessment frameworks to verify learning outcomes, addressing the need more rigorous empirical validation in the field.

Alongside pedagogical development, recent research expanded toward technological innovation and historical accuracy. Kosti et al. (2025) introduced the concept of inclusive game design (i-game), which uses advanced technologies improve accessibility personalised experiences for diverse users. Beyond digital frameworks, ensuring cultural and historical reliability remains essential. Beever and Pavlović (2017) reconstructed Mongol-era bow based ancient craftsmanship, providing accurate technical data for heritage representation, and Rumschlag (2018) highlighted the importance distinguishing between Hun Mongol military technologies in order avoid oversimplified or stereotyped narratives. Collectively, studies show that serious games cultural heritage evolving toward more inclusive, technologically advanced, historically faithful applications, though challenges remain in scaling inclusive design conducting long-term impact assessments.

Despite progress design technology historical accuracy, existing research still reveals several notable limitations. Many serious games prioritize technological novelty narrative entertainment over long-term educational impact few studies conducting longitudinal assessments trace sustained cultural learning outcomes. In addition, inclusive design has been proposed as a direction, practical applications users with different cognitive or physical abilities remain underdeveloped, cross-cultural adaptability game mechanisms has rarely been tested. Furthermore, integration specialized historical research craftsmanship and military technology from nomadic cultures into actual game development

remains fragmented, often lacking systematic translation from archaeological findings interactive game content. Future studies should therefore focus on establishing more comprehensive evaluation systems, strengthening inclusive cross-cultural design building closer interdisciplinary collaboration between heritage research and game engineering improve both academic rigor and real-world applicability.

Methodology

This study adopts mixed-methods research framework qualitative and quantitative bridge gap between Mongolian horn bow's craftsmanship/cultural attributes and visual design games, ensuring both academic rigor and practical guidance game development.

At the qualitative level, the study conducts cultural deconstruction, process analysis, and extraction of design principles related to Mongolian ox-horn bow craftsmanship through literature analysis, in-depth interviews with inheritors, field investigation, and expert evaluation. At the quantitative level, a total of 210 standardized experience questionnaires were distributed, and 196 valid responses were collected, yielding an effective response rate of 93.3%. The sample included college students, cultural enthusiasts, intangible cultural heritage researchers, and digital media practitioners. SPSS was used for reliability and validity testing, descriptive statistics, and correlation analysis in order to support the systematic evaluation of effectiveness and communication outcomes. This study also adopts design practice research as a core approach, completing 3D modeling, Unity engine development, and system iteration. Through the triangulation of qualitative coding and quantitative statistics, a reusable and scalable digital transformation method for traditional craftsmanship was established.

1. Literature Review Method: In this study, by collecting historical materials on Mongolian nomadic civilization, monographs on traditional bow and arrow craftsmanship, and policy documents on intangible cultural heritage protection we clarified the origin and development of Mongolian horn bows, their production techniques the use natural materials and the practice of mechanical principles, cultural value the evolution of their role in hunting, warfare, and the Naadam Festival, and their current status of inheritance. we sorted through literature on Unity game programming technology and digital intangible cultural heritage visualization design to grasp the technical path of gamified inheritance visual design principles and theoretical support for similar digital transformation cases of intangible cultural heritage, providing a theoretical basis for the subsequent integration visual design game programming.

2. Field Research Method: I conducted on-site interviews with inheritors of the intangible cultural heritage of Mongolian horn bow making folk artists scholars of ethnic culture, meticulously recording complete production process of horn bow from material selection, processing and shaping to assembly and debugging, every step of process, tool usage standards, traditional patterns, and decorative features. Simultaneously, I interviewed Nuomin Chaolu, an inheritor of the intangible cultural heritage, collecting visual elements such as the shape, color, and texture of actual horn bows to understand the cultural sentiments and cognitive habits of the Mongolian people towards horn bows. This provided first-hand materials for the localization, accuracy, and cultural fidelity of the game content in the visual design.



Figure 1 The Production Process of Ox Horn Bow and Arrow

(Source: Constructed by the researcher)

In the digital construction stage, based on data collected from field investigations, high-precision modeling of the components, manufacturing tools, and technological processes of the Mongolian ox-horn bow was completed using 3D modeling software, together with material mapping, skeletal rigging, and animation production, in order to digitally reconstruct traditional craftsmanship operations and production procedures (Rumschlag, 2018). On this basis, the Unity game engine was employed for scene construction, rendering optimization, interactive logic programming, and function implementation, including interactive modules for viewpoint control, step-by-step demonstration, craft explanation, and virtual experience. In this way, abstract traditional craftsmanship was transformed into visible, operable, and experiential digital content. In the later verification stage, comprehensive evaluations of the authenticity, integrity, interactivity, and communication effects of the digital visualization system were conducted through tests and feedback from intangible cultural heritage researchers, craftsmanship inheritors, and user participants. The model accuracy, interaction flow, and display effects were continuously optimized, eventually forming a set of digital implementation methods suitable for the preservation,

exhibition, and inheritance of Mongolian ox-horn bow craftsmanship, while also providing a referential technical approach and practical paradigm for the digital transformation of similar traditional handicrafts.

Conceptual Framework

This conceptual framework integrates craftsmanship of Mongolian ox-horn bows visual game design. On one hand, delves into the material layer encompassing material structure and ratio and cultural symbolic dimension bull horn bows, exploring their overall structural correlation and significance. On the other hand, through visual game design processes like 3D modeling, module production, animation formation, and realistic simulation, it aims to shape player perception encompasses sensory experience visual, auditory, tactile, emotional resonance cognitive understanding rule cognition, strategic cognition experience emotions and value emotion thus bridging traditional craftsmanship with modern game interaction and perception (Figure 1).

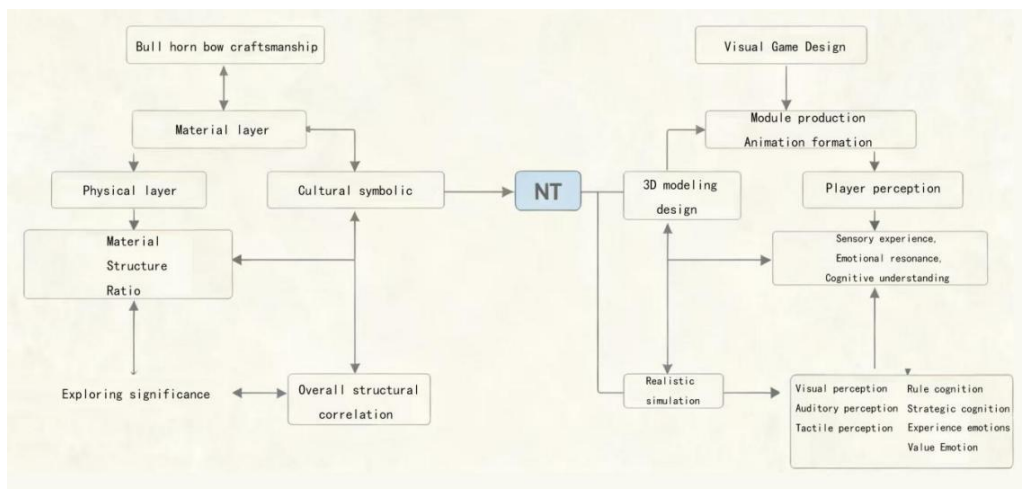


Figure 2 Conceptual Framework (Source: Constructed by the researcher)

Results

This study is not limited to the function realization of the digital system but extracts a theoretical model of digital visual transformation of traditional craftsmanship based on design practice. It constructs a five-in-one framework consisting of a culture layer, a craftsmanship layer, a digital layer, an interaction layer, and a verification layer, clarifying the core logic and implementation path from intangible cultural heritage deconstruction to digital regeneration.

The results show that the overall user satisfaction with the system is 89.3%, and the craft cognition improvement is 76%. The data come from descriptive statistical analysis of valid samples, which verifies the significant effect of digital experience on the communication of traditional craft knowledge. At the same time, the study summarizes a Unity-based digital visual design framework suitable for traditional ethnic handicrafts, including five modules: standardized craft decomposition, high-precision 3D modeling, immersive interaction design, multi-platform adaptation, and mixed-method validation.

It breaks through the limitation of single product development and rises to a transferable design paradigm and methodology system. Focusing spatial games for heritage communication, earlier studies have analyzed educational design logic and application effects, which provides a theoretical basis for the spatial interactive experience design in this research.

The results further confirm that the digital transformation based on game engine can effectively improve the readability experience and communication power of intangible cultural heritage, providing theoretical basis and replicable practice mode for the digital protection of similar ethnic handicrafts. A complete design evaluation framework for serious games has been proposed to enhance cultural understanding and user experience, which supports the effectiveness and reliability of the system constructed in this study (Tsita & Satratzemi, 2019).

1. Visual analysis design of Mongolian ox horn bow and arrow

Mongolian cow horn bows and arrows are traditional weapons and tools created by grassland people in their long-term nomadic hunting life, combining natural environment and practical needs. Their structural design follows the principles of mechanics but also contains profound national craft wisdom. Overall, the ox-horned bow and arrow consists of three core components: bow body, bowstring, and arrow. The subdivided structures of each component cooperate with each other to achieve the accuracy and power of archery. The following detailed analysis is carried out on each component.

In the unity programming, I also added a detailed information about the structure of the ox horn bow and arrow and the target of the bow and arrow contains a detailed introduction to the development story of the bow and arrow and the process flow.

1.1 Analysis of the structure of Mongolian ox horn bow and arrow

(1) Bow body: the core support structure of the bow and arrow

The bow body is the "skeleton" of the ox horn bow and arrow, assumes the key role of storing tension and releasing energy. Its structure consists of four parts: bow arm, ox horn patch, wood core, and tendon layer. Each part is closely combined through traditional bonding technology to form a whole that has both elasticity and strength.

(2) Bowstring: The key link to transmit energy

The bow string is the core component that connects the tip of the bow and transmits the energy of the bow body to the arrow. Although its structure seems simple has extremely high requirements for material and production process, directly affects the stability and range of the arrow. The bow strings of Mongolian cow horn bows and arrows are mainly made of animal tendon ropes or plant fiber ropes. Some hunting bows arrows also use a composite structure of "string tendon + metal wire".

(3) Arrow: The core component for achieving accurate shooting

Arrows are the ultimate carrier for transmitting the energy of the bow body and hitting the target. The structure consists of four parts: arrow shaft, arrow head, arrow tail, and arrow feather. The materials and dimensions of each part need be strictly matched to ensure stable flight trajectory and accurate shooting.

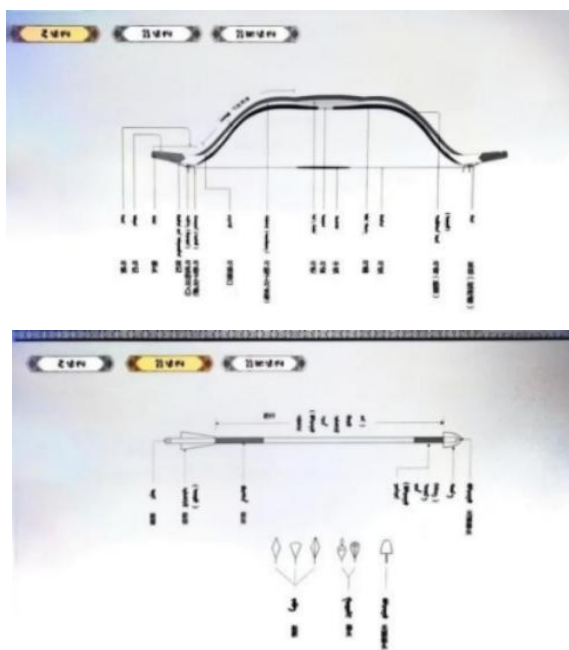


Figure 3 Interface design 1 (Source: Constructed by the researcher)

1.2 Mongolian arrow target

Modern Mongolian standard archery targets must comply with the following specifications:

Size standard: The target surface is square with a side length of 120 cm, and the thickness of the target body shall not be less than 8 cm ensure that the arrow does not penetrate after being shot, while avoiding the arrow shaft breaking target surface is 1.5 meters from the ground and is fixed on a metal or wooden

bracket. The bracket must ensure that the target surface is perpendicular and the deviation does not exceed 1° .

Material standard: The main body of the target surface is "high-density compressed felt", and the surface is covered with waterproof and wear-resistant chemical fiber fabric, which can adapt to different outdoor weather bull's eye and scoring area are printed with fluorescent pigment to ensure that the shooter can clearly identify the bull's eye position when shooting at a long distance.

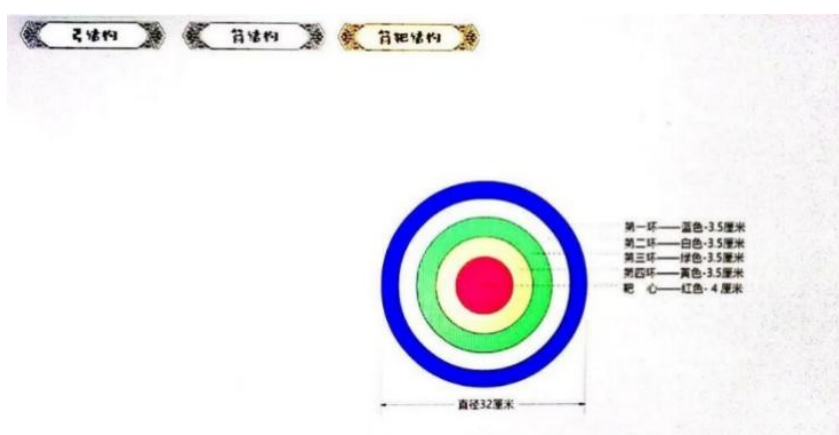


Figure 4 Interface design 2 (Source: Constructed by the researcher)

Scoring criteria: The target surface is divided into 5 scoring areas, and the center is distributed in a concentric circle:

Central area (bull's eye): 10 cm in diameter, red in color, corresponding to 10 points;

Zone 1: Outside the bullseye, width 15 cm, color yellow, corresponding to 8 points;

Zone 2: Outside Zone 1, width 25 cm, color is blue, corresponding to score 6 points;

Zone 3: Outside Zone 2, width 30 cm, color is white, corresponding to score 4 points;

Four zones: outermost, width 20 cm, color is black, corresponding to score 2 points;

The target surface is not counted if missed, and the scoring rules are in line with international archery competitions. At the same time, national characteristics are retained through color matching, red, yellow and blue are traditional auspicious colors of Mongolians.

2. Unity develops immersive archery game design

Mongolian ox-horn bows and arrows, as key carriers of grassland culture, bear the nation's historical memory and traditional craftsmanship. Integrating them into Unity archery game design enables players to enjoy archery fun while achieving digital inheritance of national culture. Based on restoring the real characteristics of bows and arrows, the game combines Unity engine's physical simulation and interaction to create an immersive archery experience aiming to let players understand their cultural connotations and gain a smooth, exciting gaming experience.

2.1 Project basic settings

In Unity, 3D model construction is first based on the real shape of Mongolian ox-horned bows and arrows. The bow body of the bow is expressed by combining cow horns and wood, and the natural texture of the cow horns and the texture of the wood are restored through texture maps; the bow string is made of a material with a high elasticity visual effect, and in terms physical attribute settings, bow string is given appropriate elastic coefficient and tension parameters with Unity's physics engine. When the player pulls the bow string, the bow string will produce corresponding deformation according to the pull force, the pull force value will be displayed in the game interface in real time. The greater the pull force, the faster the initial speed after the bow is shot and the longer the range, thereby simulating the mechanical characteristics of the real ox-horned bow and arrow.

2.2 Immersive environment design

(1) Archery operation mechanism

The game uses a first-person perspective for realistic shooting. Players operate via mouse/controller: hold and drag the left mouse button back to draw the bow drag distance determines tension release to shoot. aiming assist system slight adsorption near targets balances accessibility for novices and game challenge. Wind speed displayed indicator and gravity are incorporated wind offsets arrow trajectory gravity causes parabolic motion requiring players to adjust aiming angles enhancing the game's strategy and realism. (Mortara et al., 2014).

(2) Newbie boot level

The core goal of the newbies' guided level is to quickly familiarize players with the characteristics of game operations and horned bows and arrows. At the beginning of the level, the historical background and usage methods of Mongolian ox-horned bows arrows are demonstrated through animation, they enter practical training. Players first need to complete basic bow drawing, aiming shooting training. The system will use text prompts and voice guidance to inform players of key operation points such as bow drawing strength and aiming skills. Next, set up fixed target training, target distance gradually increases from near to fa. Players need hit certain number of bullseyes within a specified time to advance to the next stage of training. During training, the system provides real-time feedback on results, such as whether position and draw strength are appropriate, help players quickly master game controls.



Figure 5 Scene Design 1 (Source: Constructed by the researcher)

(3) Plot level break mode

The game's plot-based level mode set Mongolian historical and cultural contexts, featuring themed levels like grassland hunting tribal defense traditional archery competitions. Each level unique scenes mechanics: hunting requires shooting moving prey; defense involves resisting multi-directional enemy attacks limited arrows; competitions replicate traditional rules with virtual opponents.

Players must complete specific goals shooting prey within time limits fending off enemy waves ranking top 3 in competitions pass. Post-level ratings determine progression only qualified above unlocking next level. Clearing levels also unlocks cultural knowledge cards on like hunting culture tribal customs archery history, enabling players learn Mongolian culture while gaming.



Figure 6 Scene Design 2 (Source: Constructed by the researcher)

2.3 Competition mode

The competitive mode is divided into two types: single player competition and multiplayer competition. In the single-player competitive mode, players can choose challenging levels of different difficulties, limited-time shooting challenge, mobile target shooting challenge, wind speed change shooting challenge. The limited-time shooting challenge requires players to shoot as many targets as possible within the specified time, target will appear and disappear randomly; in the mobile target shooting challenge, target will move at different speeds and trajectories, and players need to predict the direction of the target's movement to shoot; the wind speed change shooting challenge will randomly change the wind speed and direction during the game, and players need to quickly adapt to environmental changes and adjust their shooting strategies. Players' results in single player competitive mode will be recorded in the ranking list, and players can improve their rankings through continuous challenges.



Figure 7 Game Design (Source: Constructed by the researcher)

2.4 Game features and optimization directions

(1) Game Features

Integration of cultural heritage and game experience: The game deeply explores the cultural connotation of Mongolian ox-horned bows arrows, and integrates them into various aspects of the game's model design, plot levels, cultural knowledge cards, players can understand and inherit Mongolian culture while experiencing the fun of the game, and realize the dual value of "entertainment + education".

Highly restored physics simulation: Through Unity physics engine, the physical characteristics of the horn bow and arrow are accurately simulated pulling force, elasticity, flight trajectory, etc., and the influence of environmental factors wind speed and gravity is added to allow players to obtain a real archery experience and enhance the immersion and authenticity of the game (Malegiannaki & Daradoumis, 2017).

Diverse game modes: The game sets a variety of gameplay such as novice guide levels, plot level breakthrough mode, competitive mode, etc. to meet the needs of different players. Novice players can get started quickly through novice guidance, the plot party can experience Mongolian cultural stories through the

plot levels, and the competitive party can compete with other players through competitive mode to improve the audience and playability of the game.

(2) Optimization direction

Model and scene optimization: Although the ox horn bow and scenes in the game can meet basic needs, there is still room for improvement in detail performance. In the future, the texture and light and shadow effects of the model can be further optimized, wear effect of the bow and arrow can be increased to make the model more realistic; at the same time, the vegetation, weather other effects of the scene can be optimized, increasing the four-season changes of the grassland, rainy days, snowy days and other weather scenes to enhance the immersion of the scene.

Optimization of operation experience: Further optimize the operation mechanism based on the operation characteristics of different devices. for mobile phone players, optimize the sensitivity of the bow pulling operation of the touch screen to avoid misoperation; for VR players, use the motion tracking function of VR devices to achieve more realistic bow pulling, aiming, and shooting actions, and enhance the immersion of the VR experience.

Content updates and expansion: regularly update game content, add new plot levels, competitive modes, props. keep the game fresh. the same time consider adding player customization functions, such as allowing players to customize the appearance of the horned bow and arrow color, texture, arrow style, etc. of the bow body, costumes of the character, etc., to enhance the player's personalized experience. In addition, we can cooperate with Mongolian cultural institutions to explore more cultural materials and integrate them into the game, further enhancing the cultural connotation and educational value of the game.

Discussion

From the research results, users' cognitive improvement of ox-horn bow craftsmanship reaches 76%, and the overall system satisfaction is 89.3%. The above data are obtained from descriptive statistical analysis of 196 valid samples, confirming that the visual design based on game engine can significantly improve the public's understanding and acceptance of traditional craftsmanship. This conclusion also confirms rationality of theoretical model and design framework proposed in this study: digital technology is not merely a display tool, but an important carrier that can reconstruct communication path of intangible cultural heritage knowledge, strengthen the depth of cultural experience and maintain the vitality of skill inheritance. At the same time, this study combines qualitative analysis and quantitative test, and improves the reliability and scientificity of the research conclusions through the triangulation of inheritors' interviews, expert evaluations and user questionnaire data, responding to the demand for rigorous research paradigms the field of digitalization of intangible cultural heritage (Kosti et al., 2025).³

The theoretical contribution of this study lies in the interdisciplinary integration of game design, digital media and cultural heritage protection, expanding the theoretical boundary and practical path of digital protection of intangible cultural heritage, and clarifying the internal logic and design principles of digital transformation of traditional craftsmanship. The practical contribution is reflected in the formation of a set of digital solutions that can be directly applied to the inheritance, display and promotion Mongolian ox-horn bow craftsmanship, upgraded to a popularizable methodological system instead of staying at the level of function realization of a single digital product. Future research can further combine VR/AR immersive technology, artificial intelligence interaction and multi-platform communication system to continuously optimize the theoretical model and design framework, and promote the more dynamic

creative transformation and innovative development of excellent traditional ethnic culture in the digital era.

Conclusion

The production process of Mongolian ox horn bow is not a simple "craft", but a "cultural carrier" with Mongolian historical memory, lifestyle and spiritual beliefs. Its research has irreplaceable significance for the inheritance of national culture. Through above design, we will establish immersive archery game unity and development. This study takes Mongolian ox-horned bow and arrow as the core element. In the unity's programming, a detailed information about the structure of ox-horned bow and arrow and the target of the bow and arrow is added, which contains a detailed introduction to the development story of the bow and arrow and the process flow. Through highly repaired physics simulation and diversified game modes, players can understand and inherit Mongolian culture while experiencing the fun of archery, thus achieving an organic integration of cultural heritage and game experience. In the future, by further optimizing game models, scenes and operational experiences and updating and expanding game content, expected that it will improve the quality and influence of the game, allowing more players to experience charm Mongolian culture through this game, and promote the digital inheritance and development of national culture.

Recommendations

Replace "cow horn glowing" with "texture shining with energy storage", which retains the energy storage prompt and conforms to the cow horn material, reducing the deviation of fantasy feeling.

When upgrading bows and arrows, add sound effects changes from wood friction sound to silver jewelry resonance, and use "audio-visual combination" to cover players who ignore details.

Add "optional totem stickers" as auxiliary decoration, and balance global player acceptance with Mongolian players' sense of tribal belonging.

Preset the "Performance Image Quality" switch for players to choose independently: low-end models default to reduced detail, while high-end models can choose high-precision material rendering.

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