Bridging the Gap

Exploring a Design-via-Making Approach through Digital Guidance Systems

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ABSTRACT

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Through a design-by-making approach, this paper explores the concepts of Albertian split in architecture, and workmanship of risk in craft, which thematize the divide between design and execution, and the role of material execution in creativity. Several case studies are presented where Mixed Reality (MR) techniques are employed to challenge the gap between design and execution, foregrounding the development of a novel guiding system proto
type. The prototype uses an immersive MR display system guiding a potter with a real-time comparison between the digital design and the physical object, and features color-coded geometry overlays and real-time geometry scanning interfaces. The design and fabrication of a series of pottery pieces with both the traditional sequenced approach and the integrated design-make process are documented and compared in detail for effectiveness. Potentials and limitations are discussed, and the importance of design values during making are empha sized, advocating for greater synchronicity between designing and making processes. The research aims to contribute to a paradigm shift in design, fostering collaboration between designers and makers through innovative digital tools.

1 Fabricated pottery in exhibition with illustration.

INTRODUCTION

Alberti's character Momus' argument that thinking and action should be kept apart lies at the foundation of the so-called "Albertian split," which has been at the center of architects' identity and debates since the Renaissance. (Carpo 2011; Cardoso Llach 2015; El-Zanfaly 2017). Under its influence, architects distance themselves from a build ing's material execution, privileging the intellectual labor of design over the physical labor of construction.

This relationship, prevalent in broader fine art practices, is best summarized by artist Sol LeWitt, who claimed: “All the planning and decisions are made beforehand, and the execution is a perfunctory affair.”(Alberro and Stimson 1999) However, the process of making and execution is neither perfunctory nor straightforward. The designer should not take certainty for granted during execution but rather embrace undetermined results and the workman ship of risk (Pye 2008). During execution, the workperson replaces architects and artists to complete and improve the design further with their dexterity. The technical trade and techniques processed by workers in the execution phase have great value, and can be overlooked when design and execution are completely separate. The craftsperson’s perspective and judgment of the design in combination with their understanding of craft and material, inspire a unique design method driven by making.

In pottery-throwing, a craft dating back 5,000 years (Schreiber 1999), this relationship between design and making becomes particularly evident. Unlike certain art forms where design can be fully conceptualized before hand, pottery is inherently a process of "sculpting," where the final form is shaped by both intent and improvisation. In such craft-based practices, the workmanship of risk is ever present, as a thorough understanding of clay’s moisture, materiality, and tool interactions of the craft is inseparable from the design process. However, potters in the current design-making relationship cannot easily reference the intended design easily. The understanding and realization of a design are inherently personal and subjective. Crafters often encounter difficulties in conveying the nuanced tech niques required to achieve specific design outcomes. Much of the process is left to the craftsperson's intuition and tactile engagement with the material.

This raises the question: What if a system could provide real time, incremental guidance throughout the making process, offering immediate feedback on how specific actions influ ence the form in the making? Such a feedback loop could empower makers to improvise more effectively, enabling them to achieve higher levels of design quality and creative expression. Moreover, it could unify design and execution and embrace the workmanship of risk.

OBJECTIVE

During the throwing process, the goal is to allow crafts people to reference the design intent without being constrained by it. The system would offer visual guidance overlaid on the physical environment to ensure that the final product aligns with the original design intent while giving the potter the flexibility to make real-time adjustments based on their decisions and contextual factors, such as the behavior of the clay.

STATE OF ART

Extensive research has been conducted on traditional and contemporary craft and construction practices, particularly in relation to improvisational making processes. For example, Terry Knight (Knight 2018) has studied Kolam, a traditional pattern design and making practice, and theorized the design process as a set of discrete making actions, termed making grammar. Another study examined the interrela tions between computation, design, and making, formalizing an embodied, human-centered methodology for making and learning called I∧3 (El-Zanfaly 2018; 2017). On the other hand, digital technology has also been widely adapted to aid makers. InnixAR (Oval et al. 2024) is an exemplary project that provides an alternative to paper drawings by using an augmented-reality-powered guiding system for construc tion. Hybrid Embroidery (Lee and Llach 2020) introduced a collaborative workflow that uses generative algorithms to assist the crafter in creating unplanned embroidered pieces. Furthermore, The Computational Clay (Lopez 2016) pavilion deployed an auto-correct building information model (BIM) that aided the workforce in making on-site design modifi cations based on the existing structure. In these cases, the maker has the autonomy to build in reference to the original design intent, and the agency of design is balanced between designers and workers. The projects mentioned above provide valuable foundational knowledge and inspirational prototypes for crafters, which have informed the develop ment of this project.

HYPOTHESIS

An MR-powered guiding system could unify design and execution by helping ceramics designers and potters better engage in the workmanship of risk. This approach would enhance their ability to maintain fidelity to the design while encouraging creative improvisation during execu tion. Furthermore, the utility of this system extends beyond pottery, as it offers a new way to enhance self-guided skill building and rethink the role of design archiving in the arts and Building Information Modeling (BIM) in architecture.

METHOD

Guiding System Overview

The proposed guiding system integrates mixed reality (MR) technology to enhance pottery-making. The development of the prototype follows a Design-Based Research method ology, allowing for continuous testing and refinement of the guiding system throughout its development.

First and foremost, this paper documents the experiences and findings of potters who follow conventional crafting practices by using a physical template to achieve the design intent. This pilot study enabled us to identify areas for improvement in the pottery-throwing process. The observa tions inspired the features and interfaces of the MR guiding system.

Data were collected through a combination of direct obser vation, video recordings, and user feedback forms. In addition to capturing completion times and accuracy, qual itative data on user experience, ease of use, and perceived creativity were gathered. The data were evaluated across previous iterations of the prototype.

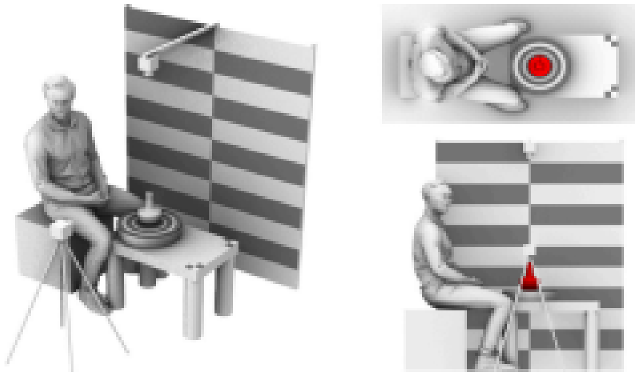
Based on these evaluations, the system was refined itera tively. The development followed two approaches. The first approach focused on clarity, providing real-time incremental feedback on deviations from the design form. The second approach for guidance was more referential, allowing for less interference and spontaneous design changes.

Guiding System Setup

The guiding system first reconstructs the existing shape of the pottery. This is achieved using two cameras focused on the object: one for the plan view and one for the eleva tion. These cameras capture the plan view and side profile, respectively (Figure 2, Figure 3). The reality capture process employs Canny Edge Detection from OpenCV (pawan_ kumar_gunjan and simmytarika5 2023), which extracts the pottery's profile as a curve in Scalable Vector Graphics (SVG) format (Figure 4, middle). The second step is to reconstruct the physical object by lofting the side profile along the main vertical axis using Rhino Compute, a stateless REST API for geometry processing (Figure 4, Figure 5).

Pottery Throwing Approaches

To test the system, we compared three approaches: a conventional approach without the guiding system, a guided approach where the MR guiding system provides direct and immediate feedback to the potter, and an improvised approach where the MR guiding system guides the potter indirectly, allowing more room for improvisation.



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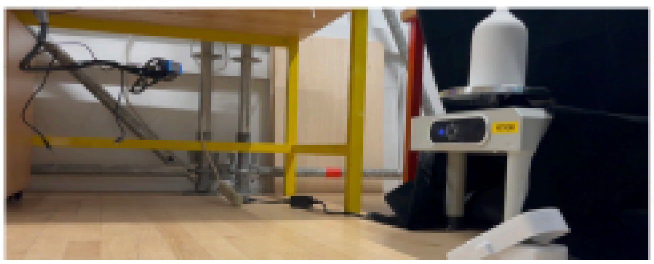
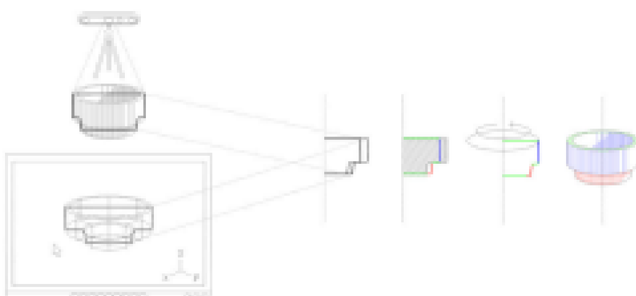
2 Setup diagram, perspective, plan, and elevation view. Pottery was placed on top of the marker plate and with a background for enhanced edge detection.



3 3 Setup in reality. Only side camera used to capture elevation view of the pottery with black drop cloth as background.



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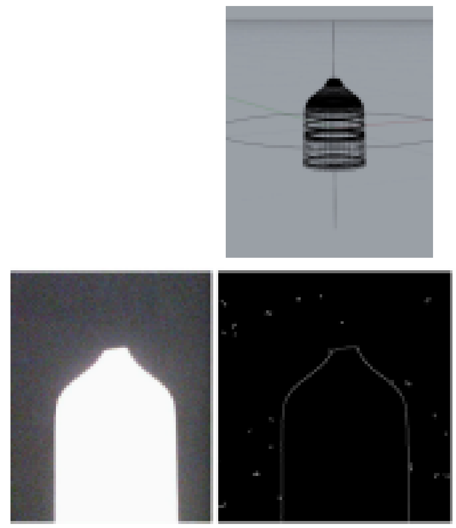
4 Backend geometry reconstruction diagram. The profile curves are extracted from both the physical pottery and design 3D model and aligned together. The physical pottery profile is trimmed and color-coded as green (match), red (excess material), and blue (lacking material). The color-coded curves are swept to reconstruct a color-coded 3D shape to represent making progress.



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5 Full reconstruction pipeline in action. From left to right: camera view of over-exposed pottery, detected edge, and reconstructed 3D mesh.

8 Improvised throwing approach: there are no 3D models to follow in the first place, the potter improvises on the design and uses the camera to capture and archive this design into a 3D model.

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6 Conventional throwing approach: the designer digitally models the design and fabri cates a physical template that restricts the execution process. The resulting pottery follows the template closely.

7 Guided throwing approach: the designer digitally models the design, and the potter following the guidance of the digital model directly by comparing it to the physical pottery. The potter has immediate feedback from design 6 and less restriction on the shape they are making.

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The conventional approach consisted of two throwing exer cises in which the craftsperson used a physical template and other conventional crafting techniques without the guiding system. This allowed us to better understand the throwing process and its relationship with pottery design, helping us identify pain points in pottery-throwing that informed the development of prototype features. The guided approach involved an immersive guiding system providing clear and immediate digital feedback, indicating the difference between the design and execution. The improvised approach featured a less controlling guiding system with minimal interference, placing the comparison between design and execution to the side as a reference.

Each approach involved two different exercises. The first exercise evaluated the guiding system during the shaping stage, where the potter uses their hands to form the rough shape of the pottery. The second exercise tested the guiding system during the trimming stage, where the potter gener ally uses tools to fine-tune the form of the pottery.

Conventional Approach: Design followed by making with a physical template

In the conventional approach (Figure 6), the designer is responsible for conceptualizing and 3D-modeling the intended design of the pottery, and then proceeds to create a physical template resembling the shape of the clay. This template provides a reference for achieving consistent dimensions and proportions in the final object. The template consists of a laser-cut acrylic piece representing the

desired silhouette of the pottery. The potter relies on the template and their skill to execute the design, shaping the clay using wheel-throwing, followed by a limited amount of hand-building. The finished object is then left to dry, setting the form.

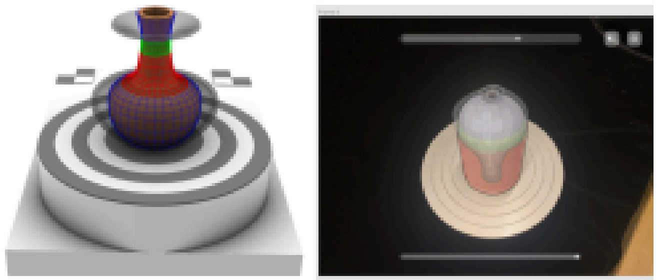
Guided Approach: Design followed by virtual guiding geometry in MR

n the guided approach (Figure 7), the design process also begins with conceptualization but adds the element of a virtual guiding geometry overlaid onto the physical envi ronment in MR. Using the developed pipeline explained in the conventional approach, the designer exports the same digital file, and the guiding system imports the shape, initi ating immersive guidance. The potter then follows virtual guides while shaping the clay, using MR technology to visu alize and adjust the design in real time. This approach allows for greater control and fewer constraints during the making process, as the potter can iteratively refine the design without the rigid constraints of the template. Once the object is shaped, it is scanned one final time for digital archiving before moving on to the drying stage.

Furthermore, it's important to note that the guiding system will be deployed separately during the shaping and trimming stages of throwing. This separation allows for two distinct exercises to be conducted, evaluating the effectiveness of the guiding system at each stage. By comparing the user expe rience and the resulting pottery in both exercises, insights can be gained into which stage the guiding system performs best, informing future iterations and improvements. These comparative analyses are further explored and discussed in the findings section, providing valuable insights into the efficacy and practicality of integrating MR technology into the pottery-making process.

The interface of the guiding system in the guided approach provides a color-coded digital display of the pottery being made (Figure 8, left). There are two virtual layers of guid ance overlaid on top of reality. The first layer is a translucent object representing the designed piece, constantly reminding the potter of the final objective. The second layer is a color coded transparent mesh over the real-life form, updated in real time to match the ever-changing vase on the wheel.

There are three colors used: green is applied when the real life form aligns with the designer's intended form, indicating that this part of the process is correct. Red indicates that the potter needs to compress a particular area. As shown in the diagram, the designed neck is thinner, and the potter needs to pinch that area. Lastly, blue indicates that the vase needs to expand to match the intended shape. For example,



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9 Design of the color-coded guiding system (left) and deployment (right).

the potter needs to pull the top of the vase outward to match the plate-like shape at the top. By juxtaposing these two layers (Figure 8, right), the system provides a subtle overlay of information on top of reality, offering crucial shape guid ance to ceramic makers.

Improvised Approach: Improvised making followed by digital capture of the final artifact

In the improvised approach (Figure 10), the design process follows a more spontaneous and experimental path. Rather than starting with a predetermined design, the potter begins with an open-ended exploration of the material, allowing the clay to inform the making process. This approach embraces improvisation and serendipity, enabling unex pected discoveries and creative expression. The potter may work intuitively, shaping the clay by hand without the use of templates or guiding geometry. The only form of guidance is a reference to the design intent and the existing shape, shown as 3D models on a side panel.

As the object takes shape, the potter may make adjustments and refinements based on intuition and aesthetic judgment. Once the object is completed, it is digitally captured using the same setup to create a digital record of the final artifact.

10 10 Guiding system in improvised approach design. The panels are placed on the side to show the 3D model of the intended design on the top, and the reconstructed reality on the bottom.

This digital capture preserves the unique qualities of the improvised-making process and allows for further analysis or manipulation in the digital realm.

The interface of the guiding system in the improvised approach utilizes a panel display instead of directly over laying digital assets onto the physical environment. The guiding system becomes a panel-based visualization that displays the scanned and designed shapes on the side (Figure 10). The development of immersive virtual displays enables low latency and a high resemblance to reality when the user is wearing an immersive display headset.

FINDINGS AND DISCUSSION

The Conventional Approach

The traditional approach to pottery-throwing represents the common practice adopted by most potters and artists. The use of physical templates provides a reliable guide for the potter to achieve the intended design. By holding and pressing the template, the clay is automatically trimmed into shape (Figure 11). This significantly reduces the level of difficulty, and the result is unsurprisingly close to the orig inal design. During the shaping process, the potter did not attempt any other throwing techniques, focusing solely on pressing and trimming. Consequently, little attention was

11 11 Shaping using a physical template. The potter is pressing and trimming the clay.

given to throwing techniques or the design itself, as the template took full control of shaping the pottery. In total, three rounds of template shaping were performed, with the first two rounds trimming the clay to shape and the final round smoothing the surface.

The result (Figure 12) closely resembles the original design. While the potter had the most straightforward experi ence using this approach, they did not fully understand how different throwing techniques affected the design. In this case, the potter felt constrained by the template, which hindered their ability to experiment with additional techniques.

The Guided Approach

Unlike the previous exercise, the guided approach using an MR headset removes the restrictive template, allowing the potter to use their hands and more general tools. Shaping by hand (Figure 13) is considerably more challenging compared to using a template. The shaping process took five rounds in total, each lasting significantly longer. Although the lack of restrictive tools caused some difficulty when the potter tried to match the original shape and turn the guiding color green, the potter was able to use various throwing techniques and adjust the design at their discretion, within the tolerance of the guiding system.

During the second session of clay throwing, the potter deployed the guiding system after a preliminary and impro vised shaping (Figure 14). While wearing the headset, they used common throwing tools like wooden ribs and a metal scraper to trim the clay to match the digital design. Rather than relying on a physical template, the potter could impro vise the form of the clay by utilizing the various properties of different tools. The pottery (Figure 15, left) is the result of shaping while wearing the headset, while the other piece (Figure 15, right) showcases a smoother shape, achieved by using the guiding system during trimming.

The MR system has significant potential for enhancing the pottery throwing experience by providing real-time

12 Final results of the conventional approach, exercise one (left), exercise two (right).

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13 Shaping with hands in the guided approach. Recording of the making process (left), screen shot of the immersive guiding system (right).

14 Trimming with tools in the guided approach. The right image shows the virtual form projected on the physical clay with a blue bottom and red top, the potter is trimming the excess top to achieve a green match on height.

15 Final results of the guided approach. Shaping stage (left), trimming stage (right).

feedback and guidance to potters. This, in turn, gives the potter more autonomy to experiment with different throwing techniques and receive immediate feedback. This rapid and flexible feedback loop allows for a greater degree of deci sion-making in crafting techniques and how to achieve the intended design.

The Improvised Approach

Without a direct overlay in the guiding system, there is no immediate comparison between the design and the physical pottery. The potter turned off the juxtaposed guidance and only referred to the design and scans on the side (Figures 16, 17). The shaping process also took five rounds, with each round lasting about the same time as in the previous exer cise. With no color to match and no exact shape to achieve, the potter had complete control over shaping, relying entirely on on-site judgment. The potter felt the least restrained and was able to work more fluidly with the material.

The improvised approach emphasizes creativity and experi mentation in pottery-throwing. This approach allows potters to create their designs freely, without the constraints of a physical template or digital guidance. The results produced (Figure 18) aligned with the hypothesis, as the pottery pieces differed the most from the original design, exhibiting unique features and forms. One notable feature is the inner-curved body, which resulted from bending the metal scraper, forming a natural curve during trimming. These impro vised design changes were scanned and archived (Figure 19). Comparing all approaches (Figure 20), the improvised approach offers a unique opportunity for potters to explore new shapes and forms, pushing the boundaries of tradi tional pottery-making techniques.

Implications of the Pottery-throwing Guiding System

The pottery-throwing guiding system sheds light on the continuous development of the craft-driven design method,

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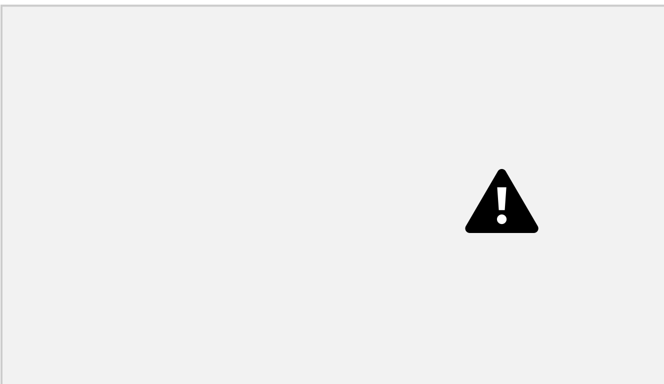

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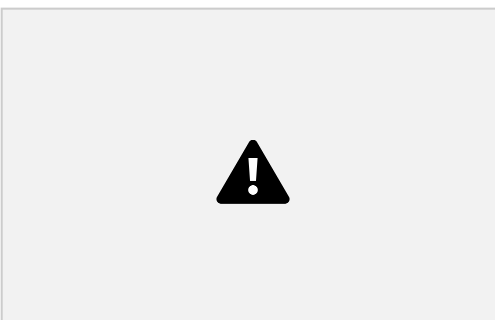

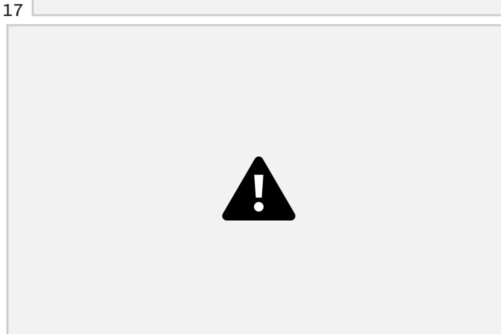

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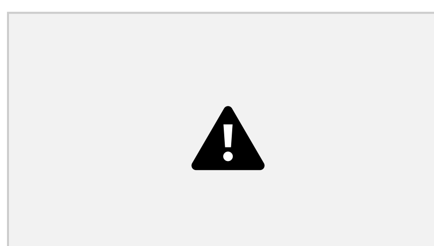

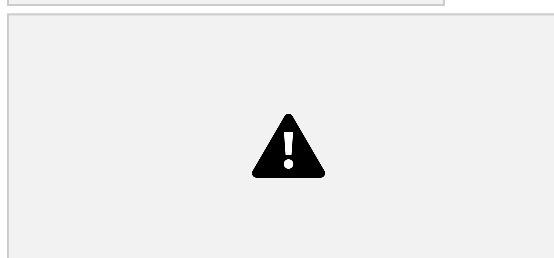

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16 Improvising with no guidance. The potter tried out new tech niques that are best fitted with the clay material and improvised a shape that deviated from the intended design.

17 The potter is referencing the intended design and the current scan. The right image shows the panels of the scan (top) and the design (bottom).

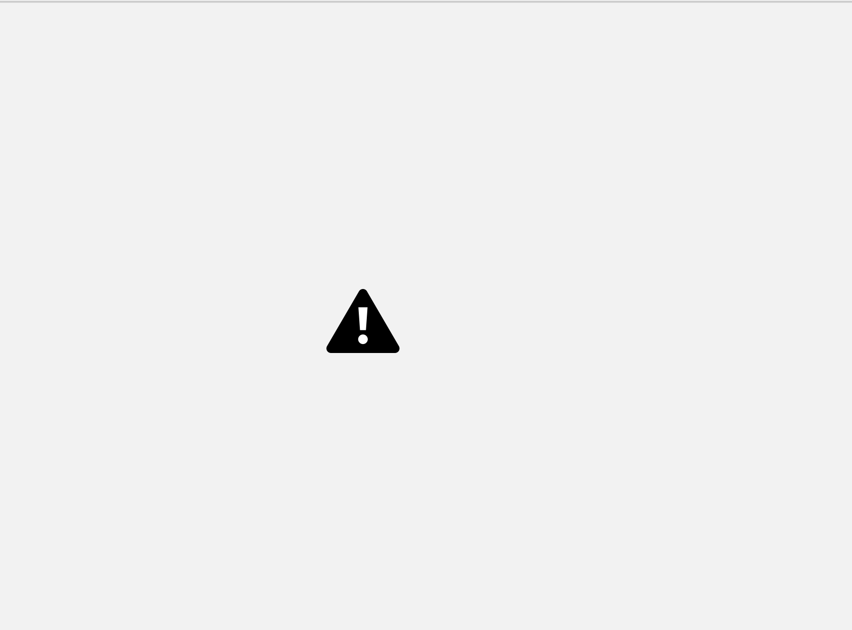
18 Final result of the improvised approach, the right image shows a deviated

design using throwing tools.

19 Digital scans archiving the progress of throwing, each scan could be extracted as a new design.

particularly in its emphasis on craftsmanship, iterative processes, and the integration of traditional techniques with modern technology. The existing prototype still has limitations, including MR display latency, headset comfort, and disruptions in crafting workflows. These technical constraints could hinder crafters from developing their skills and prevent designers from fully embracing craftsmanship during the execution process. Despite these limitations, the crafting exercises with the prototype revealed that the presence of the guiding system and its different modes offers unique implications for the agency and creativity of the maker.

On a spectrum between encouraging the workmanship of risk and aligning with the original design, the conventional approach closely follows the original design. The guided approach allows for some adjustments while still aiming to align with the design within tolerances. The improvised



approach prioritizes the craftsperson's intuitive and spon taneous creation, fully embracing the workmanship of risk.

Broader Contributions of the Guiding System The contribution of this guiding and capturing system extends beyond pottery-throwing. A potential contribution to the fields of design and making lies in rethinking the role of artifact archiving in the arts and expanding the applica tion of Building Information Modeling (BIM) in architecture. The pottery-throwing guiding and archiving prototype offers a new perspective on how BIM can be utilized among AEC (Architecture, Engineering, and Construction) parties. The consistent documentation of the project in digital models

20 A comparison between three approaches.

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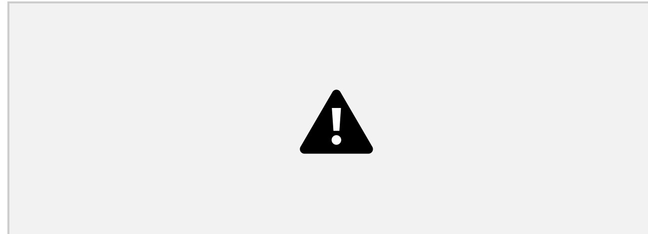

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21 An illustration of BIM diary, where each frame represents a stage of execution.

introduces the concept of a BIM diary (Figure 21), contrib uting valuable insights to the advancement of digital twins. Much like pottery-throwing guidance systems provide real time feedback and assistance to potters, BIM diaries could document the development and refinement of construction sites and reflect that progress in digital models. This would highlight the complexities involved in creating accurate digital representations of physical structures. This paral lels the iterative and collaborative nature of craft-driven architectural design, where designers and builders engage in continuous refinement and experimentation to achieve optimal outcomes. Through these parallels, we see how the pottery-throwing guiding system and craft-driven design methods in architecture share common principles of inte grating technology with tradition to push the boundaries of creativity and innovation.

CONCLUSION

In this paper, we investigated pottery-throwing through a design-by-making approach. We created an MR guiding system that can provide both direct and indirect guid ance, and conducted three experiments to compare it with conventional pottery-throwing using restraining templates. This journey through the exploration of and comparison between different approaches to pottery-throwing reveals the dynamic interplay between tradition, technology, and creativity. We found that it is essential to propose an alter native design-making pipeline for an improvised yet guided making process that allows makers to make on-site deci sions. This approach enables the digitalization of improvised physical artifacts for archiving and referencing, fostering a system that records and uncovers the continuous correc tions that differ from the traditional design drawing and restrictive instructions.

Through such a process, makers have the freedom to rely on their craft and judgment and innovate while still benefiting from guidance and support. The exploration of different approaches to pottery-throwing, craft, and design underscores the importance of embracing innovation while honoring tradition. By combining the best of both worlds, we can create a rich and dynamic landscape for the art and architecture industries, where makers are empowered to express their creativity freely, guided by the wisdom of the past and the possibilities of the future.

IMAGE CREDITS

All drawings and images by the authors.

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