PM4Pottery: A Scriptable Parametric Modeling Interface for Conceptual Pottery Design Using PM4VR

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Fig. 1. Teaser. This teaser provides a glimpse of PM4Pottery, an innovative scriptable parametric modeling interface tailored for conceptual pottery design. Designers craft Java[♭] scripts to generate real-time 3D conceptual pottery models, seamlessly integrating with Oculus Quest 2 VR headset for immersive parameter tuning using VR controllers in a virtual environment.

***Abstract*—Pottery design has traditionally been a manual and intricate process, often constrained by physical limitations. This paper introduces PM4Pottery, a groundbreaking scriptable parametric modeling interface specifically designed for conceptual pottery design through the utilization of PM4VR (Parametric Modeling for Virtual Reality). PM4Pottery seeks to revolutionize this field by offering a dynamic platform where designers can script and manipulate parameters to generate 3D conceptual pottery models in real time. The integration of PM4VR further enhances the pottery design pipeline, allowing designers' immersive parameter tuning experience in a virtual environment using Oculus Quest 2 VR headset and SteamVR plugin.**

***Keywords*—Parametric Modeling, Pottery Design, VR**

I. Introduction

Conceptual pottery design represents a dynamic and innovative approach to the art of pottery, transcending traditional constraints to usher in a realm of boundless creativity and expression [1]. Unlike conventional pottery, which often adheres to established forms and techniques [2], conceptual pottery design places a premium on originality and individuality [3]. This avant-garde form of artistic expression encourages ceramicists to explore unconventional shapes [4], experimental textures [5], and unique crack patterns [6], pushing the boundaries of the medium. Rooted in the fusion of artistic vision and craftsmanship [7], conceptual pottery design embodies a synthesis of tradition and contemporary aesthetics [8], inviting artisans to engage in a dialogue between form and function [9]. As a result, conceptual pottery becomes a canvas for digital cultural and abstract concepts, fostering a vibrant and evolving landscape within the realm of ceramic arts.

On a separate note, Virtual Reality (VR) stands at the forefront of cutting-edge technology, providing users with an immersive and interactive digital experience that transcends the boundaries of the physical world [10]. Through the use of advanced hardware and software, VR transports individuals into simulated environments, creating a sense of presence and engagement [11]. Users wear VR headsets to enter these computer-generated realms [12], where they can explore, interact, and manipulate objects in ways that mimic or diverge from

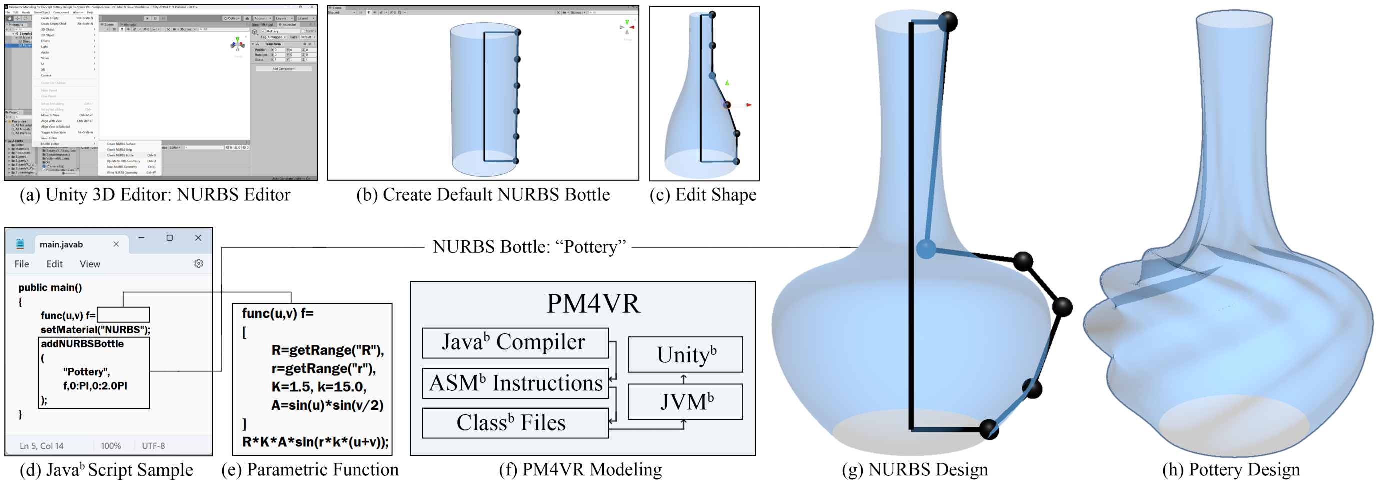


Fig. 2. Overview of our approach.

reality [13]. VR has found applications across diverse fields, from gaming [14]–[16] and entertainment to education [17]–[21], art design [22]–[25], exercise [26], [27], and beyond. With the integration of Parametric Modeling (PM) and Virtual Reality (VR), the innovative approach known as Parametric Modeling for Virtual Reality (PM4VR), introduced by Li et al. [28], marks a departure from the conventional parametric modeling methods. This transformative methodology leverages the immersive capabilities of VR, providing designers with a dynamic and scriptable interactive user interface.

Inspired by the existing works, this paper introduces PM4Pottery, a pioneering scriptable parametric modeling interface tailored for conceptual pottery design, enriched by the integration of PM4VR. As shown in Fig. 1, the incorporation of PM4VR enhances the pottery design experience, enabling designers to immerse themselves in a virtual environment through the Oculus Quest 2 VR headset via SteamVR plugin.

II. Technical Approach

Overview. The overview of our approach is presented in Fig.2. In Fig.2 (a), we develop a Unity3D Editor plugin named "NURBSEditor.cs" to support: (1) Create NURBS Bottle (Ctrl+G), (2) Update NURBS Bottle (Ctrl+U), (3) Load NURBS Bottle (Ctrl+L), and (4) Write NURBS Bottle (Ctrl+W). Upon initiating the "Ctrl+G" command, a default NURBS bottle is generated in the scene as depicted in Fig.2 (b). Subsequently, the NURBS bottle undergoes refinement by adjusting control point positions or scaling control point radii to modify weights, through the "Ctrl+U" key as exemplified in Fig.2 (c). Once a well-designed NURBS bottle, such as the one named "Pottery" in Fig. 2 (d), is achieved, it can be stored as a file (e.g., "Pottery.NURBS") using "Ctrl+W" command or loaded into the scene using "Ctrl+L" command. These operations are implemented through our C# scripts of "NURBSGeometry.cs" and "NURBSEditor.cs."

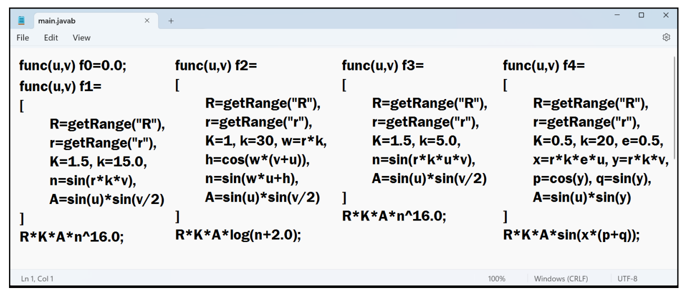
NURBS Bottle. Mathematically, for each NURBS bottle, the control points' positions are represented as $\{\mathbf{p}_i | i \in [1, n]\}$, and the control weights are the radius of each control point which are represented as $\{w_i | i \in [1, n]\}$. Then, the NURBS bottle's parametric equation $\mathbf{s}(u, v)$ is represented as:

$$\mathbf{s}(u,v) = \begin{bmatrix} r(t)\cos\theta \\ \mathbf{q}(t)\cdot\hat{\mathbf{y}} \\ r(t)\sin\theta \end{bmatrix}, \quad \mathbf{q}(t) = \frac{\sum_{i=1}^{n} w_i b_p^i(t)\mathbf{p}_i}{\sum_{i=1}^{n} w_i b_p^i(t)},$$

where $r(t) = ||\mathbf{q}(t) - \hat{\mathbf{y}}(\mathbf{q}(t)\cdot\hat{\mathbf{y}})||$, $t = (u - u_0)/(u_1 - u_0)$, $\theta = 2\pi(v - v_0)/(v_1 - v_0)$, and $b_p^i(t)$ is the p^{th} order B-spline basis function of the i^{th} control point.

Parametric Function. We propose a Java♭ function called **addNURBSBottle**("NURBS name", $\mathbf{f}(u, v)$, $u_0 : u_1$, $v_0 : v_1$). After loading from the "<NURBS name>.NURBS" file as NURBS bottle surface $\mathbf{s}(u, v)$, we construct a new surface $\mathbf{g}(u, v)$ by deforming NURBS bottle $\mathbf{s}(u, v)$ along normal direction at (u, v) with distance of parametric function $f(u, v)$:

$$\mathbf{g}(u,v) = \mathbf{s}(u,v) + \frac{\mathbf{s}_u(u,v)\times\mathbf{s}_v(u,v)}{||\mathbf{s}_u(u,v)\times\mathbf{s}_v(u,v)||} f(u,v)$$



```
func(u,v) f0=0.0;
func(u,v) f1=
[
    R=getRange("R"),
    r=getRange("r"),
    K=1.5, k=15.0,
    n=sin(r*k*v),
    A=sin(u)*sin(v/2)
]
R*K*A*n^16.0;

func(u,v) f2=
[
    R=getRange("R"),
    r=getRange("r"),
    K=1, k=30, w=r*k,
    h=cos(w*(v+u)),
    n=sin(w*u+h),
    A=sin(u)*sin(v/2)
]
R*K*A*log(n+2.0);

func(u,v) f3=
[
    R=getRange("R"),
    r=getRange("r"),
    K=1.5, k=5.0,
    n=sin(r*k*u*v),
    A=sin(u)*sin(v/2)
]
R*K*A*n^16.0;

func(u,v) f4=
[
    R=getRange("R"),
    r=getRange("r"),
    K=0.5, k=20, e=0.5,
    x=r*k*e*u, y=r*k*v,
    p=cos(y), q=sin(y),
    A=sin(u)*sin(y)
]
R*K*A*sin(x*(p+q));
```

Fig. 3. NURBS Designs (Part II).

III. Experiment Results

To evaluate the efficacy of our proposed approach, we conducted numerical experiments on conceptual pottery designs utilizing the scriptable parametric modeling interface of PM4Pottery. The implementation was carried out within Unity 3D (2019 version) on hardware comprising an Intel Core i5 CPU, 32GB DDR4 RAM, and an NVIDIA GeForce GTX 1650 4GB GDDR6 Graphics Card. Figure 4 illustrates parametric conceptual pottery models crafted using PM4Pottery

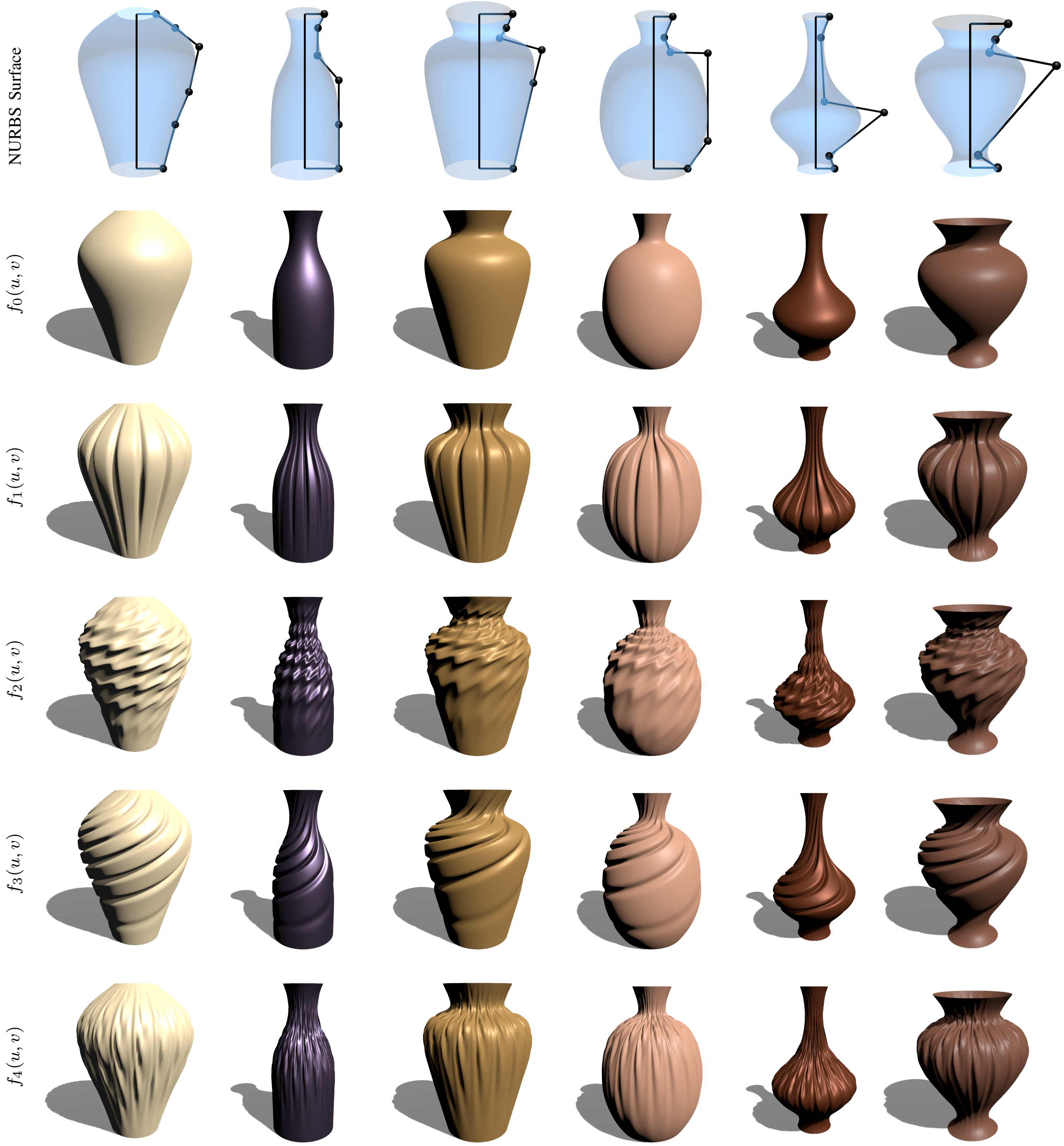


Fig. 4. Different Parametric Configurations.

under various configurations. It features six distinct NURBS bottle designs, each presented in a dedicated column, and incorporates five parametric functions ($(f_0(u, v), ..., f_4(u, v))$ displayed across five rows. This visual representation highlights the versatility of PM4Pottery, showcasing the diverse range of creative outcomes achieved by combining different NURBS bottle designs with various parametric functions.

Figure 5 illustrates parametric conceptual pottery models generated with PM4Pottery within the same NURBS bottle designs and parametric functions (as shown in Figure 2) but under different parameter values settings. Notably, the variations in the showcases models arise from adjustments to specific parameter values—R and r. Rows in the figure represent the variation of the parameter R ranging from 0.15 to 0.9, while columns illustrate the variation of the parameter r ranging from 0.15 to 0.9. This presentation effectively demonstrates how subtle adjustments to these parameters can lead to diverse outcomes in the parametric pottery designs.

Fig.6 provides a glimpse into the immersive world of virtual reality as a designer wearing an Oculus Quest 2 headset while refining conceptual pottery parameter values within the PM4Pottery interface. This visual encapsulation showcases the

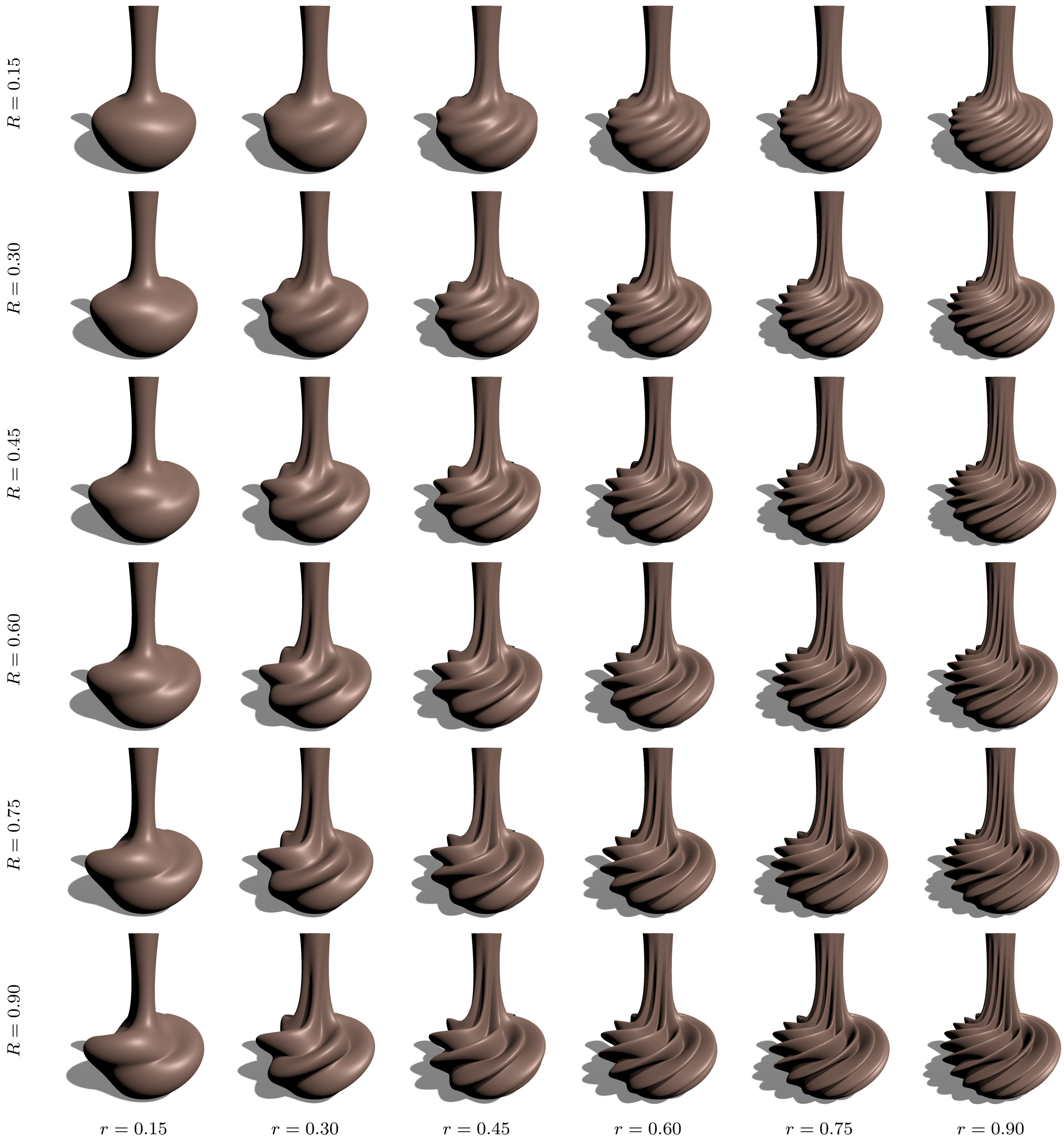


Fig. 5. Different Parameter Values.

hands-on, experiential process of fine-tuning design elements in 3D space. For a more comprehensive understanding of the experiment and to delve into the intricacies of the immersive design experience, an accompanying video can be accessed at the following link: https://youtu.be/OKZq1qsCmKE

IV. Conclusion

Manual techniques and physical constraints have long characterized traditional pottery design, as an innovative solution, in this paper, we introduce PM4Pottery, a scriptable parametric modeling interface for conceptual pottery design. PM4Pottery provides designers with an innovative tool to create sophisticated conceptual pottery models, standing as a transformative user interface that redefines the landscape of conceptual pottery design. Through its seamless integration with PM4VR and Oculus Quest 2, PM4Pottery not only serves as a powerful tool for individual designers but also opens up new possibilities for collaborative design experiences. Future developments for PM4Pottery include expanded scripting capabilities, enabling designers to harness more advanced programming functionalities for intricate pottery designs. It's also promising to explore the potential for collaborative design environments within PM4Pottery, where multiple designers can contribute to a single pottery project in real time.

Fig. 6. User Study. This figure shows a user tuning the conceptual pottery's design parameters using PM4Pottery in VR.

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