care, judgment, dexterity

CRAEFT

Craft Design Revisited

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Executive summary

This deliverable, titled "Craft Design Revisited," outlines the design, development, and validation of the Design Studio software suite under the CRAEFT project. The objective is to create an advanced virtual workspace tailored for craft professionals, integrating tools such as computer-aided design (CAD), artificial intelligence (AI)-based design tools, and virtual reality (VR) simulations to enhance the craft design process.

The deliverable is structured to be released in two phases: the first at month 18 (M18) and the second at M36 of the project. The initial version focuses on the conceptualization, preliminary analysis, and a detailed implementation plan for the software suite. Section 2, this version outlines the purpose of the Design Studio, detailing how it will support craft practitioners in overcoming challenges such as complexity in design, high costs of experimentation, and limited access to advanced manufacturing technologies. The first phase also includes the creation of wireframes and prototypes, which will be refined based on feedback from stakeholders.

Moreover, in this deliverable, we present some first applications and technical capabilities we developed and will be used by the Design Studio. The implementation of applications and capabilities is developed in WP3 under D3,1 “Craft-specific simulators”. These simulators are integrated with the Design Studio platform so that the designs produced using it are physically feasible in the context of a craft.

In addition, in Section 3, we present our work in integrating the Design Studio with additive, 3D printing capabilities to enable practitioners to create prototypes of their designs or helper objects that assist practitioners in the implementation of their designs. The first application of this capability is presented for moulds.

Finally, in Section 4, we make a first attempt to explore the innovation aspects, market potential, and IPR of this resultant software suite, so that we take these parameters into account for the future exploitation of this work.

The second version will concentrate on the evaluation of the initial implementation, updates based on feedback, and the final release of the software. The final deliverable will include the software and a comprehensive report documenting its uses and impact on the craft industry.

Overall, the Design Studio aims to empower craft professionals by providing innovative tools that streamline the design process, reduce costs, and enhance creativity. The software will serve as a versatile tool for a diverse audience, including professional artisans, students, and small businesses, supporting the growth and sustainability of traditional craftsmanship through modern technology.

Document history

Date	Author	Affiliation	Comment

2/7/2024	Peiman Sichani, Laura Werup	Khora	First Outline
13/8/2024	Peiman Sichani, Laura Werup, Xenophon Zabulis, Nikolaos Partarakis	Khora, FORTH	Second outline with input integrated from FORTH
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Abbreviations

DoA	Description of Action
MoCap	Motion Capture
CH	Cultural Heritage
CHI	Cultural Heritage Institutions
PC	Project Coordinator
RCI	Representatives of Crafts Instants
VR	Virtual Reality
WP	Work Package

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1. Introduction

This deliverable includes details for the Craft Design Studio's design and development process. It will be submitted twice: once in M18 and again in M36. The first submission of this deliverable will outline the overall purpose and objectives of the Design Studio and include a detailed work breakdown structure of how it will be created with input from all Representatives of Craft Instants (RCIs) in the project. The second submission will include design details, such as wireframes, templates, and an overview of the developed Design Studio in its final form.

1.1 Purpose and Key Features of the Design Studio

The Design Studio is an advanced virtual workspace designed for creative professionals, integrating computer-aided design (CAD), artificial intelligence (AI)-based design tools, and workflow planning to enhance the design process and reduce experimentation costs through realistic simulations. Key features include craft-specific 3D editing tools, haptic interfaces, comprehensive CAD tools, and seamless integration with digital fabrication modalities. These offer realistic artefact previews in augmented reality (AR) and virtual reality (VR) environments. The CAD toolkit supports the transfer of designs and styles from digital assets, incorporating design principles such as Gestalt principles, symmetry, rhythm, and figure/ground separation, alongside design-oriented image processing and 3D model editing. Furthermore, the Design Studio analyses additive (FDM, SLA, Dust, Metal) and subtractive (laser engraving, milling, engraving, plotting, CNC cutting, laser cutting) manufacturing technologies, identifying new applications within the craft industry in collaboration with craft training organisations. This analysis facilitates the integration of these technologies into production and educational workflows through a comprehensive software toolchain, enhancing the utility and efficiency of the design process.

1.2 Types of Problems Targeted

The primary aim of the Design Studio software suite is to address several key challenges faced by creative professionals in the craft industry. These problems include:

- **Complexity in Design and Prototyping:** Craft professionals often struggle to translate creative ideas into precise and feasible designs. Traditional design methods can be time-consuming and prone to errors, especially when transitioning from initial concepts to physical prototypes. The Design Studio addresses this by providing advanced CAD tools and AI-based design assistance, enabling users to create and refine designs more accurately and efficiently.
- **High Costs of Experimentation:** Experimentation in design, especially when involving physical prototypes, can be costly in terms of time and materials. This is particularly challenging for small-scale craft businesses and individual artisans. The design studio's simulation capabilities, including VR previews, allow designers to experiment and iterate virtually, significantly reducing the need for costly physical prototypes.
- **Limited Access to Advanced Manufacturing Technologies:** Many craft professionals lack access to advanced manufacturing technologies due to high costs and technical barriers. The Design Studio seeks to integrate additive (FDM, SLA, Dust, Metal) and subtractive (laser engraving, milling, CNC cutting) manufacturing technologies, making them more accessible and user-friendly.

This integration helps artisans and small businesses explore new applications and techniques, expanding their creative possibilities.

- **Fragmented Design and Production Workflow:** The craft industry's design and production workflows are often fragmented, involving multiple tools and processes that can be difficult to manage cohesively. The Design Studio offers a comprehensive software toolchain that streamlines the workflow from initial design to final production. This includes integration with digital fabrication technologies and the ability to transfer designs directly from digital assets.
- **Skill Development and Training:** The craft industry needs effective training and skill development to keep pace with technological advancements. The Design Studio collaborates with craft training organisations as part of the CRAEFT project to provide educational resources and tools that facilitate the learning and adoption of new technologies. This helps craft professionals continuously enhance their skills.
- **Adherence to Design Principles:** Many designers find it challenging to incorporate design principles such as Gestalt principles, symmetry, rhythm, and figure/ground separation. The Design Studio incorporates these principles into its CAD toolkit, design-oriented image processing and 3D model editing features. This ensures that the final designs are functional and aesthetically pleasing.

1.3 Intended Use and Target Audience

By catering to diverse users, from students and educators to professional artisans and small businesses, the Design Studio aims to give access to design tools to support the growth and innovation of traditional craftsmanship and foster a broader appreciation and understanding of craft practices.

The Design Studio software suite primarily focuses on **craft practitioners** who want to prototype and test their designs before designing craft products. This includes both amateurs and professional artisans who create craft products. These users will benefit from the tools that facilitate the design process, from initial concept to final production. The advanced CAD tools, AI-based design assistance, and realistic simulations will help them refine their designs more efficiently and precisely.

In addition, the Design Studio is particularly valuable for **students in craft** and design programs who need to prototype and test their ideas before finalising their craft products. The software provides an accessible platform for learning and experimentation, allowing students to explore various design principles and manufacturing techniques. Educators can use the tool to demonstrate design concepts and guide students through creating and refining their projects. Similarly, organisations or schools dedicated to craft training and skill development can leverage the Design Studio to provide their members with hands-on experience using design tools. This collaboration seeks to bridge the gap between traditional craft techniques and modern technology, ensuring that trainees are well-prepared for contemporary industry demands.

Small and medium-sized enterprises (SMEs) in the craft industry often face resource constraints that limit their ability to experiment with new designs and technologies. The Design Studio can offer businesses an affordable and efficient solution to enhance their design and production processes. By integrating advanced manufacturing technologies and streamlining workflows, the software helps SMEs improve productivity and reduce costs. As such, any design professional who works in crafts-related fields, such as product design, interior design, and fashion, can also benefit from the Design Studio. The software's features, such as 3D editing tools, haptic interfaces, and VR previews, allow these users to create detailed and innovative designs that can be integrated into their workflows.

Finally, individuals who engage in craft activities as a **hobby or personal interest** will find the Design Studio useful for bringing their creative ideas to life. With an intuitive interface and user-friendly tools, we aim to make it easy for hobbyists to create detailed designs and explore different fabrication methods without requiring extensive technical knowledge.

1.4 Added value of the Design Studio

The Design Studio offers added value to craft professionals by providing tools and technologies designed to enhance creativity, improve workflow efficiency, and reduce costs associated with design and production. This approach seeks to contribute to the growth and sustainability of the craft industry in the following ways:

1.4.1. Empowerment of Creativity and Workflow Efficiency

The Design Studio equips craft professionals with advanced CAD tools, design assistance, and 3D editing capabilities, enabling them to explore and realise their creative ideas more effectively. By providing a virtual workspace that integrates these features, designers can push the boundaries of their craft, experimenting with new styles and techniques without any methodological limitations. By streamlining the design and production workflow, the Design Studio reduces the time and effort required to move from the initial concept to the finished product. Integrating digital fabrication technologies and simulations ensures that designs can be iterated and refined quickly, allowing craft professionals to focus more on their creative processes and experiment with design.

1.4.2. Cost Reduction and Sustainability

Virtual simulations and previews in VR allow designers to test and modify their designs before committing to physical prototypes. This reduces material waste and lowers the costs associated with experimentation and production. Additionally, the software's accessibility on laptops and VR headsets seeks to facilitate access without specialised equipment, making advanced design tools available to a broader audience. By minimising material use through virtual prototyping and reducing the need for multiple physical iterations, the Design Studio also supports sustainable practices within craftsmanship to help craft professionals operate more efficiently and cost-effectively.

1.4.3. Practical Training and Safety and Low Barriers to Entry

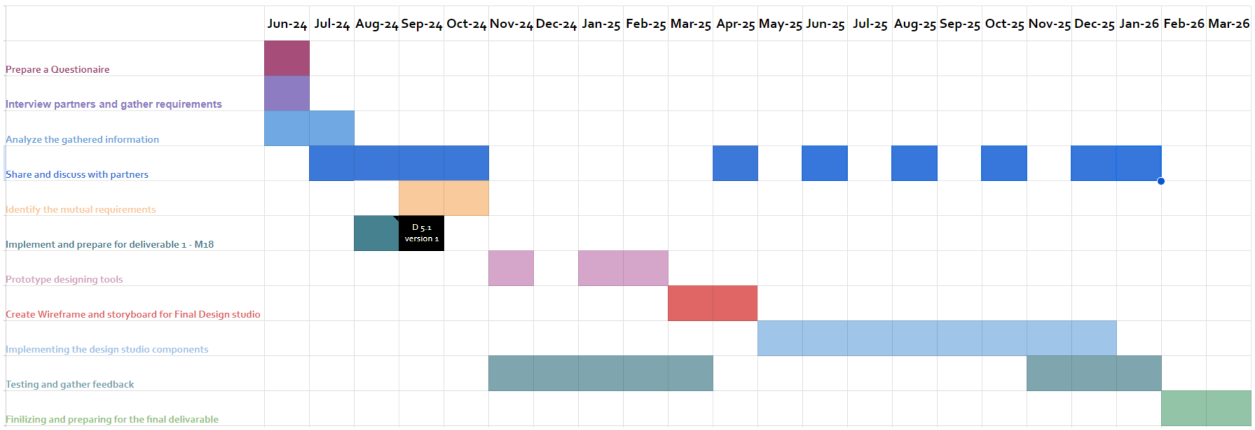
The Design Studio provides an engaging and risk-free way for users to practice their craft. Virtual simulations allow hands-on practice without the dangers associated with traditional craft techniques, such as high temperatures or sharp tools. This makes it an ideal training tool for students and hobbyists new to the craft. The software will be designed to be accessible from standard laptops and VR headsets, removing the need for users to visit a specialised craft studio. Ease of access encourages more people to explore and engage in craft practices.

1.4.4. Enhanced User Experience through VR

Virtual Reality (VR) offers an immersive, interactive craft design and practice environment. VR allows users to experience their designs in a lifelike 3D space, providing a deeper understanding of scale, proportions, and spatial relationships. This immersive experience can lead to more accurate and refined designs, as users can interact with their creations in a way that traditional 2D screens cannot offer. VR also makes the design process more engaging and enjoyable, enhancing the user experience.

2. Work Plan

This section will explain the work plan, including progress to date, future activities, and challenges. Realising the Design Studio software suite is a multi-phase process involving close collaboration with Representatives of Craft Instances (RCIs) and other key partners in the CRAEFT project. Our approach is structured to ensure that the final design meets the needs of crafts practitioners and the industry surrounding it while incorporating technological solutions. We have made an overarching workplan based on the proposal and the current status of the project as outlined below:



The above plan is dynamic and subject to change depending on partners' availability and the number of consortium members available during the spring and summer of 2024. For example, during the first phase, "Prepare a Questionnaire", we found that we should start interviewing partners first because they are the most experienced resources to identify the primitive requirements for designing crafts and establishing an innovative approach to develop a practical design studio that can fulfil the need of a craft practitioner along to classical and non-digital design tools like designing with pen and paper. Making minor modifications to the plan allows us to reach our goals realistically and anchor the design process to the needs of users. As such, the detailed work plan leading up to this deliverable reflects the following phases below.

2.1 Phase 1: Prepare Questionnaire

To design a practical design studio, we must first thoroughly understand user requirements. The design process, therefore, began by curating a comprehensive set of questions in collaboration with RCIs and other partners. This initial activity focused on understanding various craft professionals' specific needs, challenges, and workflows. We refined the questionnaire through a series of iterations to ensure it captured accurate and practical information. This involved multiple feedback sessions with RCIs to validate and improve the questions that could lead us to an effective design studio.

2.2 Phase 2: Gather answers and requirements

We conducted surveys and interviews with craft professionals, using the matured questionnaire to gather detailed insights into their design processes, technological needs, and workflow challenges. The goal of the questionnaire was to find answers to the following main questions:

- Who are the end users of the Design Studio?
- What are the current working practices and workflows?
- How do practitioners move from an idea to an actual craft?
- What are the main challenges faced by crafts practitioners?
- What digital tools are already in use and what digital tools are missing?
- Identify where and how digital and immersive technologies can support the design process

A series of interviews were conducted to gather the above information with the following participants:

Interviewee	Organisation	Expertise	Date
Xenophon Zabulis, Nikolaos Partarakis	FORTH	Computer Vision	6/6/2024
Noël Crescenzo, David Arnaud	CERFAV	Glass	7/6/2024
Madina Benvenuti & Jelena Krivokapic	MadInEurope	Heritage Professional	10/6/2024
Danae Kaplanidi, Chris Ringas	PIOP	Silversmith and Marble	12/6/2024
Ines Moreno, Arnaud Dubois	CNAM	Porcelain	20/6/2024

2.3 Phase 3: Workshops and Needs Alignment

We held online workshops with RCIs to find mutual requirements and consensus on the most critical tools needed across different craft disciplines. This collaborative approach aimed to ensure that the software suite would be versatile and broadly applicable.

2.3.1 Analysis of User Experience Requirements

The collected data resulted in a comprehensive analysis of the design studio requirements for various partners involved in craft education and practice. The analysis focuses on the needs and expectations of each partner, emphasising how a digital design studio can support their specific objectives. By examining the key points and unique requirements of each partner, this analysis aims to identify common themes and unique demands, ultimately proposing a versatile and comprehensive design studio solution.

Partner: CERFAV

Target Group: Craft Students

Design Studio Requirements:

1. **Interactive Tool:**
    - A platform for students to shape and refine their ideas.
    - Features an open palette of tools for creating and modifying shapes in VR.
    - Emphasises interactive alteration of shapes.
2. **Visualization and Collaboration:**
    - Tools for visualising, rotating, and scaling digital designs.
    - A 3D viewer to facilitate discussion and refinement with peers and instructors.
3. **Creative Engagement:**
    - Focus on creative activities using gestures or VR for designing.
    - Importance of practising shape creation from memory.
4. **Mould Design Support:**
    - Crucial for students, requiring engineering knowledge.
    - Provision of specific tools and support for mould design.

Partner: CNAM

Target Audience: Stakeholders and Students

Design Studio Requirements:

1. **Gesture Recording Focus:**
    - Emphasis on recording technical gestures specific to craft practices.
    - A tool capturing "ghost gestures" from body, materials, and tools, aiding designers, especially in fields like porcelain work.
2. **Engagement and Input:**
    - Involvement of practitioners, designers, and the CRAEFT consortium.
    - Development of a digital tool based on feedback from students and designers.
3. **Practical Applications:**
    - Example: Using gestures for designing kitchen equipment.
    - Tool to check the feasibility of designs.

Partner: PIOP

Target Group: Younger Practitioners

Design Studio Requirements:

1. **Educational Collaboration:**
    - Potential integration with the School of Fine Arts in Tinos.
2. **Digital Design Tool:**
    - Aids in drawing and designing for designers and artists, particularly those new to the field.

3. **Simplicity and Intuition:**
   - The tool should be simple and intuitive.
4. **Heritage Focus:**
   - Emphasis on traditional designs for silver and marble crafts.
   - Helping artists test designs before presenting them to craftspeople.
5. **Resource Efficiency:**
   - Saving material and time, especially for silversmiths and marble workers.

Partner: MadInEurope

Target Group: Craftspeople, designers, students, and teachers.

Design Studio Requirements:

1. **Support for Craft Design**:
   - Methodology to aid craftspeople in the design process, linking traditional and future crafts.
2. **Self-Awareness and Innovation**:
   - Tools to help users understand their skills and capabilities, promoting self-awareness and innovation.
3. **Cross-Disciplinary Practice**:
   - Facilitate interdisciplinary craft design and practice.
4. **Inspiration and Learning**:
   - Use 3D scanning and social media to inspire and educate younger practitioners.

Partner: FORTH

Design Studio Features:

1. **Material Feasibility Evaluation:**
   - Input sketches to evaluate feasibility, particularly for wood carving.
2. **Simulation Tools:**
   - Realistic rendering of 3D models.
   - Pottery simulator for shape modification.
   - Woodturning and carving simulators.

Comparative Analysis

Common Themes Across Organizations:

- **Support for Design and Creation:** All partners emphasize the need for tools that support the design and creation process, whether through VR, gesture recording, or traditional design aids.
- **Educational Integration:** There is a strong focus on integrating these tools into educational settings, allowing students and younger practitioners to learn and experiment with new techniques.

- **Resource Efficiency:** Many partners highlight the importance of saving time and materials, especially when dealing with expensive or time-consuming resources like marble or recyclable materials.

Unique Requirements:

- **CERFAV:** Focuses heavily on interactive and VR-based tools for shape creation and mould design.
- **CNAM:** Emphasises gesture recording and the involvement of a diverse group of stakeholders.
- **FORTH:** Highlights the importance of realistic rendering and various simulators for different materials.
- **PIOP and MadInEurope:** Both stress simplicity and intuition in their tools, with a strong emphasis on heritage and traditional designs.

Summary of findings

A comprehensive design studio tool should combine the strengths identified by each organisation, including VR interactivity, gesture recording, realistic rendering, and material feasibility evaluations. To be valuable, it should be flexible enough to cater to both traditional craft practices and innovative design processes, making it an asset in educational and professional settings.

2.3.2 Current tools available

As the user requirements for the "Design Studio" are being collected and the software design approach evolves, technically, we are preparing the software modules that will support it.

The central concepts in the development of design aids are:

1. The designs exhibit realistic appearance
2. The designs are "craft-specific", meaning that they are realistic and feasible using the context of techniques of the craft they belong in.

For this reason, in D3.1, two software modules are proposed. The first regards a visualization toolbox and the second is the interactive simulation of crafting techniques. The latter, constraints the designer in creating designs using simulated craft methods.

We have used the visualization toolbox developed in D3.1, to create applications that simplify the creation of artefact designs and predict the appearance of products that implement these designs. We demonstrate the feasibility of the approach in several utility applications for the design of traditional and novel craft products.

2.3.2.1. Moulded, cast, and sculpted objects

The first category of design aids regards moulded, cast, and sculpted objects made from various materials, including glass, metal, plastic, wax, marble, and wood. Leveraging the advanced capabilities of the visualisation toolbox, this application provides highly accurate simulations of light interaction with transparent, translucent, reflective, and textured materials, ensuring that artisans can see a realistic representation of their designs before they are physically created.

This application aims for crafts that produce solid 3D objects produced mainly from moulded, cast, and sculpted objects, found in glassblowing, metalworking, printed plastics, wax crafting, marble sculpting, woodworking, and other crafts. The common characteristics between them are:

1. The use of dielectric and conductive materials that are difficult to render with conventional renderers, such as glass, and metal.
2. The sufficient representation of object geometry through 3D models.

The result is the visualisation of the final appearance of custom moulded, cast, and sculpted pieces, from vases and sculptures to jewellery and decorative items, across a variety of materials. The visualisation shows crafted objects made from glass, metal, plastic, wax, marble, and wood would look in various settings, aiding in the selection and placement of artisanal items within a space. The examples below demonstrate this for two sculptures for which the 3D model was obtained from the 3D scanning of a masterpiece of Tinian marble crafts. The 3D scanned model is shown and then rendered in multiple environments as made from gold, colourless glass, and 3D-printed white plastic filament.

In Figure 1, shown are the original photogrammetric scan and its renderings from the same, lateral viewpoint. In Figure 2, shown are snapshots for the three renderings rotated in three distinct poses, in the same environment. The original artefact can be found in the CAP here, as well as the entry for the artist, Yannoulis Chalepas.

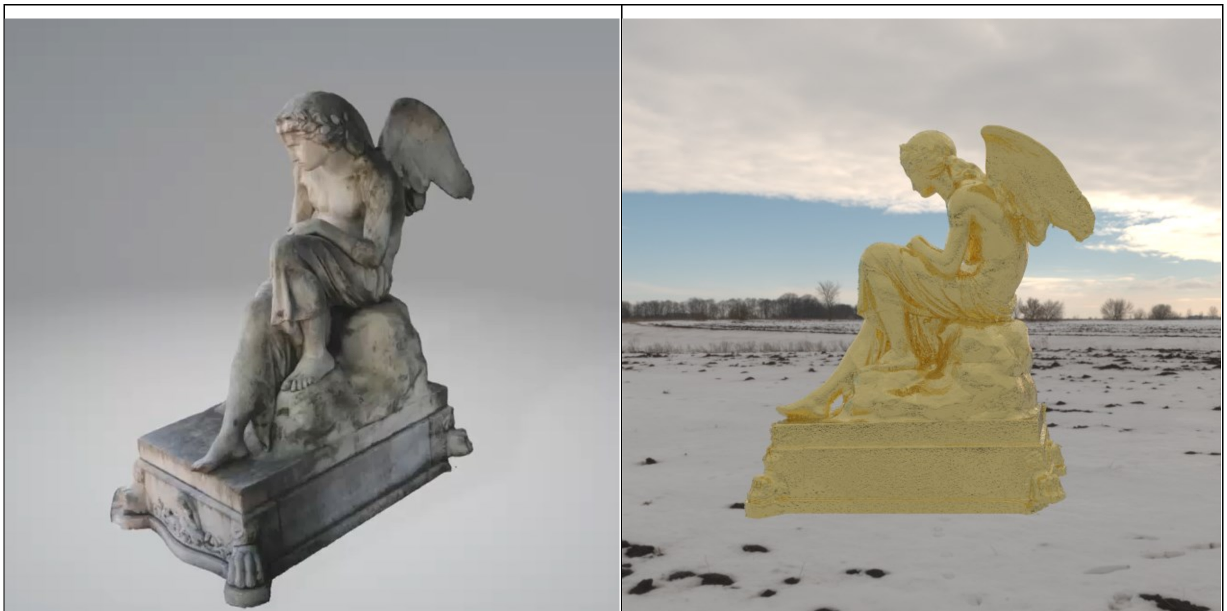


Figure 1. Original scan and renderings or a marble sculpture in gold, glass, and matte plastic.

Figure 2. Peripheral views of three renderings of Figure 1.

Moreover, the software can be used to predict the appearance of more complex structures made from multiple materials. In Figure 3, shown are the renderings of a sculpture made from two interlocking pieces, one made out of glass, plastics, and metals, from different viewpoints.

Figure 3. Renderings of a Nefertiti sculpture made from two materials.

These results can be also found in the form of 360 rotational videos on the CRAEFT YouTube page as indicated in Table 1.

Table 1. Rotational videos of the renderings are shown in Figure 3.

Black matte plastic and gold	https://youtu.be/g4ff7cvGo3A
Silver and copper	https://youtu.be/qrEds_k-SO4
Silver and gold	https://youtu.be/Y-eV3ChF4OQ
Copper and bronze	https://youtu.be/wdIhObnp4-k
Turquoise matte plastic and gold	https://youtu.be/Gk34YuJM_NA
Grey matte plastic and salmon matte plastic	https://youtu.be/w3Fr592hMf0

2.3.2.2 Stained glass windows

Stained glass traditionally refers to windows, but it is not limited to them. While stained glass windows are the most common and well-known application, especially in churches, cathedrals, and other historic buildings, stained glass can also be used in various other objects and artistic expressions. Some of these include stained glass panels that are often used indoors and add an artistic and colourful touch to entryways. Using the visualisation toolbox we have created a few applications that promote the use of material-specific design for windows and other stained-glass artefacts.

To support this use of stained glass a specialised application simulates the appearance of stained-glass windows for their designs. The application computes the 3D model from the design and applies the colours, styles, and materials indicated by the design. The designs can be provided as “masks” that define the colours and dimensions of the glass pieces.

The application operates as follows. The image is segmented into regions of approximately the same colour. The segmentation method employed is [13], but any other segmentation approach could be used. Once the image has been segmented into colour regions the mean colour of each region is calculated, in the HSV domain[1]. The mean colour is going to be assigned as the colour of the piece of stained glass needed to represent the corresponding image region.

In Figure 4, two illustrative examples are provided. In the examples, we show the initial design (left), a close-up view of the photorealistic rendering of the stained-glass window for a particular outdoor environment (middle), and a far-away view of the same scene showing the room that this window is going to be installed (right). In the example of the top row, plastic printable material was used for the rig. In the bottom row, we used the traditional approach and simulated rough copper for the skeleton rig.

[1] We prefer averaging colours in the HSV domain because the “mean colour” result is more compatible to human perception than averaging colours in the RGB domain.

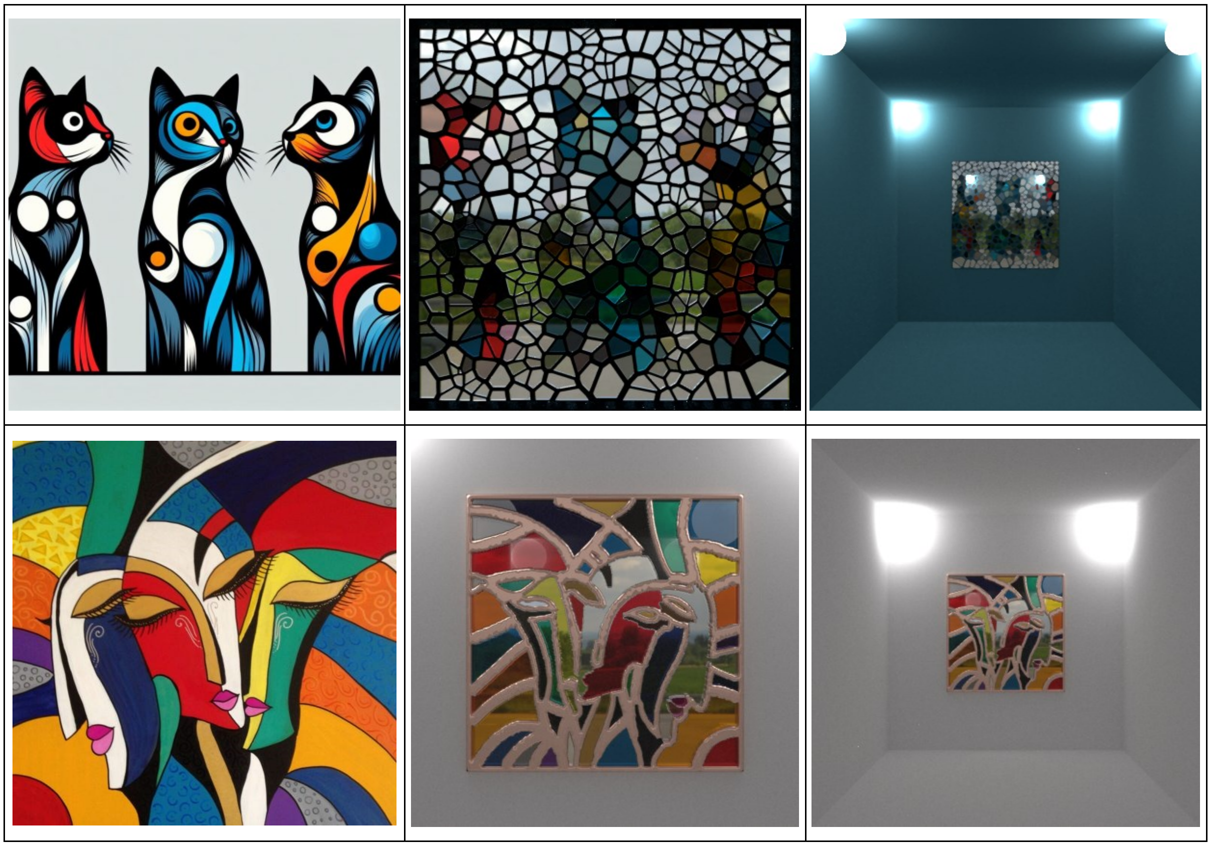


Figure 4. Examples of stained-glass application. Left: design. Middle and right: photorealistic prediction for a given indoor and outdoor environment.

The stained-glass designer is an application that enables the user to create visual simulations of how compositions of stained-glass pieces would appear. The application operates using an input image, which is segmented into pieces that would form a window of stained glass. A metallic frame is also simulated on which these pieces are placed. The colours of the stained glass are based on the colours of the image. In this way, an artist can design an image with the pieces and directly see how this composition would appear as a stained-glass window. Alternatively, the user can directly specify the pieces of glass and their colours, based on his/her inventory of glass pieces. The window is then simulated in a built environment with natural (outdoors) and artificial (indoors) illumination. The simulator renders the appearance of the glass, the outdoor environment, as well as the stained-glass projections that are formed in the simulated environment when natural light passes through the stained-glass window (Figure 5).

Figure 5. Stained glass designer.

2.3.2.3 Tiffany lamps

A Tiffany lamp is a type of stained-glass lamp originally designed and produced by Louis Comfort Tiffany and his design studio in the late 19th and early 20th centuries. These lamps are best known for their intricate and colourful glass shades, often featuring nature-inspired motifs such as flowers, dragonflies, and peacock feathers. The glass is hand-cut and assembled using a technique called copper foil, where thin strips of copper are wrapped around the edges of each piece of glass and then soldered together to create the lampshade.

By creating a variant of the method for the stained-glass windows we can design Tiffany lamps and preview the ambience they create (see Figure 6). A video preview can be found at https://www.youtube.com/shorts/Crfac6MLmyQ

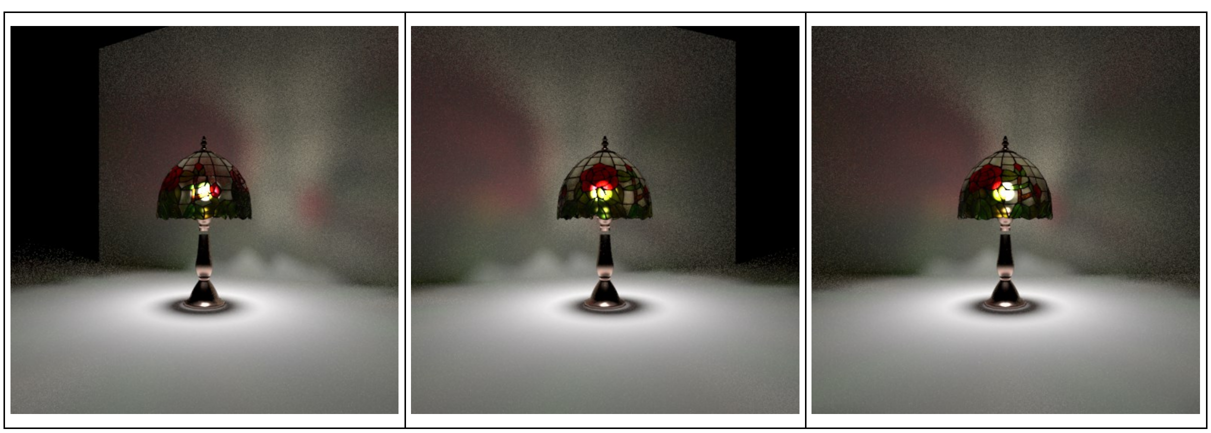


Figure 6. Renderings of a Tiffany lamp.

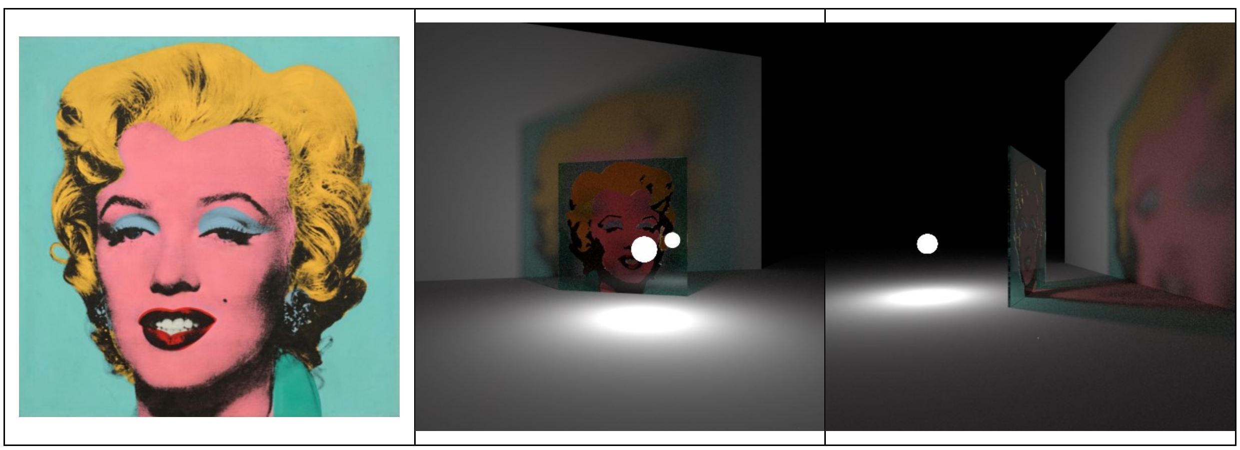
2.3.2.4 Novel products

New types of products can be designed using the visualisation toolbox. Given that any type of material, texture, and environment can be simulated, any type of new design can be previewed. We provide two examples of non-existing products, which can be implemented through manual practice or using a conventional 3D printer[2].

Similarly to stained glass windows and Tiffany lamps, coloured and semi-transparent planar screens can be assembled from 3D printed parts or by conventional printing on a sheet of (2D) rice paper. In this case, the example regards a collection of thin plastic parts produced using a 3D printer and semi-transparent filament, which should be glued together to create the final product.

Out of software, the utility takes as input an image and performs colour quantisation according to the number of colours determined by the user. It then creates the masks corresponding to each colour.

The image below illustrates the expected result. Numerous materials and illumination configurations can be used to investigate the interaction of light with semi-transparent and translucent materials that are printed or moulded and used for internal decoration. In Figure 7, we illustrate the generality of the approach by simulating a light source, a titled colour pane, and two planar and grey surfaces. Clear-coloured glass is simulated in this case to create the coloured projection on the background wall.



[2] Both are inspired by the "Shot Marilyns" a series of silkscreen paintings produced in 1964 by Andy Warhol, each canvas measuring 40 inches square, and each a portrait of Marilyn Monroe. To create this example, the input images were obtained from Wikipedia at: https://en.wikipedia.org/wiki/Shot_Marilyns

Figure 7. Top two rows: simulation experiments that illustrate the interaction of light with semi-transparent objects (see text). Bottom row: photorealistic previews of the designed artefact, in specific environments, from both sides.

Using the same artwork and the original photograph[3] used to create the silkscreens, we extended the utility to create sculptures composed of multiple pieces that a practitioner can assemble. In this case, each piece corresponds to a colour. To create a 3D sculpture, the original photograph was treated by the method in [] which provides depth estimation from a monocular image.

This way, the depth map associated with the photograph can be "transferred" to Warhol's work and provide a depth estimate for each location on the artwork. As shown in Figure 8(top two rows), each segmented image region can be directly converted into a 3D solid. The assembly procedure exhibits similar constraints to solving a conventional jigsaw puzzle. In the example, three pieces must be placed before being able to insert the eyelids in place. The last row of the figure predicts the same structure as if printed from a more expensive material in a resin 3D printer.

[3] Publicity portrait of Marilyn Monroe as Rose Loomis in the 1953 film Niagara. Photograph by Gene Kornman.

Figure 8. Top two rows: Visual demonstration of the assembly of a multi-coloured printed statue, using matte filament; the last image shows the assembly result. Bottom row: prediction of the appearance of the same structure, as if the pieces were printed from semi-transparent, coloured resins.

2.3.2.5 Cane working

In glassblowing, cane refers to rods of glass with colour; these rods can be simple, containing a single colour, or they can be complex and contain strands of one or several colours in pattern. Cane working refers to the process of making a cane, and to the use of pieces of cane, lengthwise, in the blowing process to add intricate, often spiral, patterns and stripes to vessels or other blown glass objects.

Based on the visualisation toolbox, an application utility is provided that simulates the appearance of cane work compositions. The user specifies the number, shape and dimensions of the canes that will comprise the result. In addition, a twisting parameter is provided that determines the final shape of the simulated artefact. In Figure 9, the rendering of example designs is shown.

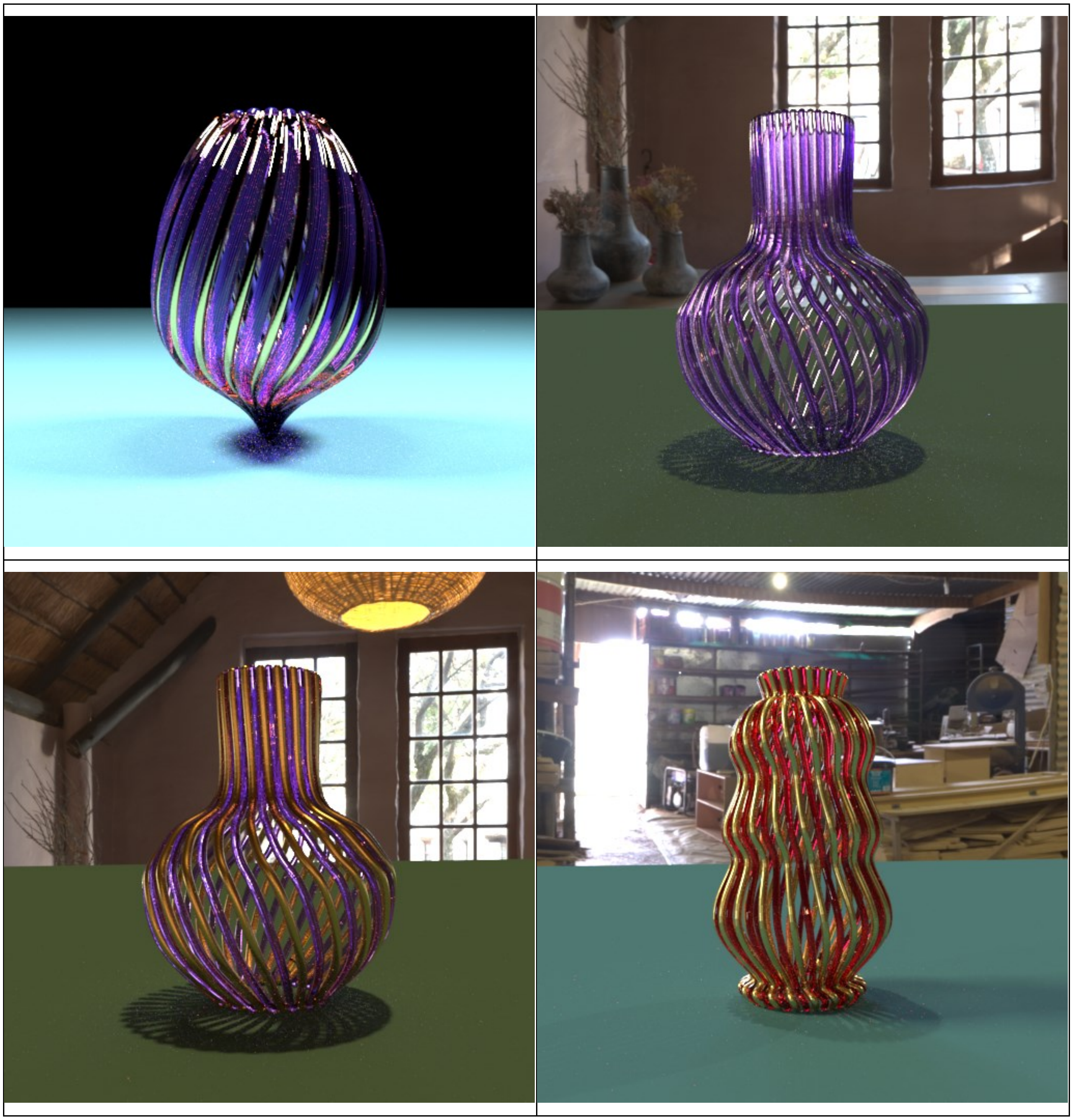


Figure 9. Rendering of cane work models.

2.3.2.6 Metal engraving

Metal engraving is a process of cutting or carving designs, patterns, or text into the surface of a metal object. This technique has been used for centuries to decorate, personalize, and mark metal items. The process involves several key steps and can be applied to various types of metals, including gold, silver, brass, copper, and steel. The application predicts the appearance of engraved pieces of metal, by converting carving designs into 3D models of carved items. Anaglyph creator is an application that takes as input a 2D pattern and creates an anaglyph, as the result of an engraving process. In the example below, this is simulated on a metallic sheet of silver. The GUI allows the user to define the parameters of the engraving, such as its thickness and depth (see Figure 10, top). The bottom row of the same figure shows the design rendered in a realistic environment and as if made from gold.

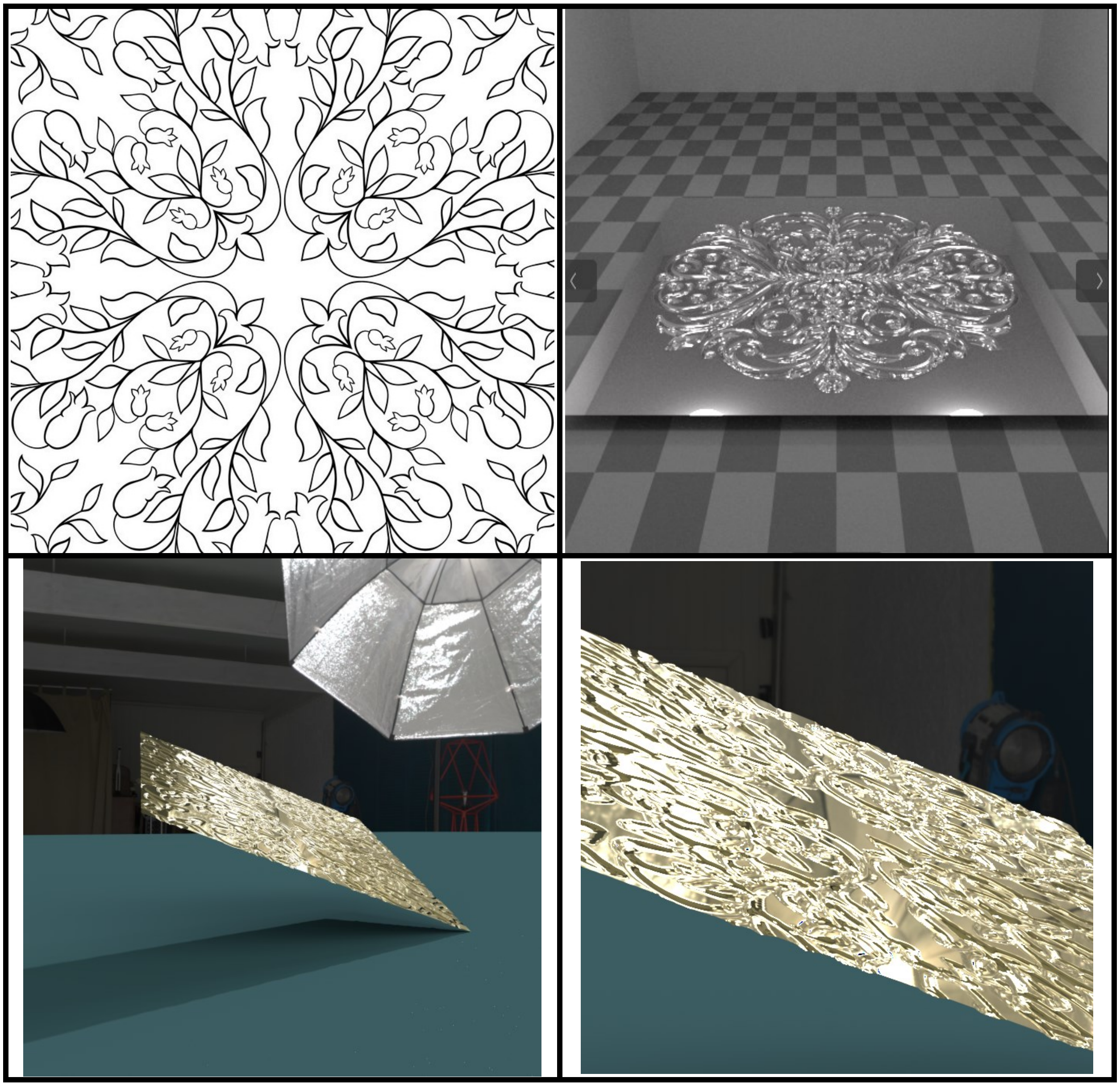


Figure 10. Anaglyph creator.

2.3.2.7 Ceramics and glazes

Glazing in ceramics enhances both aesthetic and functional qualities. It provides a wide range of colours and finishes, enabling intricate decorative effects such as glossy, matte, or textured surfaces. Functionally, glazing makes ceramics waterproof, more durable, and easier to clean by creating a non-porous surface that resists scratches, stains, and bacteria. Additionally, glazes offer chemical and thermal resistance, protecting ceramics from acidic or alkaline substances and enhancing their suitability for culinary, laboratory, and oven use. Properly formulated glazes ensure food safety by preventing harmful substance leaching. Artistically, glazing allows for creative expression through techniques like layering and sgraffito, producing unique effects such as crackling and drips. The implementation of this utility can be found in D3.1. Using this approach, we can artificially apply glazing to any given 3D model. In Figure 11, a 3D model of a plate is textured and rendered with rough and fine glaze. We observe a more realistic rendering as evidenced by the highlight on the right side of the plate.

Figure 11. 3D model of the plate (top-left), rendered only with textured (top-right), with smooth glaze (bottom-left), and with rough glaze (bottom-right).

Similarly, we apply the same approach in Figure 12, for a textured 3D model of a porcelain vase. The light source is on the top right of the vase.

Figure 12. Renderings of a textured vase model as a matte object (left) and after application of a thin glaze layer (right).

Moreover, the glaze may be coloured. In Figure 13, a shallow matte plate made of clay is shown on the left. In the middle, shown is the same model with a transparent glaze, and on the right with a reddish glaze.

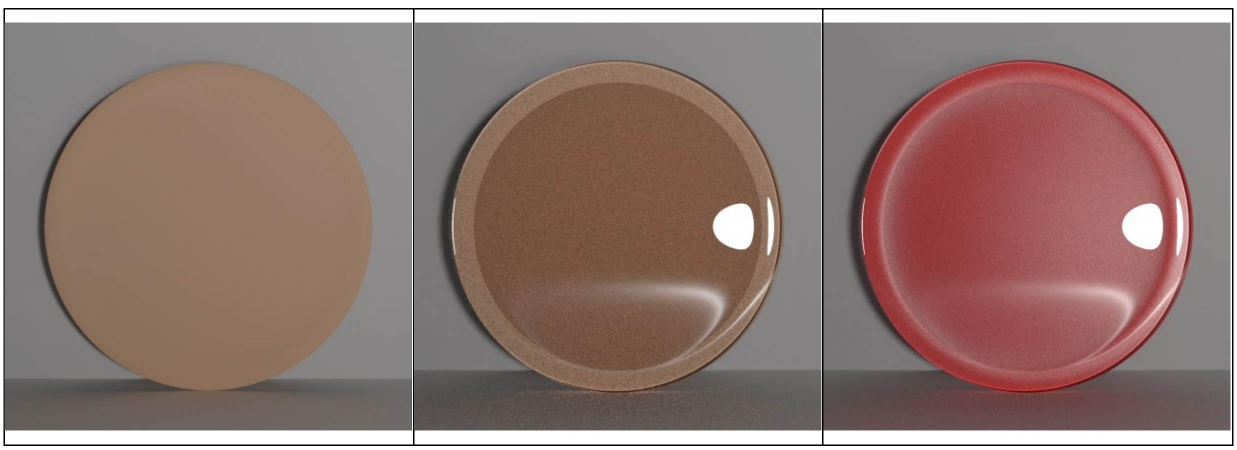


Figure 13. Renderings of a matte clay plate (left), after application of a transparent glaze (middle), and after application of a reddish-coloured glaze (right).

2.3.3 Interactive simulations for design

The goal of craft-specific interactive simulators is to interface with the craft-specific simulators created in D3.1. In this way, craft actions that have an impact on the design of the product or its final appearance come into play. As these simulators are craft-oriented, when a virtual object is created using these simulators, the recording (or "log") of this digital activity is visual and kinematic instructions on how to create this object.

To provide a generic approach that can be instantiated for multiple crafts, we create simulators for elementary actions that can be combined in conventional game engines. These simulators implement additive, subtractive, interlocking, and shaping actions and are specialised to the specific craft action.

Some of the simulation elements we need are already provided by conventional game engines. Specifically, the simulation of rigid object kinematics and collisions is provided. To date, we have progressed in implementing these actions additive, subtractive, and shaping in turning scenarios. In addition, interlocking has been implemented for fabric manufacturing.

2.3.3.1 Solids by Revolution

Using the interactive simulation toolkit from D3.1, we implemented a volumetric editor which enables the authoring of 3D solids and predicts their appearance.

This design aid regards pottery and, specifically, the shaping of clay of the potter's wheel. We also use this first example to show the way we use the inner workings of three tools provided by the toolbox reported in D3.1. In this case, the central role is played by the mass-preserving tool. Nevertheless, additive and subtractive tools are also available, because the potter may add or remove clay during turning, by wetting the clay to aid its re-homogenisation. To reduce computation and make the simulation interactive, the geometry of solids by revolution is exploited. In the examples shown in Figure 14, the left panels show the real-time updated 3D rendering and the right panels show the inner representation maintained by the toolbox. The user can edit the voxel grid and inspect the result from any viewpoint, in real-time. The video demonstration can be found at https://youtu.be/Yc7FtCdOeSs

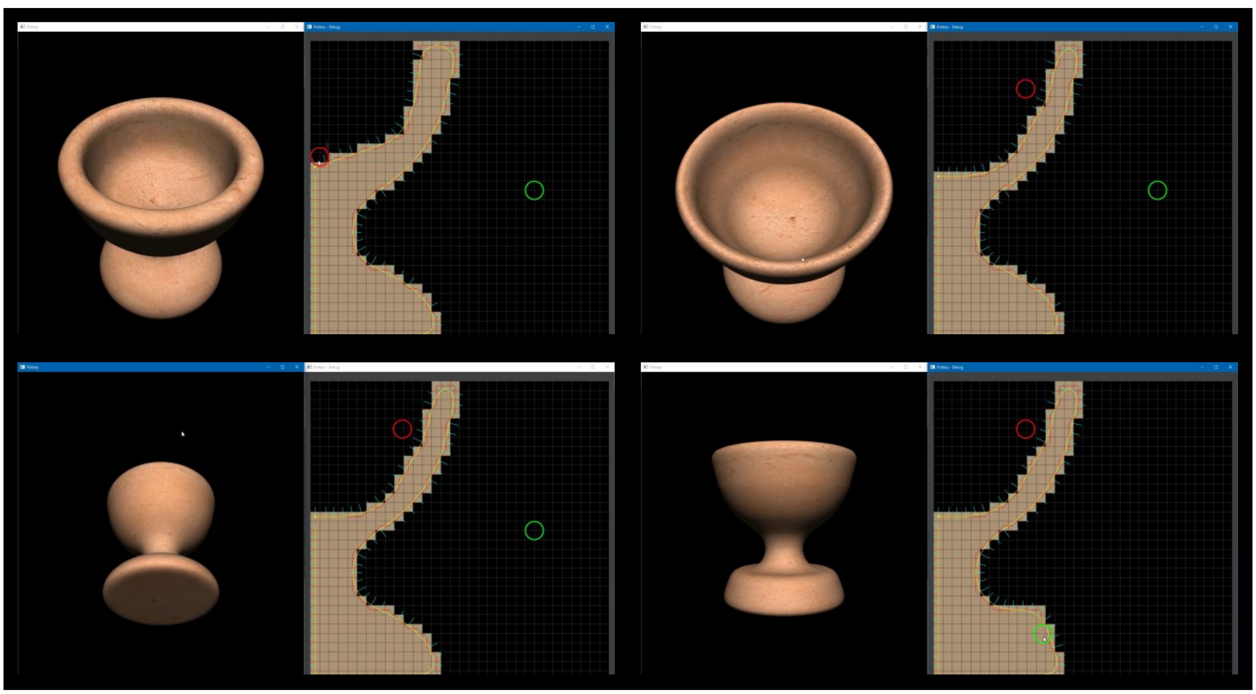


Figure 14. Virtual pottery and software representation are maintained for real-time rendering in the Design Studio.

In the case of woodturning, only subtractive functions are provided. That is, as in all subtractive crafts, when a cut is made it cannot be undone. In the examples, we use the tool knowledge elements from the CAP (in the context of glass) and obtain their, associated 3D models:

- Corner chisel
- Round gouge

Using the above links, the user can additionally access the associated knowledge with these tools, such as visual and 3D examples of use, as well as verbal documentation (e.g. usage instructions or suitability per task). To show that the design aid is indeed craft-specific, we follow a recording of a honey dip creation. Indicative scenes from the recording are shown in Figure 15.

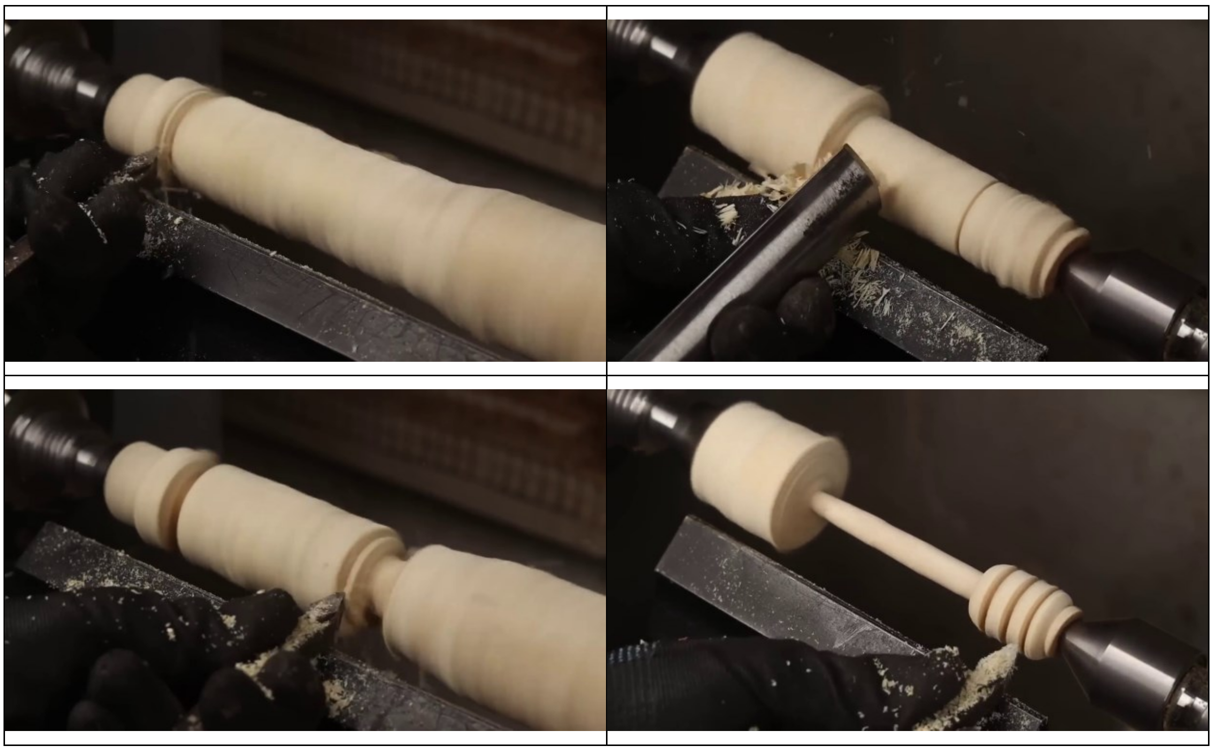
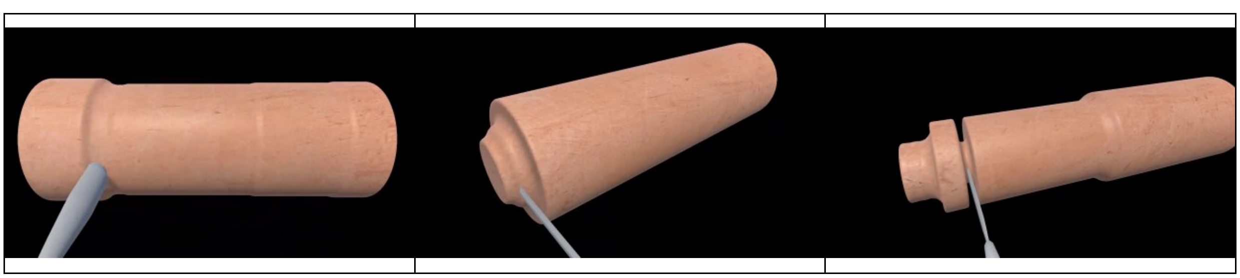


Figure 15. Key frames of a honey dip creation.

Our effort to follow it is shown in Figure 16 and the complete video can be found at https://youtu.be/U99i7hgC0g0



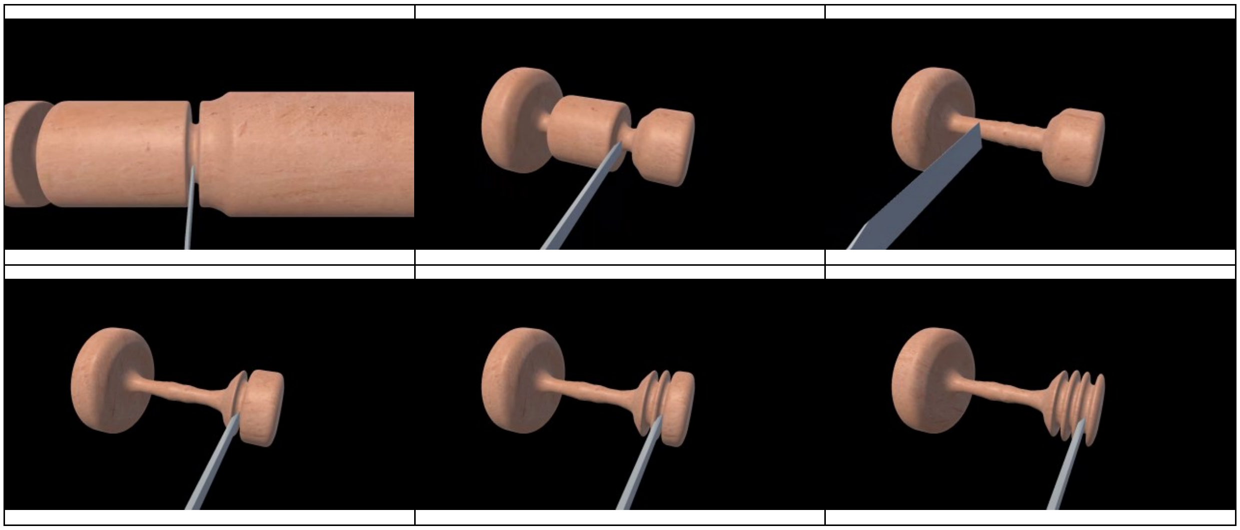


Figure 16. Virtual, craft-specific design of a honey dip.

In glassworks, revolution helps to cope with gravity that attracts molten glass downwards but is also used in shaping highly deformable material. The design tool illustrates the design bottommost part of the vessel in a craft-oriented fashion. The mass-preserving tool is used as in pottery, but this craft-specific simulator differs in the following ways:

- The revolution of the material is not continuous about a stable axis but about a moving one.
- The angular velocity is not constant but variable (sinusoidal, in specific) and palindromic.
- Two tools are required to cope with the viscous nature of molten glass, which in reality are held by two collaborating and synchronously moving persons.

In the example, a shaping action is shown, illustrating the shaping of a glass vessel's "foot"[4]. The simulation is applied to the foot-shaping process steps, which is crucial for the stability of the vessel. The representation of this action is associated in the CAP with the following video in Leg and foot laying slowmotion3 where the recorded steps were inspected in slow motion.

Two tools are used and their 3D models are obtained from the CAP, namely:

- Battledore
- Jacks

In Figure 17, keyframes from our recreation of the aforementioned step, for two viewpoints. The full videos for these viewpoints can be found at https://youtu.be/Bt0Xo5d-VCQ and the following two https://youtu.be/OzXdKQdLfg8.

[4] The foot refers to the base of the vessel, which provides stability and allows it to stand upright.

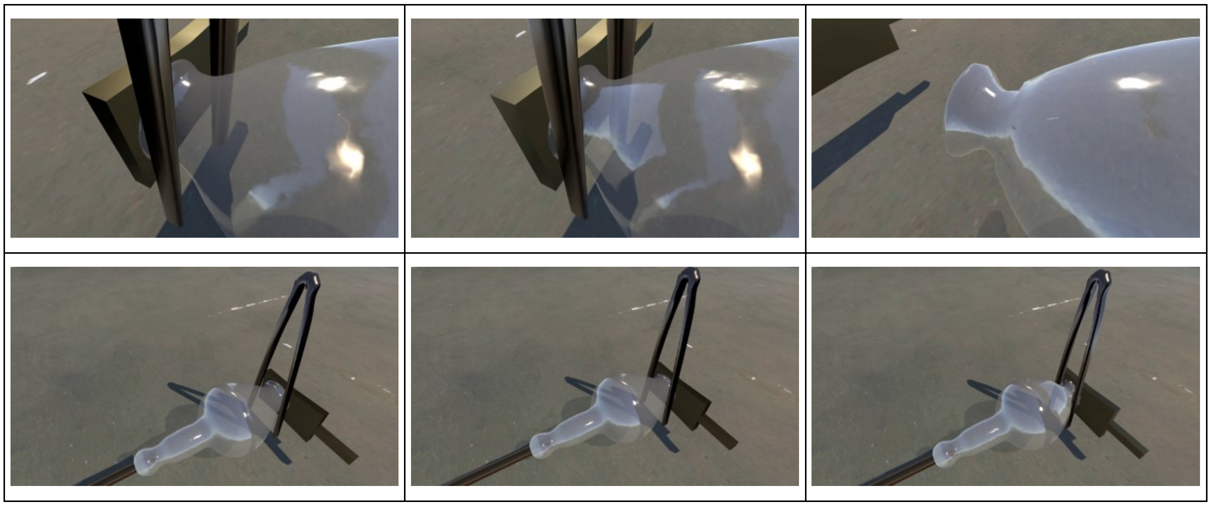


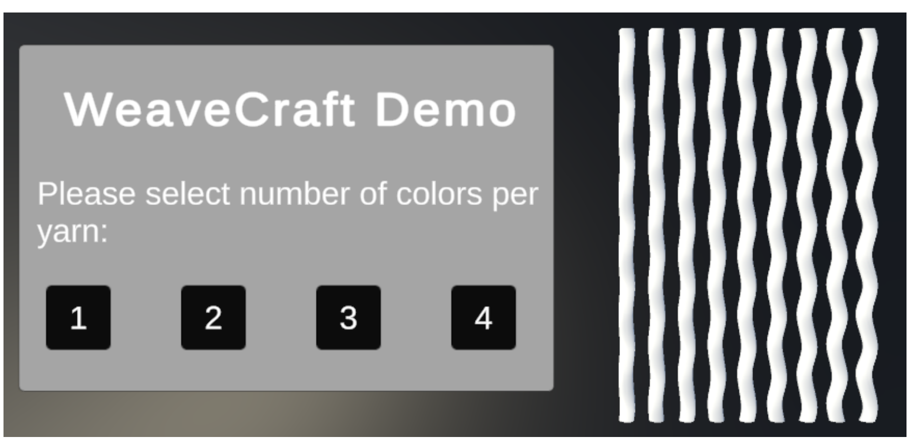
Figure 17. Interactive and craft-oriented design of a glass vessel.

2.3.3.2 Textile design

Loom weaving is an old art that has led to extinction as years pass by. Industrialization has automated this process to a large extent, thus fewer and fewer people tend to learn to create handmade weaves.

This project aims to develop an application for the simulation of the loom weaving process, utilizing 3D yarn models to create various weave patterns e.g. satin, plain, twill etc. This simulation takes place inside a Unity game engine environment, where users can learn about different weaving techniques through a dedicated user interface. This allows people interested in this art to practice weaving seamlessly and engagingly, without the need of a master weaver for supervision.

Using the weaving simulator from D3.1, we developed a user interface to allow the user to create their textile designs, with their selections of colours. The utility operates as follows. First, the user selects how many and which colours of weft will be used. Second, the user selects the type of weave that will be used for the textile. The selection menus are shown in Figure 18.



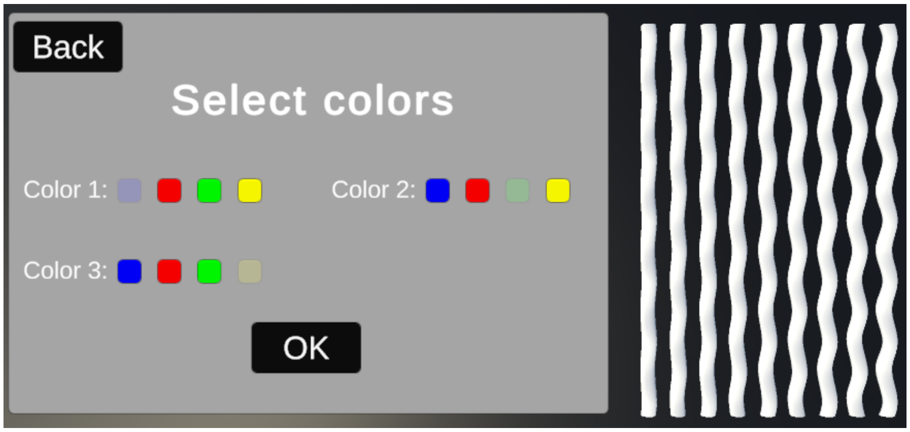
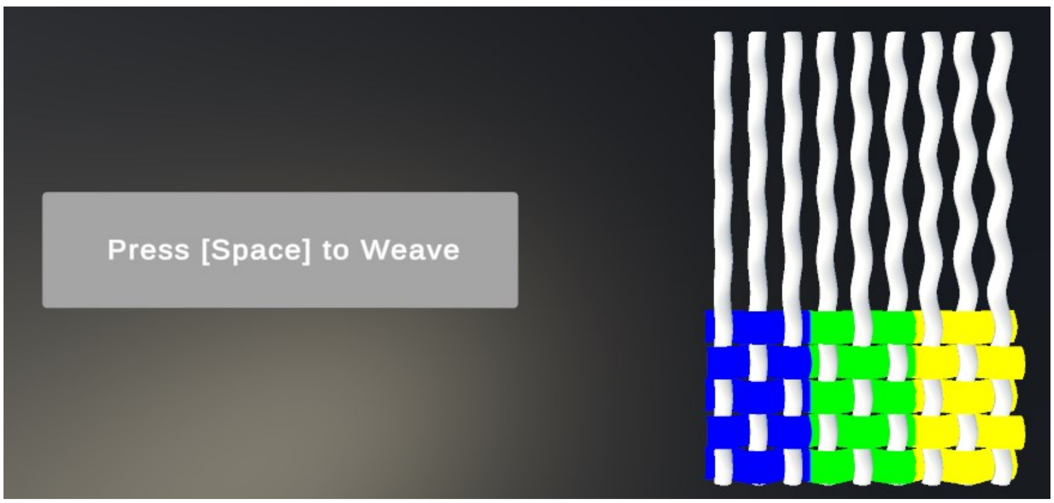


Figure 18. Configuration screen for textile design simulation.

Next, the user creates their patterns, by selecting which colour weft will be next used. As shown in Figure 19, the system displays the result in real time predicting the appearance of the woven design.



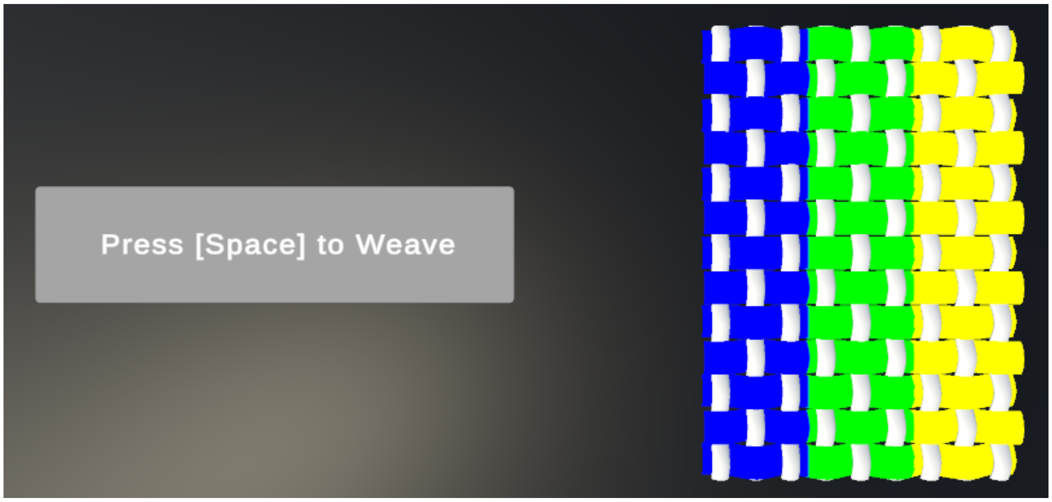


Figure 19. Simulated weaving for textile design.

The next steps are the implementation of more weave patterns (i.e., satin, twill, etc) and providing greater variety in the selection of colours for wefts and yarns. Furthermore, it incorporates a colour wheel for colour selection to allow the user to choose from a wider range of colours. Also, it enables the user to extend a weave to be of arbitrary height and length.

2.4 Phase 4: Create Wireframe, Storyboard, and Prototype

Based on the analysis and our preliminary findings, we will begin developing prototypes of key components of the Design Studio. These prototypes will be tested with RCIs to gather feedback and make necessary adjustments. Initially, the plan was to have a wireframe ready by M16; however, the process has been delayed since one of the significant challenges is the variety of requirements and needs of each RCI. To address this, we are conducting multiple discussion iterations to find common ground and identify tools that can be used across different crafts.

In addition, analysing the gathered information accurately is another challenge due to the complexity and diversity of the data. We use advanced data analysis techniques and involve experts to ensure thorough and accurate analysis. Analysing the gathered information has progressed slower than anticipated. To mitigate this, we are optimising our workflows and increasing the frequency of bilateral meetings and feedback sessions with RCIs to accelerate progress since we aim to analyse with care to build something relevant for end-users.

We expect to have the first version of the wireframe, storyboard, and prototype ready by M24 (March 2025), reflecting all the analysis's results, requirements, and inputs from crafts partners.

2.5 Phase 5: Implementation and Preparation for Deliverables

The core features of the Design Studio, including CAD tools, AI-based design assistance, and XR integration, will be developed and implemented in iterative cycles. Each cycle will involve testing and feedback from RCIs to ensure the tools meet user needs. We will integrate additive and subtractive manufacturing technologies into the Design Studio, enabling users to transition from design to production. This integration will involve developing interfaces and workflows that support various fabrication methods. For detailed technical descriptions of interactive additive and subtractive manufacturing technologies, please refer to Section 3.

The developed tools will undergo validation with RCIs and project partners to ensure they function as intended and provide real value to craft professionals. This phase will include hands-on testing, workshops, and training sessions. The integration of different immersive and non-immersive software application components will be sequenced according to the practical needs of RCIs and partners. Software components will be integrated into the Design Studio based on their intended use.

Based on the validation results, we will refine and improve the Design Studio. This may involve additional development cycles to address any issues or incorporate new features based on user feedback.

3. Integration with additive and subtractive manufacturing technologies

A software tool capable of converting 3D files (in .stl format) into G-code for 3D printing has been developed to support the design studio. The .stl file format is important in 3D printing and CAD, containing geometric data of 3D objects through triangular facets. This tool's development process involves slicing the 3D model into layers and generating the printer head's path in G-code.

During the first year of the project, three approaches were utilised. The first regards the usage of custom classes for computational geometry, the second regards the usage of the "numpy-stl" library for mesh operations and the third regards the integration of an open-source 3D slicer in the form of a programming library.

3D slicing and G-code generation require a foundation in several mathematical concepts. These include vector calculus, linear algebra, and computational geometry. A triangle in 3D space is defined by three points. The normal vector to the triangle's surface, essential for determining its orientation, can be calculated using the cross product of two edges of the triangle. Infill patterns are generated by intersecting the model's slice with a grid pattern. The percentage of infill determines the density of the grid. Mathematically, this is akin to finding intersections between the perimeter lines of the slice and the lines of the grid. The intersection function uses linear algebra to solve for the intersection point between a line and a plane, crucial for slicing the model into layers.

The first approach constructs a computational geometry framework through custom Python classes to represent geometric entities like points, lines, and triangles. It allows detailed control over the slicing process and flexibility in algorithm implementation. Key components include:

- **Geometric Classes:** These form the foundational entities for the manipulation of 3D models.
- **Slicing Algorithm:** The algorithm intersects horizontal planes with the model's triangles, creating line segments representing each layer's contours.
- **Infill and Support Generation:** Algorithms for calculating infill patterns and generating supports based on geometric calculations.

Despite offering deep insights and flexibility, this approach has limitations, especially in handling complex models, potentially leading to longer processing times and inaccuracies.

The second approach leverages the numpy-stl library for efficient .stl file and mesh operation handling in Python. This method aims to simplify development and improve performance through:

- **Mesh Processing:** Employing numpy-stl for direct operations on the mesh structure.
- **Vectorized Computations:** Using numpy for enhanced performance in computations.
- **Integration with Geometry Libraries:** Facilitating the use of advanced features through existing computational geometry libraries.

The third approach simplifies even further the process by implementing a scripting library and a command line interface that integrates the open-source slicing library. Through this approach, the creation, editing and altering of slicing profiles is radically simplified allowing the support for a wider collection of 3D printing equipment. This approach has been tested both with a custom cartesian prusa i3-based implementation which represents most of the inexpensive derivatives available on the market and with an evolved coreXY version by Creality (k1 max).

3.1 Solids

This section presents the results of the slicing process for different 3D models: a cube, and an octahedron. Each model was processed with a layer height of 0.2 and an infill percentage of 50%. The figures below illustrate the slicing outcomes, highlighting the precision and challenges encountered in slicing complex shapes.

Currently, our focus is placed on the third approach. Figure 20 below shows a 3D model and photographs from its 3D printing using the cartesian setup.

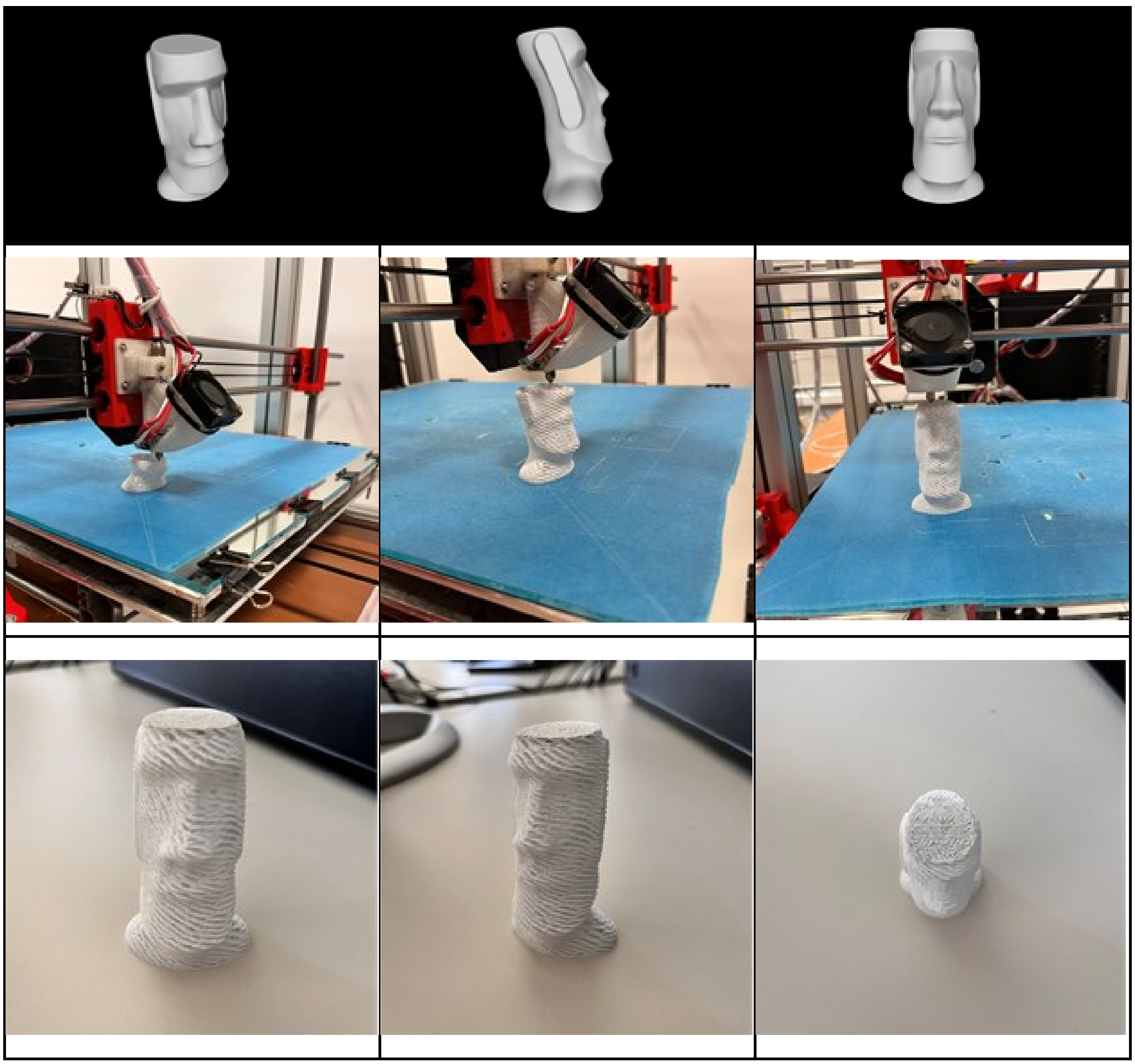


Figure 20. A 3D model, its printing, and the final result.

All of the discussed approaches provide valuable perspectives on the slicing process, each with unique advantages and challenges. Future efforts will focus on optimising algorithms, supporting complex model slicing, and integrating user feedback to enhance functionality and user experience. Furthermore, the goal is to provide all the details of the configuration of the printing procedure as arguments for the script, to ensure the quality of the print in all aspects.

3.2 Moulds

This subsection explains the implementation of a Python script designed to process a 3D model stored in an STL file format. The primary goal of the code is to create a mould of a given 3D object. This involves loading the STL file, extracting its vertices, computing the bounding box, generating a voxel representation with added padding and a hole, and exporting the processed model as a new STL file.

3.2.1. STL file loading and vertex extraction

We can load any .stl file in this script, as well as any other files containing 3D objects such as .obj, .ply etc. The model we used for test purposes was named models. This file contains a 3D model, specifically a small bust of a human being (referred to as the MAOI model). The vertices of the 3D model are extracted and displayed to understand the structure of the model. The number of vertices and faces is also computed to verify the integrity and complexity of the model.

3.2.2. Voxel Grid Generation

The utility calculates the bounding box of the model by determining the minimum and maximum coordinates along each axis (X, Y, and Z). Padding is added to the bounding box to ensure that the model is fully enclosed. This is achieved by expanding the minimum and maximum coordinates by a predefined padding value. The padded bounding box is then used for subsequent voxel grid generation.

The resolution of the voxel grid is determined based on the longest dimension of the bounding box. The user can also specify the resolution based on the purpose of use. Large resolutions (eg. 100) may need more time to complete the process. This ensures that the voxel grid accurately represents the dimensions of the 3D model. The grid is generated using a uniform spacing along each axis. A 3D array (voxel grid) is initialised with ones. This array will later be modified to represent the internal and external structure of the 3D model.

The boundaries of the voxel grid are set to zero to create an external shell. This step is crucial for defining the limits of the voxelized model. A circular hole is created in the top padding of the voxel grid. This is done by iterating through the grid and setting the voxels within a defined radius from the centre of the top face to zero.

3.2.3. Internal Structure Detection

A mesh object is created from the vertices of the STL model using the times library. This mesh object is used to perform spatial queries. Points are generated within the bounding box to evaluate whether they lie inside or outside the STL model. These points are used to map the internal structure of the model.

The script checks each point within the bounding box to determine if it lies inside the STL model. This is performed in batches for efficiency. Points inside the model are identified and used to modify the voxel grid. The result of the operation is shown in Figure 21. The voxel grid is visualised by displaying slices along the Z-axis. This provides a clear understanding of the internal and external structure of the voxelized model. The marching cubes algorithm is implemented through the image-measure library is employed to extract the surface of the voxel grid. This algorithm generates a mesh representation of the surface, which is crucial for the final export. The processed model represented as a new mesh, is exported to an STL file named mould with hole 4K20.stl. This file contains the modified 3D model with the added padding and hole.

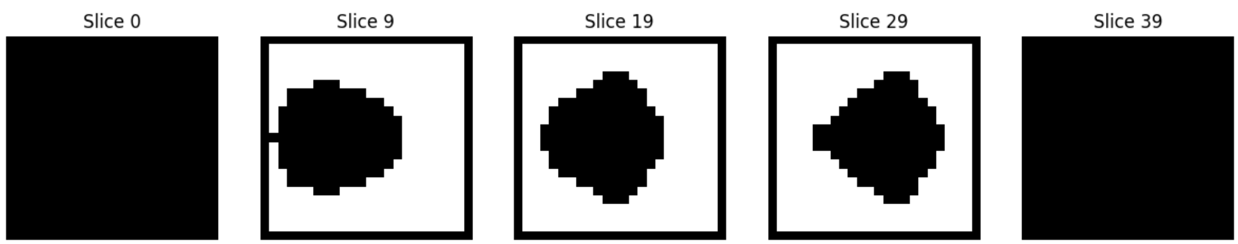


Figure 21. Slices of the 3D voxel grid along the Z-axis. Black regions indicate voxels set to zero, while white regions indicate voxels set to one.

3.2.4. Visualisation and Export

The final step involves visualising the resulting mould using a 3D plot. This plot displays the 3D structure of the model, providing a visual confirmation of the modifications made during the process. We show the generated 3D model using transparent surface rendering in MeshLab and using our visualisation toolbox, in Figure 22.

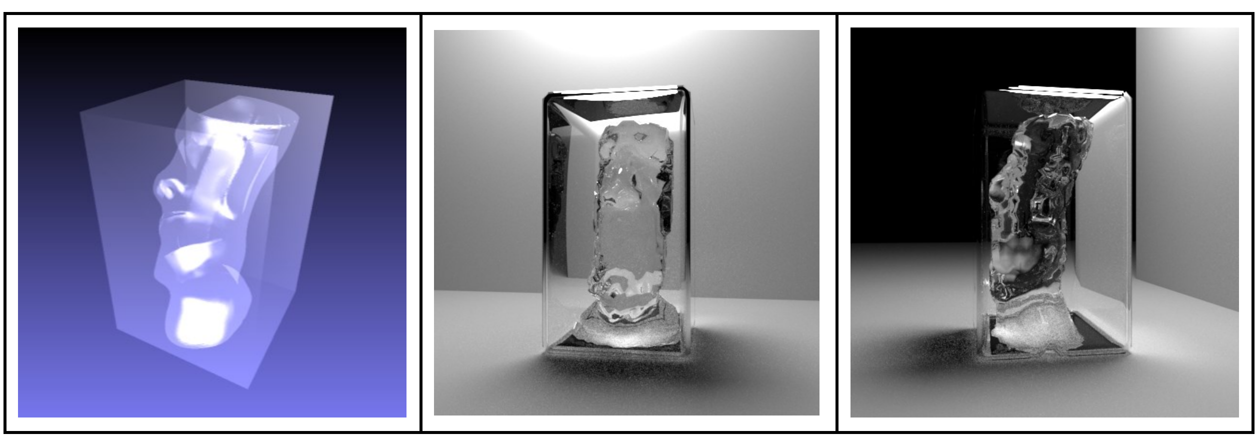


Figure 22. Rendering of the mould 3D model using transparency to illustrate its hollow structure.

3.2.5. Results

Finally, the mould was 3D printed as shown in Figure 23. We can observe that the structure of the model has indeed been captured inside the mould and can be filled with any desired material for use.

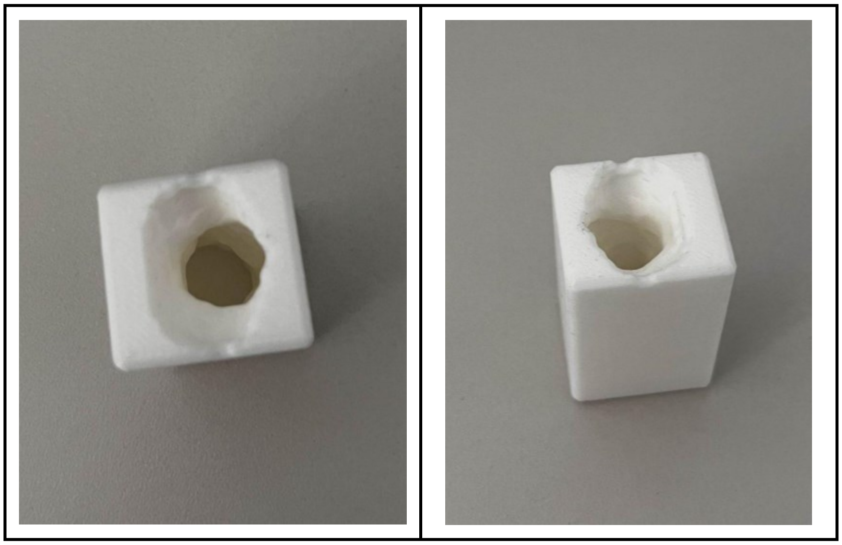


Figure 23. A 3D printed, single-part mould.

However, this mould is usable once, meaning it has to be broken to extract the moulded object. To decrease mould material waste, we added another feature to the mould design. Specifically, we split the moult into two parts. The process is known as "two-part moulding" or "two-part casting." The mould is often referred to as a "two-part mould" or "split mould". In this technique, the mould is made in two separate halves, which are designed to fit together precisely. Once the casting material is poured in and solidified, the two halves of the mould can be separated to remove the cast object. The mould can then be reused multiple times for additional castings. This method is commonly used in various industries, including ceramics, metal casting, and plastic injection moulding. The 3D-printed result is shown in Figure 24.

Figure 24. A two-part mould.

4. Innovation of the Design Studio

The Design Studio is a virtual workspace designed to elevate the creative design process by integrating computer-aided design, and AI-based design capabilities, and support workflow planning. The virtual studio is engineered to provide a simulation environment, minimising experimentation costs and offering features to support exploration, training, and producing pre-defined forms of crafts and craftsmanship.

Within the Design Studio, craft-specific 3D tools are incorporated to cater to the unique intricacies of selected crafting techniques. These tools empower designers with precision and customization options, ensuring a fit for various craft forms such as, for example, glassblowing, marble cutting, and wood carving.

Haptic interfaces introduce a tactile dimension to the virtual workspace, enabling a physical engagement of designers with their creations. This interactive feature enhances the design experience as it seeks to foster a deeper connection between the creator and the digital artefact.

The inclusion of computer-aided design tools within the Design Studio provides designers with a toolkit for conceptualization and refinement and ensures efficiency and accuracy in the design process while accommodating diverse design requirements. The Design Studio links the digital and physical realms, facilitating the realisation of virtual designs through various fabrication methods used to make tangible creations. Realistic artefact previews are offered in virtual and mixed-reality environments. This capability provides designers with immersive experiences, allowing for visualisation and evaluation of designs in real-world contexts. The virtual previews enhance the design experience by providing dynamic perspectives and insights into the creation of crafts.

The benefit is the feedback during the design process. Visual updates enable quick iterations and refinements of the design, reducing the time and cost associated with physical prototypes. This is particularly important in sculpted, cast, and moulded products as the mistakes cannot be remedied.

4.1 Innovation Rationale

- **Efficiency and Cost Reduction:** Traditional design processes often involve extensive experimentation, increasing costs, and time investments. The Design Studio's simulation environment seeks to reduce the need for physical experimentation, thereby minimising associated costs and expediting the design cycle.
- **Craft-Specific Precision:** Crafting involves intricate techniques that demand specialised tools. Including craft-specific 3D editing tools ensures that designers have precise instruments tailored to the nuances of different craft forms and can train effectively. This precision allows for detailed customization and accuracy in crafting virtual designs.
- **Tactile Engagement for Enhanced Design Experience:** Haptic interfaces introduce a tactile dimension to the virtual design space. This hands-on engagement enhances the design experience and fosters a deeper connection between the designer and the digital artefact, promoting a more intuitive, fun, and immersive creative process.
- **Versatile Computer-Aided Design Functionality:** Integrating computer-aided design tools within the Design Studio provides a toolkit. This functionality gives designers the ability to conceptualize and

refine, accommodating diverse design requirements and ensuring an efficient and adaptable design process.

- **Transition to Physical Creations:** A critical aspect of the Design Studio's innovation is its interface with digital fabrication modalities. This feature streamlines the transition from virtual design to tangible creations, ensuring a pathway for bringing digital designs to life through various fabrication methods.
- **Immersive Artefact Previews:** Realistic artefact previews in mixed and virtual reality environments offer designers immersive experiences. This capability allows for the visualisation and evaluation of designs in real-world contexts, providing new perspectives and insights during the design phase.

4.2 Market Potential

- **Design and Creative Industries:** Design studios, creative agencies, and professionals in design-centric industries stand to benefit from the Design Studio. Its integration of tools and simulation power addresses the needs of designers seeking efficient, precise, and immersive experiences to test, refine, and practice craft design.
- **Educational Institutions:** The Design Studio offers an educational tool for institutions providing design courses. Its immersive and hands-on features make it an ideal platform for teaching design principles and computer-aided design techniques and fostering a deeper understanding of crafting processes.
- **Crafting and Artisan Communities:** Crafting enthusiasts and artisan communities can leverage craft-specific 3D editing tools to enhance their design capabilities. The Design Studio will be a digital place for artisans to experiment with designs, simulate crafting processes, and bring virtual creations to life.
- **Digital Fabrication and Manufacturing:** Digital fabrication and manufacturing industries can benefit from the Design Studio's interface with digital fabrication modalities. This feature seeks to streamline the design-to-production pipeline, offering efficiency gains and reducing time-to-market for physical creations.
- **Gaming and Virtual Reality (VR) Platforms:** The Design Studio's compatibility with virtual reality and mixed reality environments positions it as a potential asset for gaming and other virtual platforms. Its immersive artefact previews can be integrated into virtual worlds.
- **Online Design Platforms:** Platforms dedicated to online design collaborations and marketplaces can integrate the Design Studio to provide users with a virtual workspace for exploration, design, and creation. This inclusion adds value by offering advanced design functionalities, simulation capabilities, and immersive previews to users engaged in collaborative design projects.
- **Consumer Electronics and Technology:** Companies in the consumer electronics and technology sectors may find applications for the Design Studio in product design and development. Its combination of AI-based design and realistic simulation contributes to efficient prototyping and innovation in product design.
- **Startups and Innovation Hubs:** Startups and innovation hubs looking to test design processes in virtual spaces can explore the Design Studio. Its features make it an attractive tool for those seeking creativity and efficiency in their design initiatives.

4.3 IPR holders

Based on Craeft's GA the organizations that are participating in the formulation of this innovation are KHORA, FORTH, ETH, and CETEM. IPR ownership will be the subject of a joint exploitation agreement and will be defined based on the commonly understood contribution of each participating organization to the formulation of the IP.

5. Conclusion

This deliverable has outlined the details of the Craft Design Studio's design and development process, the overall purpose and objectives of the Design Studio and a detailed work breakdown structure of how it will be created with input from all Representatives of Craft Instants (RCIs) in the project. After analysing interview data with RCIs, we see that the main benefit of a design studio for end-users is the feedback during the design process. Visual updates enable quick iterations and refinements of the design, reducing the time and cost associated with physical prototypes. This is particularly important in sculpted, cast, and moulded products as the mistakes cannot be remedied.

The next version of this deliverable will be submitted by the end of the project in M36, including the design details, such as wireframes, templates, and an overview of the developed Design Studio in its final form.

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