CRAEFT

care, judgment, dexterity

Craft Design Revisited

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Executive summary

This deliverable (D5.1), submitted at Month 36 (M36), reports the design, development, and end-of-project evaluation of a suite of craft-oriented digital design and visualisation services, together with their integration into a practitioner-facing demonstrator, the Craeft Design Studio. The work consolidates three years of joint effort across technical partners and craft-domain stakeholders (RCIs), and positions the resulting capabilities as modular, reusable services intended to be exploitable beyond a single application and aligned with Craeft's ambition to contribute to the European Collaborative Cloud for Cultural Heritage (ECCCH).

Craeft craft design faces a recurring set of challenges: the cost of physical experimentation, difficulty translating ideas into feasible craft outputs, limited access to advanced digital tools, and fragmented workflows across disconnected applications. D5.1 addresses these challenges through a service-oriented approach: each major capability (interactive craft simulators, material-aware rendering, feasibility-oriented tools, and output-generation workflows) is implemented as an independently deployable module that can be combined into end-to-end user workflows.

To ensure relevance, the deliverable formalises requirements through a structured partner-facing process and consolidates them into two traceable requirement families:

1. REQ-UX-01…07: cross-cutting UX/UI requirements.
2. REQ-TOOL-01…07: capability requirements.

The primary technical outputs are organised into three capability blocks:

Craft-specific design services (Section 3). D5.1 delivers a coherent set of design tools grouped around reusable craft action primitives—additive, subtractive/shaping, solids by revolution, transform, and interlock. These are demonstrated across multiple craft-relevant examples (e.g., pottery shaping, woodturning, glass vessel shaping, tin punching reliefs, rigid stained-glass-style compositions, and woven compositions). The key contribution is not only geometric editing, but process-aware, craft-grounded interaction, where tools encode craft constraints and make the "how" of making explicit and inspectable.

Visualisation services (Section 4). The visualisation toolbox provides critique-ready, photorealistic preview across a wide range of artefacts and materials. Demonstrations include multi-material previews on scanned sculptures, industrial glass exemplars, bottle variants, stained-glass windows and Tiffany lamps (including interior context), cane work, metal engraving preview (Anaglyph Creator), ceramics and glaze appearance variants, and curated virtual showroom contexts. The emphasis is on trustworthy appearance prediction (tint, transmission, specular response, glaze roughness) and on supporting iterative comparison across design alternatives.

Digital fabrication services (Section 5). The deliverable extends design-to-realisation workflows with:

1. a slicing-to-G-code toolchain for solid 3D printing (including discussion of alternative implementation approaches and current focus),

2. an automated mould generation workflow using voxelisation and shell construction (including a two-part mould variant to reduce waste and improve reusability), and
3. an open-source laser engraving pipeline (SVG → CAM → GRBL-compatible G-code), validated through engraving of a traditional rosette motif. Together, these components operationalise Craeft's goal of bridging digital design with accessible, affordable fabrication pathways.

Design Studio integration and evaluation (Section 6). The Craeft Design Studio is presented as a reference implementation that integrates the above services into a single workspace with a stable navigation model and a clear tool taxonomy (Interactive Simulations vs Visualisation Toolbox). The deliverable documents UX artefacts (user journey, information architecture, UI templates, interaction models), implementation principles (module architecture, Unity UI integration), and integration points to other Craeft components.

An end-of-project evaluation with seven participants provides directional evidence about baseline readiness:

- Strongest results concerned navigation and contextual understanding (mean 4.43/5) and UI layout consistency (mean 4.00/5).
- Performance was rated lowest (mean 3.14/5), indicating responsiveness and feedback loops remain central to user confidence.
- Peer recommendation yielded an average 5.57/10 (median 6/10), consistent with an early-stage research prototype: usable for exploration, but requiring refinement for sustained professional use.
- Task completion was high for "start and explore" actions, but dropped for output lifecycle actions:

These findings directly inform the report's prioritisation of clearer output handling, stronger run-state feedback, and improved reliability of export/render pathways.

Innovation, exploitation, and IPR (Section 7). D5.1 frames innovation in terms of resource-efficient craft design (reducing cost and risk of experimentation), craft-specific precision (tools aligned with craft constraints), immersive and interactive preview, and practical bridging to digital fabrication. The deliverable outlines market potential across design and creative industries, education and training, artisan communities, digital fabrication sectors, and VR/MR platforms. Identified IPR contributors are KHORA, FORTH, ETH, and CETEM, with ownership to be managed according to the Craeft Grant Agreement.

Summary.

In aggregate, D5.1 delivers (i) a modular suite of craft design and visualisation services, (ii) concrete digital fabrication bridges, and (iii) an integrated Design Studio demonstrator with an evidence-based evaluation. The overall outcome is a technically coherent foundation for craft-facing digital design workflows that can be incrementally strengthened (performance, output lifecycle clarity, reliability) and extended to additional craft domains and ECCH-oriented deployments

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
20/8/2024	Peiman Sichani, Laura Werup, Xenophon Zabulis, Nikolaos Partarakis	Khora, FORTH	Final Deliverable sent to project reviewers
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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, titled "Craft Design Revisited" (D5.1), documents the design, development, and implementation of craft-oriented digital services and their integration into a practitioner-facing workspace, carried out within Work Package 5 of the Craeft project. The deliverable has been submitted in two phases: the initial version at Month 18 (M18) outlined the overall purpose, objectives, and requirements of the work, including a detailed methodology for engaging with Representatives of Craft Instances (RCIs) across the consortium. This final version, submitted at Month 36 (M36), presents the complete implementation, covering the developed design and visualisation services, their integration with additive and subtractive manufacturing capabilities, the Design Studio demonstrator, and an assessment of innovation and market potential.

A central ambition of the Craeft project is the integration of its outcomes into the European Collaborative Cloud for Cultural Heritage (ECCCH), an open, distributed infrastructure that enables cultural heritage institutions, researchers, educators, and practitioners to share and reuse digital tools and resources across Europe. The work presented in this deliverable is developed with this ambition in mind: the craft-specific design and visualisation services described in Sections 3 and 4 are designed as modular, reusable components that can, in the future, be deployed as independent services within the ECCH. The Design Studio, described in Section 6, serves as a demonstrator use case that illustrates how such services can be assembled into a coherent, end-to-end digital workspace for craft professionals.

1.1 Craft-specific design facilities

1.1.1 Types of Problems Targeted

The craft design and visualisation services developed in this deliverable address a set of well-documented challenges faced by craft professionals, educators, and small businesses. These challenges motivated the design decisions taken throughout the project and remain relevant to future exploitation and ECCH integration:

Complexity in Design and Prototyping: Craft professionals often struggle to translate creative ideas into precise and feasible designs. Traditional methods are time-consuming and error-prone, particularly when transitioning from initial concepts to physical prototypes. The design services developed here, including CAD-based tools and AI-assisted design aids, support users in creating and refining designs more accurately and efficiently.

High Costs of Experimentation: Physical prototyping is costly in both time and materials, particularly for individual artisans and small-scale craft businesses. The simulation and visualisation services developed in this deliverable allow practitioners to experiment and iterate virtually, significantly reducing the need for costly physical trials.

Limited Access to Advanced Manufacturing Technologies: High costs and technical barriers prevent many craft professionals from accessing additive and subtractive manufacturing technologies. The manufacturing preparation services described in Section 5, covering 3D printing, mould generation, and laser engraving, are designed to make these technologies more accessible and integrated into craft workflows.

Fragmented Design and Production Workflow: Craft design and production typically involve multiple disconnected tools and processes. The service-oriented architecture adopted in this deliverable provides a coherent, interoperable toolchain that supports the full journey from initial concept to physical production, including the transfer of designs directly from digital assets.

Skill Development and Training: Keeping pace with technological change requires effective learning environments. The services developed here support educational contexts, providing accessible platforms for learning, experimentation, and guided skill development in collaboration with craft training organisations within the Craeft consortium.

Adherence to Design Principles: Incorporating design principles such as Gestalt principles, symmetry, rhythm, and figure/ground separation is challenging without dedicated tool support. The design services embed these principles into their CAD toolkits and image processing features, ensuring that outputs are both technically feasible and aesthetically grounded.

1.1.2 A service-oriented approach

The design and visualisation facilities developed in this deliverable are conceived as modular and extensible components rather than as parts of a single monolithic application. Their architecture follows a service-oriented logic, in which each design aid, simulation environment, and visualisation tool is implemented as a distinct yet interoperable unit. This approach ensures flexibility, long-term technical sustainability, and explicit alignment with the European Collaborative Cloud for Cultural Heritage, into which these components are intended to be integrated.

Each major capability, including craft-specific simulators, material-aware rendering tools, feasibility checking mechanisms, and manufacturing preparation utilities, is implemented as an independent functional component. These components share common data structures, interaction principles, and exchange formats, while their internal logic remains self-contained. This separation allows individual services to evolve, be extended, or be replaced without requiring structural changes to the broader framework, and enables the gradual addition of new craft domains as the project's coverage expands.

The overall architecture distinguishes between a foundational layer, supporting navigation, workspace logic, data persistence, and export functions, and a craft-specific layer embedding material behaviour, gesture-informed modelling, constraint-based validation, and domain-specific interaction techniques. Decoupling general platform functionality from craft intelligence allows new services to be integrated without disrupting existing ones, which is essential for scalability and for alignment with shared European digital heritage infrastructures.

This service-oriented structure is adopted with the explicit goal that the design and visualisation facilities can be translated into cloud-based or distributed services deployable within the ECCH. A material rendering facility, a glaze simulation tool, or a mould-generation utility could, for example, be made accessible as independent reusable services to cultural heritage institutions, educators, researchers, or practitioners through the Cloud environment. The use of standardised 3D formats and clearly defined data exchange mechanisms supports interoperability with shared repositories of digital assets and metadata.

From a workflow perspective, the service-oriented approach allows practitioners to combine facilities according to their specific needs. A user may create a form within a craft-specific simulation service, assess its feasibility through embedded constraints, preview its material behaviour under realistic rendering conditions, and prepare it for manufacturing through slicing and export utilities, without these steps being rigidly sequenced. This flexibility supports educational, experimental, and professional contexts equally. It also ensures technical sustainability: rendering technologies, simulation models, and fabrication preparation tools can each be updated independently, reducing long-term maintenance complexity.

1.2 The Design Studio

The Design Studio is a practitioner-facing shell application developed within the Craeft project to demonstrate how the craft design and visualisation services described in this deliverable can be integrated into a coherent, end-to-end digital workspace. It serves as a reference implementation and use case demonstrator, illustrating how reusable, ECCH-oriented services can be assembled to support the full design journey, from initial ideation through feasibility checking, material simulation, and manufacturing preparation.

The Design Studio integrates CAD-based design tools, AI-assisted design aids, and material visualisation services within a unified workspace. It supports realistic artefact previews in both desktop and virtual reality (VR) environments, and connects with digital fabrication modalities including additive (FDM, SLA, powder-based, and metal) and subtractive (laser engraving, milling, CNC cutting, and plotting) manufacturing technologies. The CAD toolkit incorporates design principles such as Gestalt principles, symmetry, rhythm, and figure/ground separation, supporting both technically rigorous and aesthetically informed design work. The full implementation of the Design Studio, including its UX/UI design, Unity-based architecture, and integration with Craeft components, is documented in Section 6.

1.2.1 Intended Use and Target Audience

The Design Studio demonstrator, and more broadly the services it integrates, targets a diverse audience of craft practitioners, educators, students, and small businesses. This breadth of audience reflects both the accessibility goals of the Craeft project and the intended reach of ECCH-deployed services.

Craft practitioners and professional artisans represent the primary user group. Both amateurs and professionals benefit from tools that support the design process from initial concept to physical production, enabling them to prototype and iterate digitally before committing to materials and time.

Students and educators in craft and design programmes are a key audience for the learning and training contexts supported by the services. The platform provides an accessible environment for exploring design principles and manufacturing techniques, while educators can use it to demonstrate concepts and guide project work. Craft training organisations within the Craeft consortium have directly informed this use case through the requirements elicitation process described in Section 2.

Small and medium-sized enterprises (SMEs) in the craft industry, often constrained in their ability to invest in new technologies, can benefit from the cost-effective, integrated approach to design and manufacturing preparation offered by the services. Streamlined workflows and virtual prototyping directly address the resource limitations common among craft SMEs.

Design professionals working in crafts-adjacent fields, including product design, interior design, and fashion, can also integrate these tools into their workflows, leveraging the 3D editing, simulation, and VR preview capabilities for innovative design development.

Hobbyists and individuals with a personal interest in craft will find the intuitive interface and accessible tooling sufficient to explore design ideas and fabrication methods without requiring specialist technical knowledge.

1.2.2 Added value of the Design Studio

The craft design and visualisation services developed in this deliverable, and their integration in the Design Studio demonstrator, offer measurable added value to craft professionals and to the broader cultural heritage community.

Creativity and Workflow Efficiency: The advanced CAD tools, design assistance features, and 3D editing capabilities equip practitioners to explore and realise creative ideas more effectively. Streamlined integration between design, simulation, and fabrication stages reduces the time required to move from concept to finished product, allowing practitioners to focus more on the creative dimension of their work.

Cost Reduction and Sustainability: Virtual simulation and VR-based preview capabilities allow designers to test and refine designs before committing to physical materials, reducing waste and lowering production costs. Accessibility from standard laptops and VR headsets removes the need for specialised studio equipment, broadening participation. These features also support sustainable craft practices by minimising unnecessary physical iterations.

Safe and Accessible Training: Virtual simulations provide a risk-free environment for practising craft techniques without exposure to the hazards associated with traditional methods, such as high temperatures or sharp instruments. This makes the platform particularly valuable as a training tool for students and newcomers to craft disciplines.

Immersive Design Experience: VR capabilities enable users to experience their designs in a lifelike three-dimensional space, providing a richer understanding of scale, proportion, and spatial relationships than conventional screens allow. This immersive engagement supports more accurate design decisions and makes the design process more compelling for a broad range of users.

2. Requirements

2.1 Requirements for design and visualization tools

The design and visualisation tools developed in this deliverable, described respectively in Sections 3 and 4, are the primary technical contributions of the Craeft project within Work Package 5. They are conceived as reusable, independently deployable services intended for future integration into the European Collaborative Cloud for Cultural Heritage (ECCH). Their requirements were derived from two complementary sources: a structured elicitation process conducted with craft domain experts and RCI partners (detailed in Section 2.2), and a set of foundational principles that govern the architecture, quality, and long-term sustainability of cloud-oriented services.

Two guiding principles shaped all tool development from the outset. First, produced designs must exhibit a **realistic visual appearance**, enabling users to anticipate how artefacts would look once materialised through physical craft processes. Second, designs must be **craft-specific**, not merely geometrically plausible, but realistically producible within the techniques, constraints, and material behaviours of the relevant craft domain. These two principles underpin the distinction between the design tools (which support the creation of craft-feasible forms) and the visualisation tools (which support their accurate material and optical rendering). From a **functional** standpoint, the tools must support:

- **Active, iterative design interaction**: practitioners must be able to shape, modify, and refine artefacts dynamically, not merely view or import predefined models. This requirement was expressed consistently across all partner interviews and is treated as a structural requirement rather than a feature preference.
- **Craft-domain specificity**: each tool must embed the constraints, material behaviours, and interaction paradigms of its target craft domain. Generic 3D modelling capabilities are insufficient; tools must encode craft knowledge, whether through constraint-based shaping, gesture-informed interaction, or material simulation, so that feasibility is embedded in the creative act.
- **Feasibility grounding**: design outputs must remain physically realisable within the corresponding craft technique. This includes constraint-based validation (e.g., wall thickness, rotational symmetry, mould-extractability) and, where applicable, linkage with craft-specific simulators developed under WP3 (D3.1).
- **Realistic material and surface rendering**: visualisation tools must produce accurate previews of how designed artefacts will appear in their final material form, covering a broad range of craft domains including glass, ceramics, metals, and organic materials. Rendering quality must be sufficient to support trustworthy design decisions.
- **Coverage of diverse craft domains**: the tool suite must collectively address the craft practices represented in the Craeft consortium, including moulded and sculpted objects, stained glass, Tiffany lamps, caneworking, metal engraving, ceramics with glazes, and textile-based interlocking structures, among others.

From an **architectural** standpoint, the tools must satisfy the following requirements to be suitable for ECCH deployment and long-term reuse:

- **Modularity and independence**: each tool must be implemented as a self-contained functional unit with well-defined inputs, outputs, and interfaces, so that it can be deployed, updated, or replaced independently of other components.
- **Standardised data exchange**: tools must consume and produce artefacts in standardised 3D formats (e.g., OBJ, STL, SVG) and use clearly defined metadata and material conventions, ensuring interoperability with shared ECCH repositories and with other Craeft components.
- **Separation of craft logic from platform logic**: craft-specific rendering models, simulation behaviours, and constraint systems must be encapsulated within each tool, decoupled from the broader platform infrastructure. This separation is essential for the tools to function both as standalone services and as modules within an integrating application such as the Design Studio.
- **Scalability to additional craft domains**: the architecture must allow new craft-specific tools to be developed and added to the suite without redesigning existing components, reflecting the diversity of practices across European cultural heritage.

From a **usability** standpoint, and consistent with the requirements contributed by RCI partners, the tools must:

- Remain accessible to users with varying levels of digital expertise, from students and younger practitioners to professional artisans and heritage specialists, without compromising the depth of functionality available to advanced users.
- Support educational contexts, including critique-ready viewing, guided interaction scaffolding, and reset/iteration patterns that facilitate learning and skill development.
- Enable resource-efficient workflows, reducing material waste and time expenditure through early digital exploration and feasibility checking before physical production is initiated.

These requirements collectively informed the selection, scoping, and implementation of the design tools presented in Section 3 and the visualisation tools presented in Section 4, as well as the manufacturing preparation services described in Section 5.

2.2 Requirements for the design studio

2.2.1 Method

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:

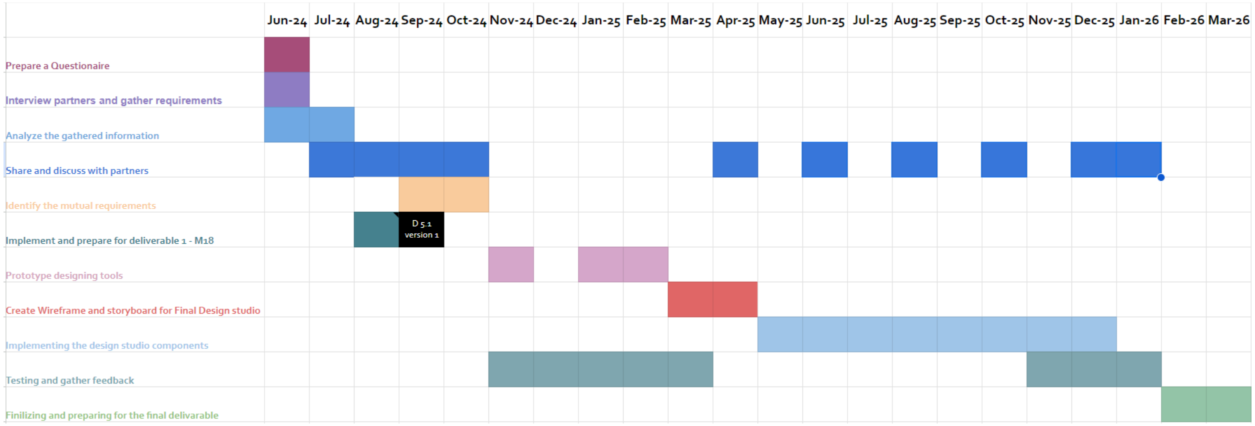


Figure 1. Work plan

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.

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.

Phase 2: Gather answers and requirements

Following the questionnaire preparation, requirements were gathered through interviews and structured exchanges with consortium partners. 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:

The primary intent was to extract:

1. user groups and role definitions (students, educators, professionals, SMEs, heritage practitioners)
2. current working practices and decision points in craft design
3. pain points and failure modes (time/material waste, infeasible designs, lack of feedback loops)
4. expectations for how digital/immersive tools should support—not replace—craft practice

5. module needs and tool priorities that could fit within a shared platform

The interviews were guided by the following questions:

1. Who are the end users of the Design Studio?
2. What are the current working practices and workflows?
3. How do practitioners move from an idea to an actual craft?
4. What are the main challenges faced by crafts practitioners?
5. What digital tools are already in use and what digital tools are missing?
6. 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

Synthesis approach. Interview outputs were consolidated into (i) partner-specific requirement summaries, (ii) cross-partner themes, and (iii) prioritised "capability clusters" that could map to Design Studio modules and shared UI patterns. The synthesis intentionally separated: (1) common platform needs (navigation, workspace patterns, consistent controls, persistence/export) from (2) craft-specific needs (simulation behaviours, gesture recording, mould support, feasibility logic).

This separation ensured that the Design Studio could be built as a scalable framework where craft-specific modules can be integrated without redesigning the whole interface each time.

2.2.1.3. 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.

Workshops were used to align priorities and ensure that requirement interpretation was consistent across partners. The focus was not only to collect additional needs but to resolve tensions between:

- highly craft-specific workflows versus platform-wide usability
- expert users who want deep control versus students who need simplicity
- conceptual “design support” features versus technically feasible implementation steps

A core workshop output was agreement on a Design Studio direction that supports both:

- **learning and training contexts** (students, educators, guided exploration, safe practice) and
- **professional exploration contexts** (rapid iteration, feasibility checking, export readiness)

2.2.2 Interview synthesis: partner-specific requirements

Interview findings were synthesised into partner-specific requirement statements and rationales. The synthesis explicitly distinguishes between (i) cross-cutting needs that must be satisfied by the common UI/UX layer, and (ii) specialised capabilities that require dedicated tools or feature modules. For traceability, the interview-derived requirements are recorded below using REQ-INT identifiers.

CERFAV (Glass), Target group: Craft students

CERFAV emphasised the Design Studio as a practice-oriented learning environment. Priority was placed on an interactive ‘make-and-iterate’ workflow, where students can create forms in 3D, inspect results reliably during critique sessions, and access scaffolding for complex steps such as mould design.

Derived requirements:

- REQ-INT-CER-01 The Design Studio shall provide an interactive toolset enabling students to shape and refine ideas in 3D.
- REQ-INT-CER-02 The Design Studio shall provide an open palette of VR-friendly tools for creating and modifying shapes (freeform and constrained edits).
- REQ-INT-CER-03 The Design Studio shall provide critique-ready visualisation controls (rotate/scale/inspect) and a 3D viewer mode suitable for peer and instructor review.
- REQ-INT-CER-04 The Design Studio shall support VR-native creative engagement (e.g., gesture-based interaction) where appropriate to the learning context.
- REQ-INT-CER-05 The Design Studio shall provide mould design support appropriate for students (templates, guidance, and/or checks).
- REQ-INT-CER-06 The Design Studio should support exercises that help students practice shape creation from memory (e.g., reconstruction tasks).

CNAM (Porcelain), Target group: Stakeholders and students

CNAM focused on the capture and reuse of tacit knowledge, notably craft gestures, as a core asset for design and education. The capability was framed not only as recording, but as replayable data supporting review and iterative improvement. CNAM also highlighted feasibility checking as a practical complement to ideation.

Derived requirements:

- REQ-INT-CNAM-01 The Design Studio shall provide gesture recording for technical craft gestures, capturing 'ghost gestures' involving body, tools, and material interaction.
- REQ-INT-CNAM-02 The Design Studio shall enable playback and visualisation of recorded gestures to support analysis, learning, and design review.
- REQ-INT-CNAM-03 The Design Studio shall support co-design and iterative refinement cycles with practitioners, designers, and consortium partners.
- REQ-INT-CNAM-04 The Design Studio shall provide a mechanism to check feasibility of proposed designs.

PIOP (Silversmith & Marble), Target group: Younger practitioners

PIOP emphasised accessibility and heritage grounding. The Design Studio should reduce barriers for younger practitioners by providing intuitive workflows, design aids that enable communication of ideas, and mechanisms to test design concepts digitally before committing costly materials and time.

Derived requirements:

- REQ-INT-PIOP-01 The Design Studio shall be simple and intuitive, minimising setup effort and reducing interface complexity for newcomers.
- REQ-INT-PIOP-02 The Design Studio shall provide digital drawing/design aids that help new entrants externalise and communicate ideas.
- REQ-INT-PIOP-03 The Design Studio shall support testing designs prior to presentation to craftspeople, enabling iteration without material waste.
- REQ-INT-PIOP-04 The Design Studio should embed a heritage lens where relevant (support for traditional design references for silver and marble crafts).
- REQ-INT-PIOP-05 The Design Studio shall explicitly support resource-efficient iteration (material/time saving use cases).
- REQ-INT-PIOP-06 The Design Studio should support educational collaboration scenarios (e.g., integration into arts education contexts).

MadInEurope (Heritage professionals), Target group: Craftspeople, designers, students, teachers

MadInEurope framed the Design Studio as both a tool and a methodology support layer. Emphasis was placed on reflective practice, learning loops, and the ability to work across disciplines, while maintaining continuity with traditional craft values and heritage contexts.

Derived requirements:

- REQ-INT-MIE-01 The Design Studio shall provide methodological support for craft design that bridges traditional practice and future-oriented making.
- REQ-INT-MIE-02 The Design Studio should include features that promote self-awareness of skills/capabilities and support innovation (reflection and learning loops).
- REQ-INT-MIE-03 The Design Studio shall support cross-disciplinary craft practice by enabling representations and workflows that can be shared across disciplines.
- REQ-INT-MIE-04 The Design Studio should support inspiration and learning for younger practitioners, including integration of 3D scanning and showcase/sharing practices.

FORTH (Computer Vision), Target group: Feature focus (cross-craft)

FORTH highlighted the importance of credibility in digital exploration. The core needs were feasibility evaluation from early representations, rendering realism to ensure trust in previews, and a set of craft simulators to support technique-specific exploration for selected materials.

Derived requirements:

- REQ-INT-FORTH-01 The Design Studio shall provide material/technique feasibility evaluation from early design inputs (including sketches), particularly for wood carving.
- REQ-INT-FORTH-02 The Design Studio shall provide realistic rendering of 3D models to support trustworthy previews.
- REQ-INT-FORTH-03 The Design Studio shall include a pottery simulator focused on shape modification.
- REQ-INT-FORTH-04 The Design Studio shall include woodturning and wood carving simulators.

2.2.3 Analysis of User Experience Requirements

Requirements per partner

The analysis below summarises the major requirements contributed by each partner and highlights cross-cutting themes. This analysis served as the foundation for the Design Studio's UX structure, module taxonomy, and UI template design.

CERFAV, whose primary target group consists of craft students working in the field of glass, framed the Design Studio as an interactive environment that supports early-stage ideation and refinement. Particular emphasis was placed on enabling students to shape and reshape their ideas in three dimensions and to communicate these ideas effectively for critique and discussion. The environment was expected to provide an open palette of tools for creating and modifying forms, including capabilities suitable for immersive contexts. Iterative exploration was considered essential, with strong support for interactive shape alteration. In addition, visualisation tools such as rotation, scaling, and inspection functionalities were regarded as necessary in order to facilitate peer and instructor feedback. CERFAV also stressed the importance of dedicated support for mould design, acknowledging that mould creation often requires technical or engineering knowledge and therefore benefits from guided workflows and specialised tooling within the digital environment.

CNAM, addressing both stakeholders and students in the porcelain domain, emphasised the central role of gesture and process representation in craft design. Their perspective highlighted that craft knowledge is embodied not only in final artefacts but also in the actions and techniques that produce them. As such, they identified the need to capture and record craft-relevant gestures and actions—referred to as "ghost gestures"—originating from the body, tools, and materials. These recordings were seen as valuable resources for both designers and learners, enabling craft techniques to inform design decisions more explicitly. CNAM further stressed that the Design Studio should reflect practitioner and consortium input in its structure and functionality, and that it should be capable of validating design feasibility through craft-informed constraints. Practical examples were considered important, particularly cases where gesture-based understanding directly informs the evaluation of whether a design can be realistically executed within the material and technical limits of porcelain practice.

PIOP, whose focus lies on younger practitioners working in silver and marble, foregrounded simplicity and accessibility. From their perspective, the Design Studio should function as an intuitive design aid that lowers barriers to entry for users with limited digital experience. The ability to draw and design in a straightforward and approachable manner was identified as a core requirement. Simplicity and clarity of interaction were considered fundamental design criteria rather than secondary concerns. At the same time, PIOP emphasised the need to support heritage-oriented design languages relevant to silver and marble craftsmanship. Resource efficiency was another key concern: the ability to test and evaluate designs digitally before presenting them to craftspeople or committing to material production was seen as a means of saving both time and materials, particularly in contexts where resources may be limited.

MadInEurope, working across craftspeople, designers, students, and teachers in a broader heritage context, approached the Design Studio as a methodological bridge between traditional practice and future-oriented innovation. Rather than focusing solely on functional features, they highlighted the importance of supporting the craft design process as a structured methodology. The environment should encourage reflection on skills and capabilities, helping users to become aware of their strengths and identify opportunities for innovation. Cross-disciplinary practice was considered important, particularly in heritage contexts where techniques and materials often intersect. MadInEurope also underlined the potential of 3D scanning and digital culture as entry points for younger practitioners, suggesting that digital tools can serve as inspirational and educational pathways that connect tradition with contemporary forms of engagement.

FORTH contributed requirements primarily related to simulation fidelity and feasibility evaluation. Their emphasis was on ensuring that material behaviour and technical constraints are incorporated into the design process from its early stages. This includes the possibility of performing feasibility checks starting from preliminary representations, such as sketches or early three-dimensional forms. Realistic rendering and physically informed simulation tools were considered necessary to support this objective. In addition, specific simulation modules—such as Paster Turning for shape modification and wood carving simulations—were identified as essential components of a craft-grounded Design Studio experience, ensuring that interaction with digital models remains closely aligned with real-world craft processes.

Cross-partner analysis: common themes and differentiators

A comparative analysis across interviews identified three dominant themes. First, all partners emphasised active support for design and creation, rather than passive viewing. Second, educational integration was consistently cited as a key adoption pathway, requiring learnability, guidance, and critique-ready presentation. Third, resource efficiency (time and material saving) was repeatedly described as a primary value proposition, particularly for expensive or time-consuming materials. In addition to these commonalities, each partner contributed distinct specialised requirements: CERFAV prioritised VR-native shape manipulation and mould support; CNAM prioritised gesture recording and replay; FORTH prioritised feasibility evaluation and realistic rendering; and PIOP/MadInEurope stressed simplicity, heritage grounding, and methodological support for innovation.

2.2.4 Consolidated Requirements and Translation into UX/UI Design

Interview-derived requirements were consolidated into two layers. Layer A defines suite-wide UX/UI requirements that must hold across all tools to ensure coherence and reuse of learned interaction patterns. Layer B captures specialised tool and capability requirements requested explicitly by craft experts and partners. This layered structure was used to translate interview needs into a stable information architecture, a baseline interaction model, and a scalable screen/layout system.

Consolidated requirement sets

Layer A requirements define the common UX/UI baseline, including a project-first workflow, stable navigation, consistent manipulation grammar, embedded guidance, and critique-ready viewing. Layer B requirements define craft-specific capabilities such as mould design support, gesture recording and playback, feasibility evaluation, realistic rendering, and selected craft simulators.

Layer A: Suite-wide UX/UI requirements

- REQ-UX-01 The system shall provide a project-first dashboard (create/open/recent projects) supporting a coherent workflow from ideation to review.
- REQ-UX-02 The system shall maintain a stable information architecture with two primary tool families: Interactive Simulations and Visualization.
- REQ-UX-03 The system shall ensure consistent core interactions across tools (camera navigation, object manipulation, predictable controls).
- REQ-UX-04 The system shall provide embedded learning support within tools (concise guidance, tooltips, and clear error states).
- REQ-UX-05 The system shall provide critique-ready viewing (rotate/scale/present) and clearly communicated tool states to support teaching and peer review.
- REQ-UX-06 The system shall prioritise simplicity and intuitive UI decisions over feature density, with particular emphasis on younger practitioners and new entrants.
- REQ-UX-07 The system shall support resource-efficient iteration through fast preview loops and clear reset/rollback patterns where craft constraints allow.

Layer B: Tool and capability requirements

- REQ-TOOL-01 VR shape creation and modification palette (freeform and constrained edits) for exploratory ideation (CERFAV).
- REQ-TOOL-02 Mould design support (templates, guidance, checks) suitable for students (CERFAV).
- REQ-TOOL-03 Gesture recording and playback (‘ghost gestures’) capturing body/tools/material interactions (CNAM).
- REQ-TOOL-04 Feasibility evaluation from early inputs (including sketches), particularly for wood carving (FORTH/CNAM).
- REQ-TOOL-05 Realistic rendering for trustworthy previews (FORTH).
- REQ-TOOL-06 Interactive craft simulators: pottery shape modification; woodturning; wood carving (FORTH).
- REQ-TOOL-07 Photo Booth rendering workflow: the system shall provide a guided render/output tool within the Visualization Toolbox, including renderer selection(FORTH).

UX/UI design artefacts

The consolidated requirements were operationalised through three primary UX/UI artefacts. First, a user flow defined the top-level information architecture and the navigation pathway from splash screen to dashboard, project actions, and tool families. Second, a tool-level interaction specification established a baseline manipulation grammar for interactive simulations, formalising consistent keyboard-driven tool translation and axis-selected tool rotation (W/A/S/D and, where applicable, Q/E for movement; X/Y/Z + mouse movement for rotation) as the shared control pattern across craft tools. Third, screen-level UI layouts were produced for the dashboard and representative tool pages to demonstrate the navigation structure and provide a scalable pattern for additional tools.

2.2.5 Key UX/UI decisions derived from requirements

In response to REQ-UX-01 and REQ-UX-02, the UI architecture adopts a dashboard-led, project-first workflow and a two-family tool taxonomy (Interactive Simulations and Visualization). The user flow includes project creation and opening, recent projects, project type selection, and a file explorer, followed by entry into the relevant workspace. Workspaces are structured around a toolbar and an object-properties panel to provide a consistent editing context across tools.

In response to REQ-UX-03, the prototype implements a shared interaction grammar for interactive simulation tools and exposes it through an in-tool Help Panel to support learnability and cross-tool consistency. The grammar separates tool translation from tool rotation. For translation, the active tool is repositioned using keyboard input. In Plaster Turning, W/A/S/D translates the tool up/left/down/right (screen-aligned planar positioning). In Wood Carving, W/A/S/D translates the tool forwards/left/backwards/right, and Q/E moves the tool up/down, reflecting the need for depth and vertical control in a subtractive 3D workspace. For rotation, both tools apply axis-selected rotation: the user presses X, Y, or Z to select the rotation axis and then moves the mouse to rotate the tool about the selected axis. This axis-gated mechanism reduces accidental rotations and supports interaction transfer between craft tools. All other on-screen UI controls and tool-specific buttons remain unchanged.

In the Plaster Turning workflow, tool-specific UI controls support adding/removing material, selecting primitive shapes, toggling mass-preserving manipulation, saving and loading templates, and controlling turntable parameters (e.g., speed/animation). These controls complement the shared translation/rotation grammar and respond directly to the interview emphasis on iterative form exploration and educational reuse.

In response to REQ-TOOL-05 and REQ-TOOL-07, the Visualization Toolbox includes a Photo Booth tool that operationalises rendering requirements as a controlled, user-guided workflow. The implemented UI exposes explicit renderer selection (CPU-based rendering as the default option, with GPU-based rendering available where compatible hardware and drivers permit), and a preset selector that governs the output format (Simple OBJ for rapid iteration; optional Textured OBJ when UV-mapped textured output is required). The workflow requires the user to select the relevant input files prior to initiating rendering and provides an integrated Guide entry point to support first-time users. This design translates the interview requirement for trustworthy visual previews into an implementable pipeline while preserving a consistent, low-friction interaction pattern across the suite.

2.2.6 Summary of findings

A comprehensive design environment for craft practice must integrate the strengths identified by the participating organisations. These include immersive and interactive shaping of forms, the recording and representation of gestures, realistic rendering of materials and surfaces, and the evaluation of feasibility in relation to specific craft techniques. To be meaningful in both educational and professional contexts, such an environment must remain flexible. It should accommodate established, tradition-based workflows while also supporting experimental and innovation-oriented design processes.

As user requirements for the Design Studio were progressively collected and refined, the corresponding software architecture evolved in parallel. The technical preparation focused on defining and implementing software modules capable of supporting the identified needs. Two central principles guided the development of the design aids. First, the produced designs should exhibit a realistic visual appearance, enabling users to anticipate how artefacts would look once materialised. Second, the designs should be craft-specific. This means that they are not merely geometrically plausible, but realistically producible within the techniques, constraints, and material behaviours of the craft domain to which they belong.

In Deliverable 5.1, these principles led to the proposal of two complementary software modules. The first consists of a visualisation toolbox aimed at realistic rendering and inspection of artefacts. The second concerns the interactive simulation of crafting techniques. The latter introduces craft-informed constraints into the design process, guiding users to create forms through methods that simulate actual craft procedures. In this way, feasibility is embedded within the creative act rather than evaluated only at a later stage.

The visualisation toolbox developed in D5.1 has since been used to create applications that simplify the generation of artefact designs and support the prediction of their final appearance. Through a series of utility applications addressing both traditional and novel craft products, the feasibility of this approach has been demonstrated. These applications illustrate how realistic rendering and craft-aware modelling can function together as a coherent design aid.

Across all partners, several shared needs became apparent. There was consistent emphasis on active interaction as the foundation of design and creation. Rather than limiting users to viewing or importing predefined models, the environment should allow them to shape, modify, and iteratively refine artefacts. This interactivity is essential not only for professional experimentation but also for learning contexts, where understanding emerges through manipulation and feedback.

Educational integration was another common priority. The Design Studio must operate effectively within training environments, supporting critique, guidance, and progression from novice to more advanced skill levels. In this respect, usability and clarity of interaction are not secondary considerations but structural requirements.

Resource efficiency also emerged as a recurring value proposition. By enabling early feasibility checking and iterative exploration in digital form, the system reduces unnecessary material consumption and saves time otherwise spent on unsuccessful prototypes. This aspect is particularly significant in crafts where materials are costly or labour-intensive.

At the same time, partners stressed that advanced functionality must not compromise accessibility. The environment should remain intuitive for students and younger practitioners, even while supporting more complex features. This tension between simplicity and extensibility informed the adoption of consistent user interface templates and predictable interaction patterns across modules.

In addition to these shared requirements, several needs were specific to particular craft domains, such as mould design support, gesture recording, or specialised feasibility checks. These domain-specific demands reinforced the decision to adopt a modular architecture. A common platform layer provides shared navigation logic, user interface structures, and data persistence and export mechanisms. On top of this layer, craft modules implement domain-specific interactions, simulations, and constraints. Such a structure allows new modules to be added or existing ones to be expanded without redesigning the entire user experience.

The alignment of requirements directly informed the outputs developed between M18 and M36. A coherent user journey was defined, typically moving from a dashboard to module selection and then to a dedicated workspace. The separation between Interactive Simulations and the Visualisation Toolbox was established as a high-level functional distinction. Consistent workspace interface patterns were introduced to host multiple craft modules within a unified environment. Furthermore, implementation priorities were defined, leading to the delivery of specific craft modules—such as Paster Turning and wood carving simulations—by M36, while additional tools, including extended visualisation outputs, were specified for subsequent integration.

3 Design tools

The design tools reported in this section are implemented as modular craft-design services, intended to support early-stage ideation while remaining grounded in craft-feasible operations. In practical terms, we structure design interaction around a small set of elementary craft actions: adding material, removing material, shaping by constrained motion, transforming surfaces, and interlocking parts. These action primitives are reusable across domains and can be composed into craft-specific workflows.

A key design choice is that the tools do not only output geometry; they also aim to maintain a process-aware representation of how a form was created. This aligns the "design record" with the craft act, and supports two recurring requirements from our elicitation: (i) active, iterative interaction, and (ii) feasibility grounding through craft-specific simulators and constraints, rather than post-hoc checks. These tools connect to the craft-specific simulation toolkit (WP3, D3.1) and draw on knowledge assets.

3.1 Additive construction tools

Additive operations are essential in craft design because they support rapid exploration of form and local corrections (e.g., adding clay during wheel-based shaping). In our implementation, additive modelling is treated as a first-class action, compatible with real-time preview and later hand-off to visualisation and fabrication steps (Sections 4 and 5).

The following figure points to a short demonstrator showing additive construction in the Design Studio. The example emphasises fast, reversible exploration: material is "built up" in a controlled way so that a novice user can prototype a volume and then refine it through subsequent subtractive and shaping tools.

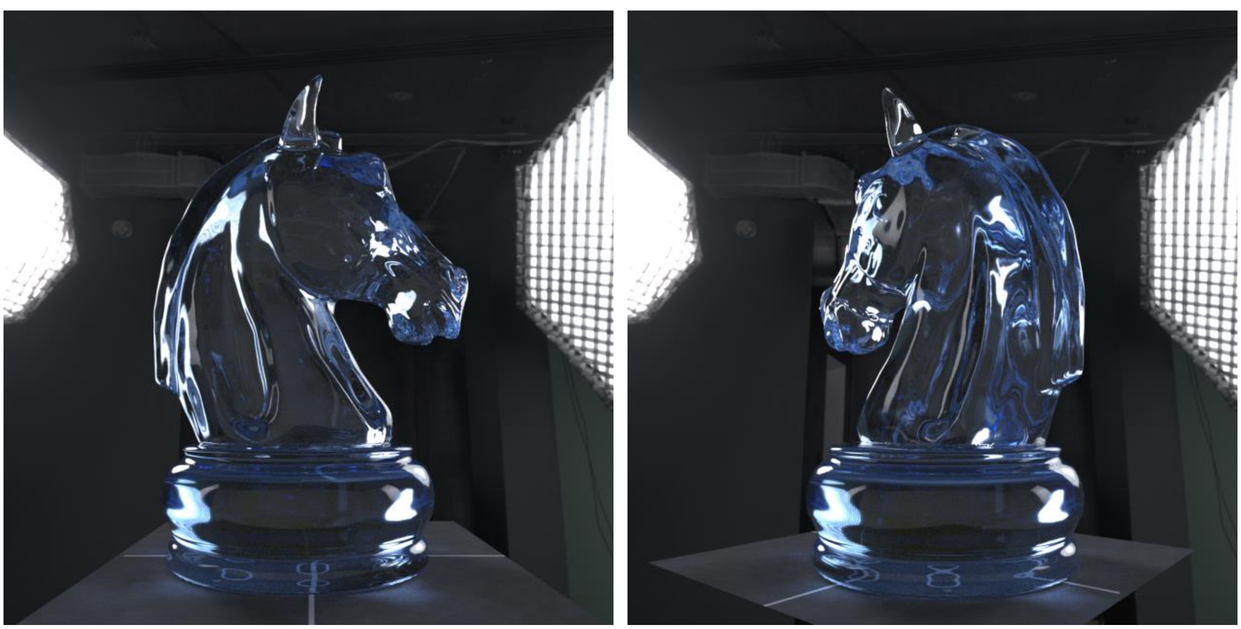


Figure 2. Additive modelling demonstrator within the Design Studio. Video: https://youtube.com/shorts/EInULaUCWtk

Additive construction is closely connected to mould-centric workflows, where the designer must reason not only about the final artefact, but also about part separation, extractability, and the geometry that will be physically fabricated. The following figure illustrates mould-related design support as it appears in the Design Studio toolchain.

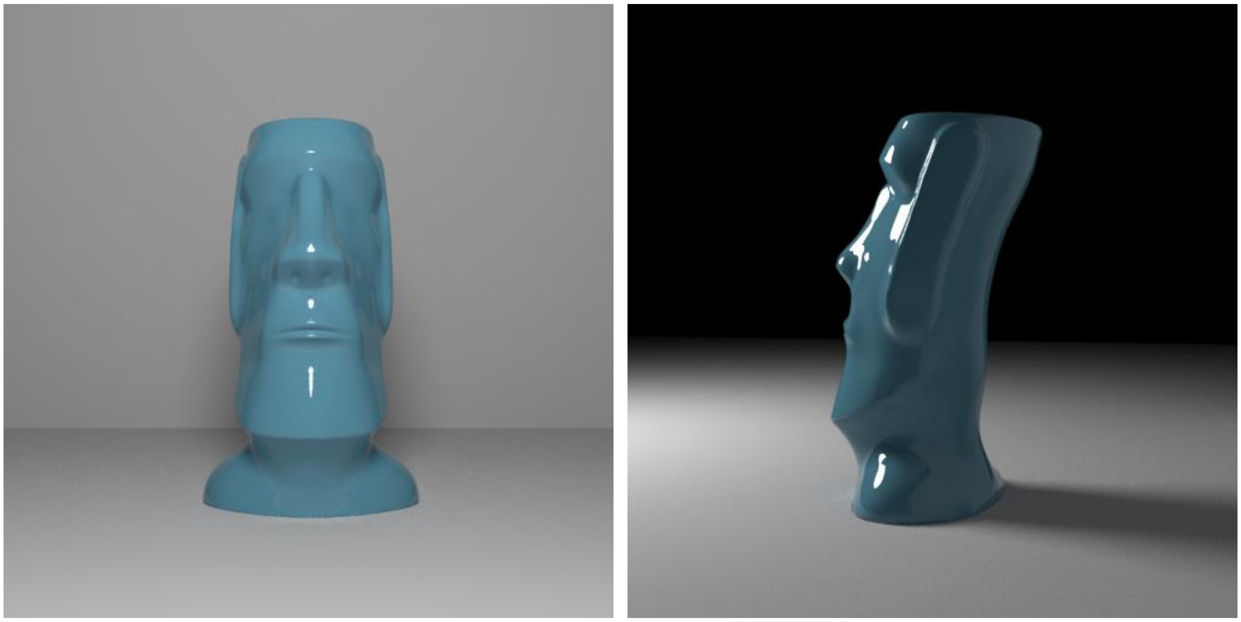


Figure 3. Moulds. Design Studio support for mould-oriented workflows.

3.2 Subtractive and shaping tools

Subtractive and shaping operations implement the core idea of craft-specific interactive simulators: a digital form is modified through operations that correspond to real craft actions, so that the created object remains meaningful from a practitioner's perspective. This is achieved by specialising elementary actions (add, subtract, shape) to craft contexts, while relying on conventional game-engine capabilities for rigid-body kinematics and collisions when appropriate. At M36, we demonstrate this approach in turning scenarios (pottery and woodturning) and in a craft-specific glass shaping example.

3.2.1 Solids by revolution: pottery shaping

In pottery, the wheel enables an efficient design space: many vessels are well-described as solids of revolution, but crucially the craft action is not "editing a mesh"; it is redistributing material under constraints. We therefore implement a volumetric editor where a mass-preserving tool supports shaping that resembles the real practice. Additive and subtractive actions are also available, reflecting real interventions during turning (e.g., adding clay or removing material, supported by wetting and re-homogenisation).

The figure demonstrates how the tool maintains, in parallel, (i) a photorealistic preview that updates in real time and (ii) an internal volumetric representation used for shaping and constraint handling. This dual representation supports rapid iteration while keeping the modelling grounded in the craft action.

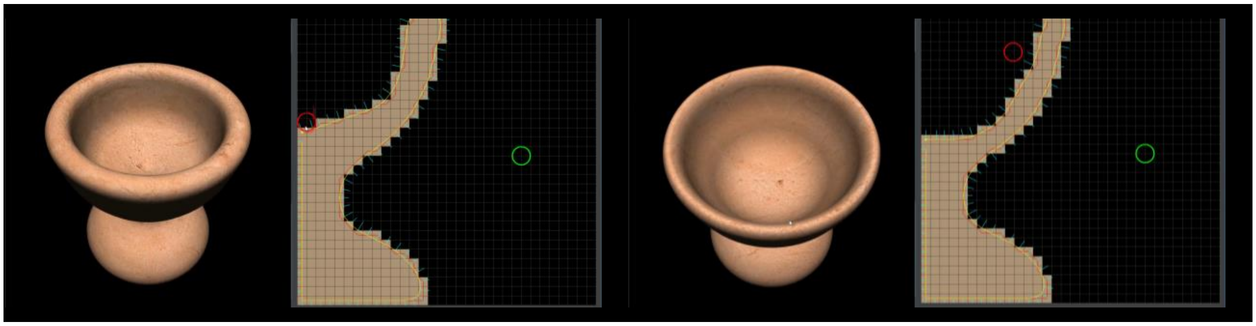


Figure 4. Pottery shaping by solids of revolution: real-time rendering (left) and maintained internal representation (right). Video: https://youtu.be/Yc7FtCdOeSs

3.2.2 Solids by revolution: woodturning replication (honey dip)

In woodturning, the interaction is fundamentally subtractive: material removal is irreversible, and the shape emerges from tool trajectories applied to a rotating blank. We demonstrate craft-specificity by following a recorded exemplar (honey dip creation) and recreating its main shaping stages digitally. Tool assets (e.g., corner chisel and round gouge) are linked to their knowledge entries so that the design activity can be interpreted in relation to real tools and their use.

Figure 5 provides keyframes from the reference making process used as an exemplar. These frames act as an operational "specification" for the digital recreation, linking the output geometry to a recognisable craft sequence.

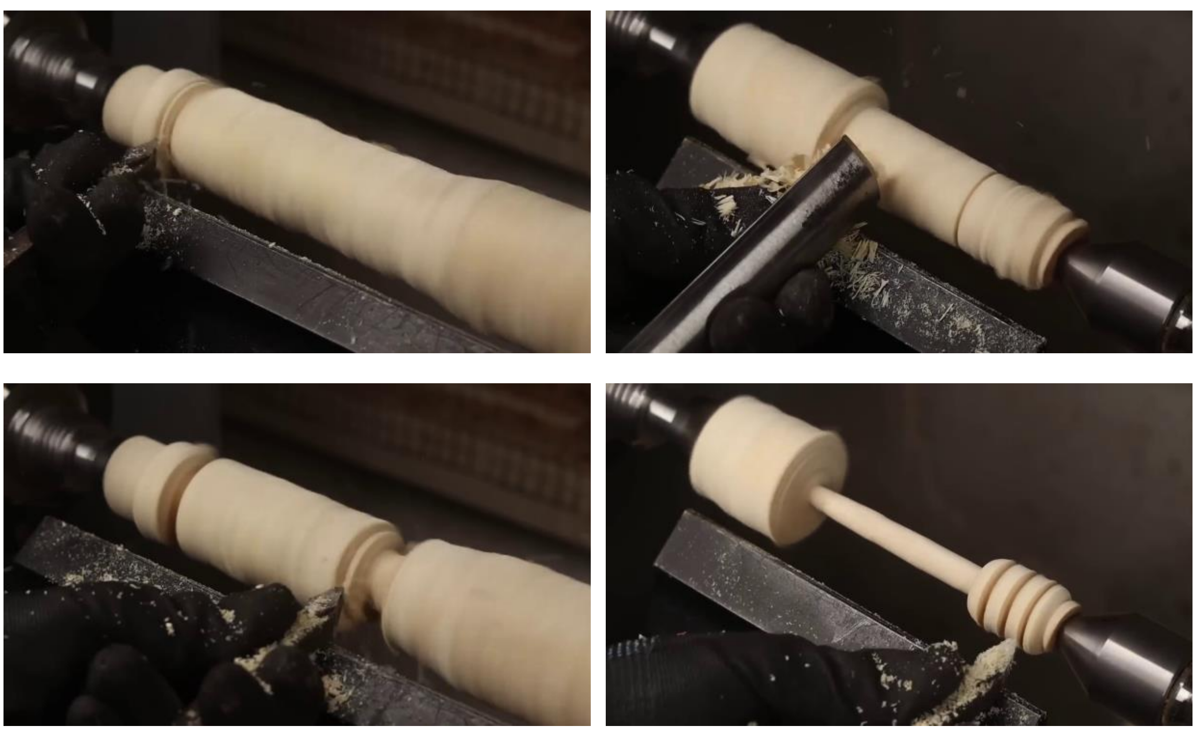


Figure 5. Woodturning exemplar: keyframes from a honey dip creation sequence.

Figure 6 shows the corresponding virtual recreation: the designed object is produced through craft-oriented subtractive steps that mirror the exemplar's structure. This establishes that the tool is not only producing a plausible 3D shape, but is doing so through a process that resembles the practice it models.

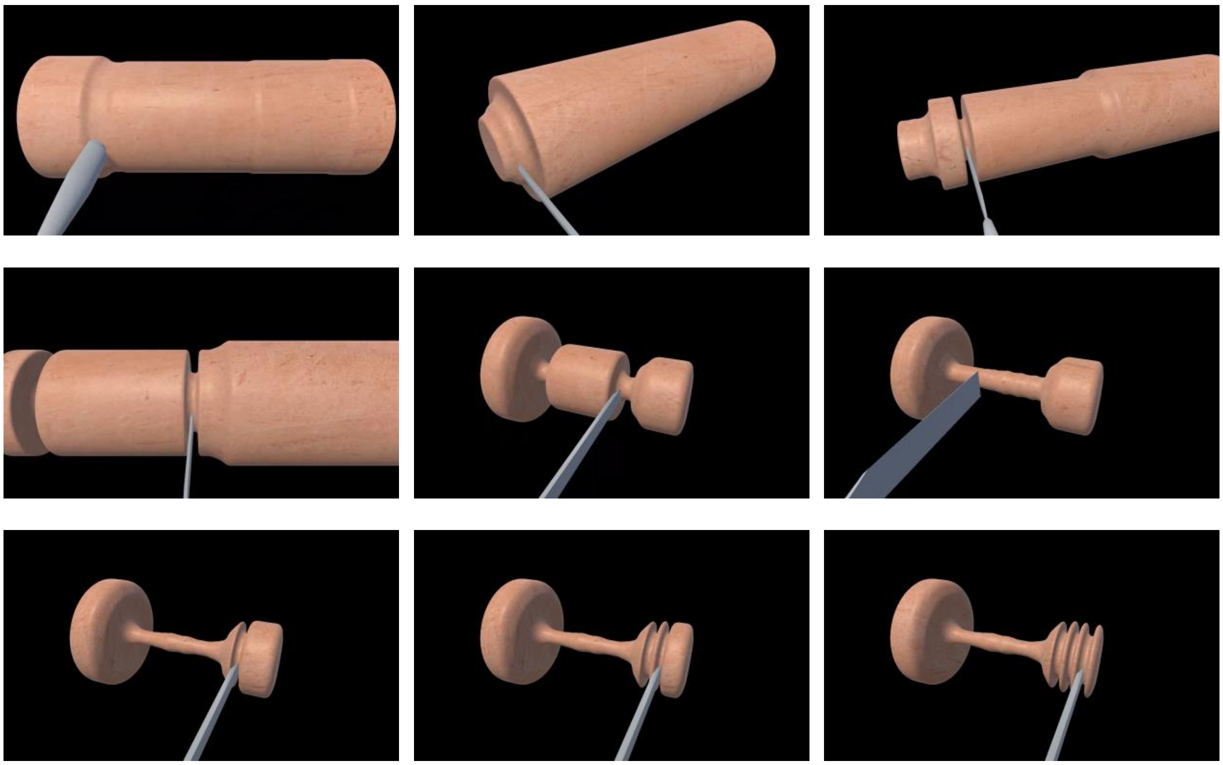


Figure 6. Virtual, craft-specific design of a honey dip. Video: https://youtu.be/U99i7hgC0g0

3.2.3 Solids by revolution: glass foot shaping under viscous constraints

In glassworks, rotational motion is used both to manage deformation under gravity and to shape highly deformable material. However, the craft constraints differ substantially from pottery: the effective axis may be moving, angular velocity may be intentionally varied, and shaping often involves coordinated two-tool interaction that, in reality, may require two practitioners acting synchronously.

Figure 7 illustrates a craft-oriented simulation of the foot-shaping step of a glass vessel. Two viewpoints are shown to support critique-ready inspection, and to make clear that the design tool captures the multi-constraint nature of the action.

Two tools are used and their 3D models are obtained from the CAP, namely: Battledore and Jacks. In Figure 7, 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.

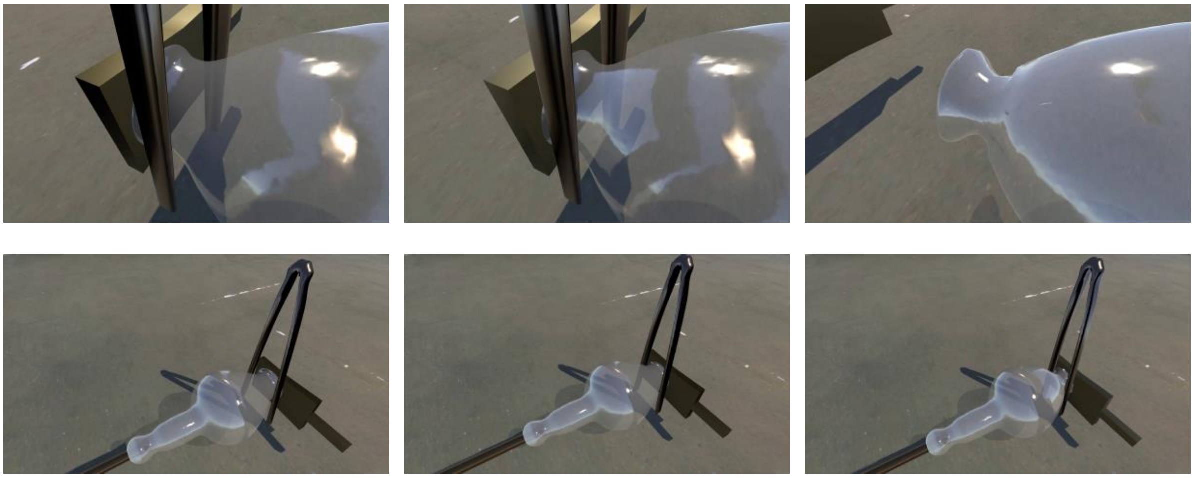
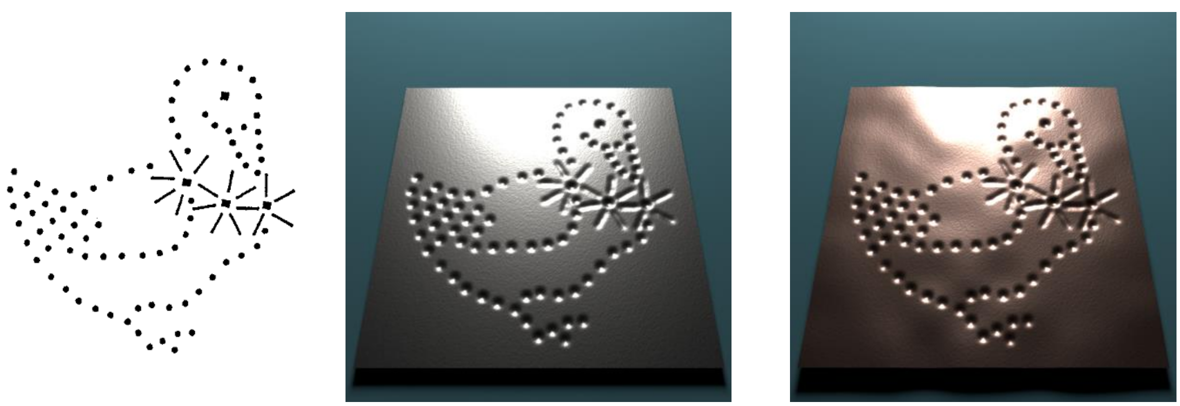


Figure 7. Interactive, craft-oriented simulation for shaping a glass vessel foot (two viewpoints). Videos: https://youtu.be/Bt0Xo5d-VCQ and https://youtu.be/OzXdKQdLfg8

3.3 Transform tools

Transform tools address design operations where the primary change is neither bulk addition nor bulk subtraction, but a controlled transformation used to introduce ornamentation, texture, or functional relief. In Craeft, these tools are particularly relevant because they connect craft practice to downstream visualisation (Section 4) and to fabrication preparation (e.g., engraving workflows in Section 5).

Tin punching is used here as a validation of generality: a surface deformation method can reproduce a wide variety of relief styles and intensities without changing the overall object topology. The figure serves as a “palette” of achievable deformations, supporting the idea that the same transform mechanism can be reused across multiple ornamentation scenarios.



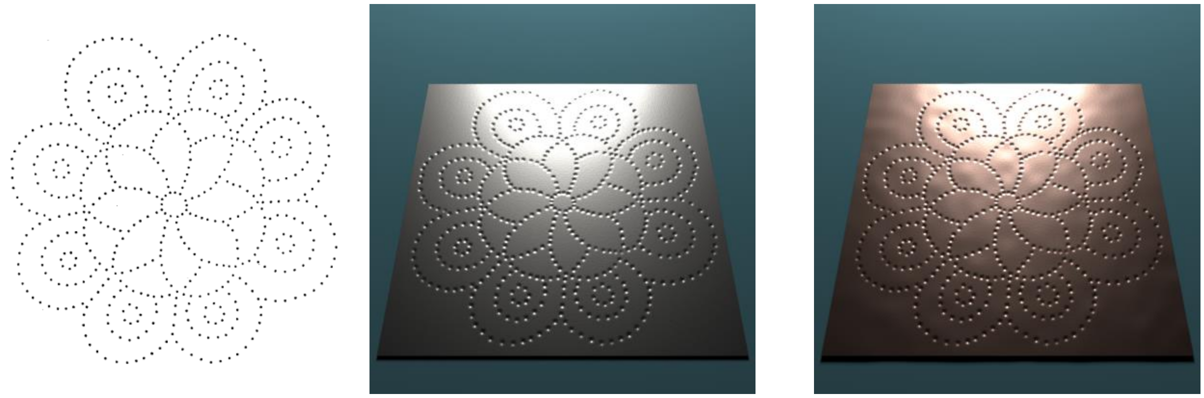


Figure 8. Transform tool example (tin punching): range of punched relief patterns illustrating breadth of surface deformations.

3.4 Interlock tools

Interlocking is a recurring craft principle: an artefact is assembled from parts whose geometry and tolerances must be mutually compatible. We treat interlocking in two complementary regimes: (i) rigid part compositions (e.g., stained-glass camework-like assembly), and (ii) woven compositions (textile patterns), where interlock is defined by a repeated topological pattern.

3.4.1 Interlock: rigid compositions from image-based designs

For rigid compositions, a practical entry point is to begin from a design image and convert it into a set of manufacturable parts: a supporting frame (skeleton) and the pieces that will be inserted into it. This bridges a familiar 2D design practice with a 3D, part-based representation suitable for preview and further processing.

The figure demonstrates the conversion from an original image to a structured stained-glass-like composition: the derived parts make interlock explicit and provide a design representation that can be inspected, edited, and later previewed photorealistically.

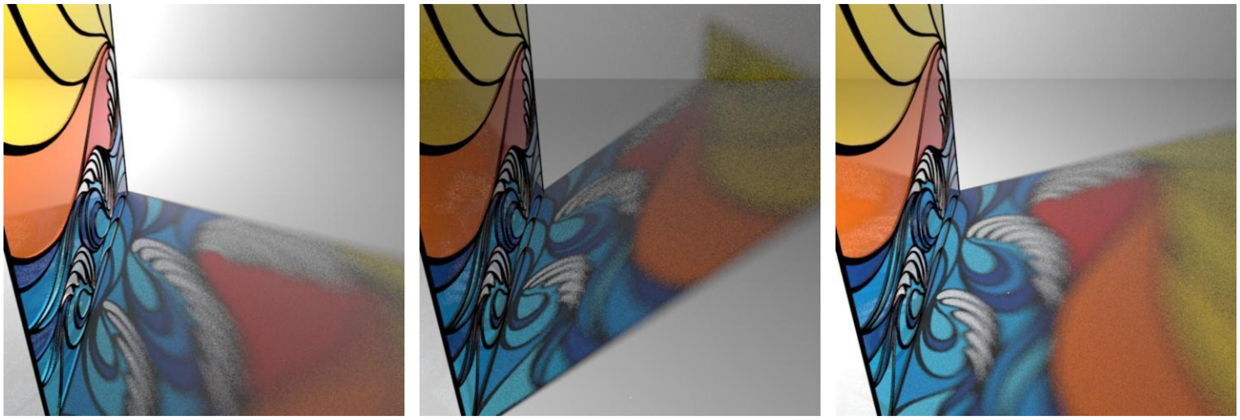


Figure 9. Image-to-interlocking composition and derived stained-glass-style part structure.

3.4.2 Interlock: woven compositions

To support textile design, we build on the weaving simulator (WP3, D3.1) and provide a UI that allows users to configure a weave and preview the resulting pattern. This supports learnability (clear parameterisation) while enabling rapid iteration on colour and structure.

Textile design begins with a concise configuration step: users choose the number and colours of wefts and the weave type. This establishes a controlled design space that can be expanded with additional patterns (e.g., satin, twill) without changing the overall workflow.

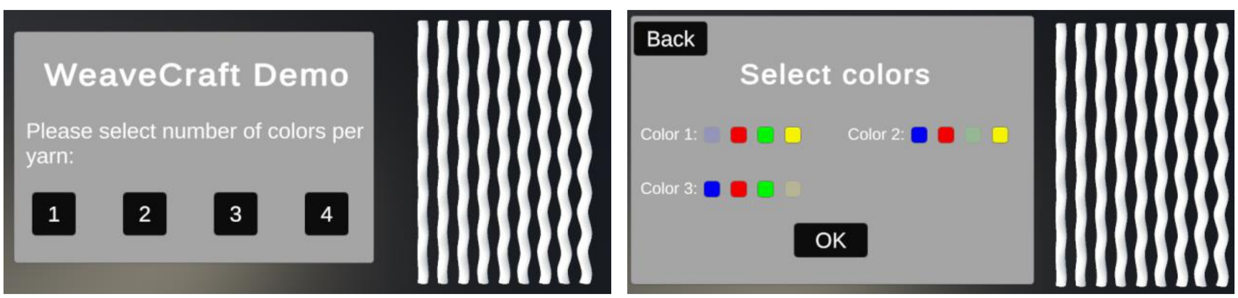


Figure 10. Textile design tool: configuration screen for weaving simulation.

After configuration, the simulator provides real-time visual feedback of the emerging pattern. This immediate preview supports resource-efficient iteration by letting users explore combinations before committing to physical weaving.

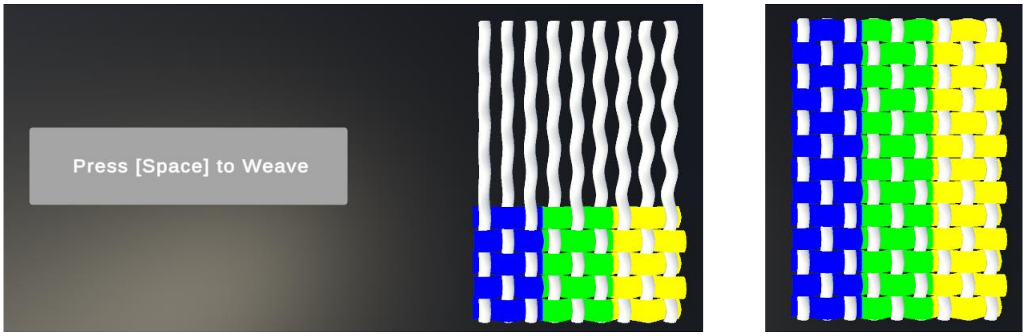


Figure 11. Textile design tool: real-time simulated weaving preview for the selected pattern and colour sequence.

4. Visualisation tools

This section presents Craeft visualisation tools that provide critique-ready, photorealistic previews of craft designs under controlled lighting and environments. The aim is pragmatic: to let users assess material appearance (transmission, reflection, tint, roughness, glazing), scale and placement (how an object reads in a room), and design alternatives (material variants, colour choices, configurations) before committing to labour-intensive craft steps or fabrication. In the broader Craeft toolchain, these visualisation utilities reuse the rendering and material capabilities developed in other work packages (notably WP3; see also D3.1 where relevant), but package them into craft-facing workflows.

4.1 Moulded, cast, and sculpted objects

This category targets crafts where (i) geometry is available as a 3D model (e.g., from modelling or scanning) and (ii) the key uncertainty is appearance: how the same form reads when realised in different materials (metal, glass, plastics) and placed in different environments. The examples below use scanned sculpture geometry and demonstrate rapid exploration of material hypotheses.

Figure 12 compares the original scanned surface with photorealistic renderings that treat the same geometry as different materials. This supports a common design task: separating "shape decisions" from "material decisions", while still previewing their interaction. The original artefact can be found in the CAP here, as well as the entry for the artist, Yannoulis Chalepas.

Figure 12. Photorealistic renderings of the same sculpture realised as gold, colourless glass, and matte white 3D-printed plastic (matched viewpoint).

Material appearance is viewpoint dependent, especially for specular and transmissive media. The next figure therefore shows peripheral views to support qualitative inspection of highlights, reflections, and silhouettes.

Figure 13. Peripheral views of the three material variants from Figure 12, shown under the same environment lighting and camera settings

Beyond single-material objects, the toolbox also supports multi-part designs, where interlocking pieces are assigned different materials. This is essential for many composite artefacts; e.g., glass + metal, or plastic + metal assemblies.

The software can be used to predict the appearance of more complex structures made from multiple materials. In Figure 14, shown are the renderings of a sculpture made from two interlocking pieces, one made out of glass, plastics, and metals, from different viewpoints.

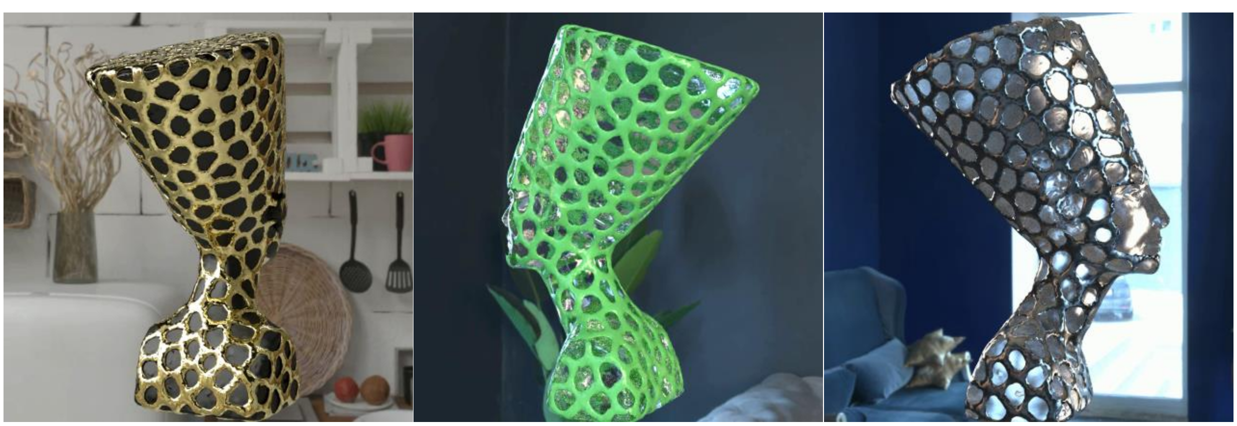


Figure 14. Multi-material preview of a two-part (interlocking) sculpture: renderings from multiple viewpoints showing distinct material assignments per part.

To complement still images, we also provide 360° turntable videos for selected material pairings so users can judge appearance continuously across view angles, in Table 1.

Table 1. 360° turntable videos for selected multi-material renderings.

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

4.2 Industrial exemplars

Industrial glass products are useful "sanity checks" because they combine controlled geometry with visually sensitive structure (ribs, grooves, repeating patterns). They therefore stress-test how reliably the pipeline renders thin features, repeated structure, and directional reflections/transmission.

Fluted glass is a canonical case where geometry drives perception: small, repeated corrugations strongly affect the apparent translucency and distortion of the background.

Figure 15. Fluted glass exemplar rendered with physically plausible transmission and surface reflections.

Glass tiles provide another industrial reference: planar elements with regular geometry that amplify highlight behaviour and inter-reflections, making them well suited for visual comparison across lighting setups.

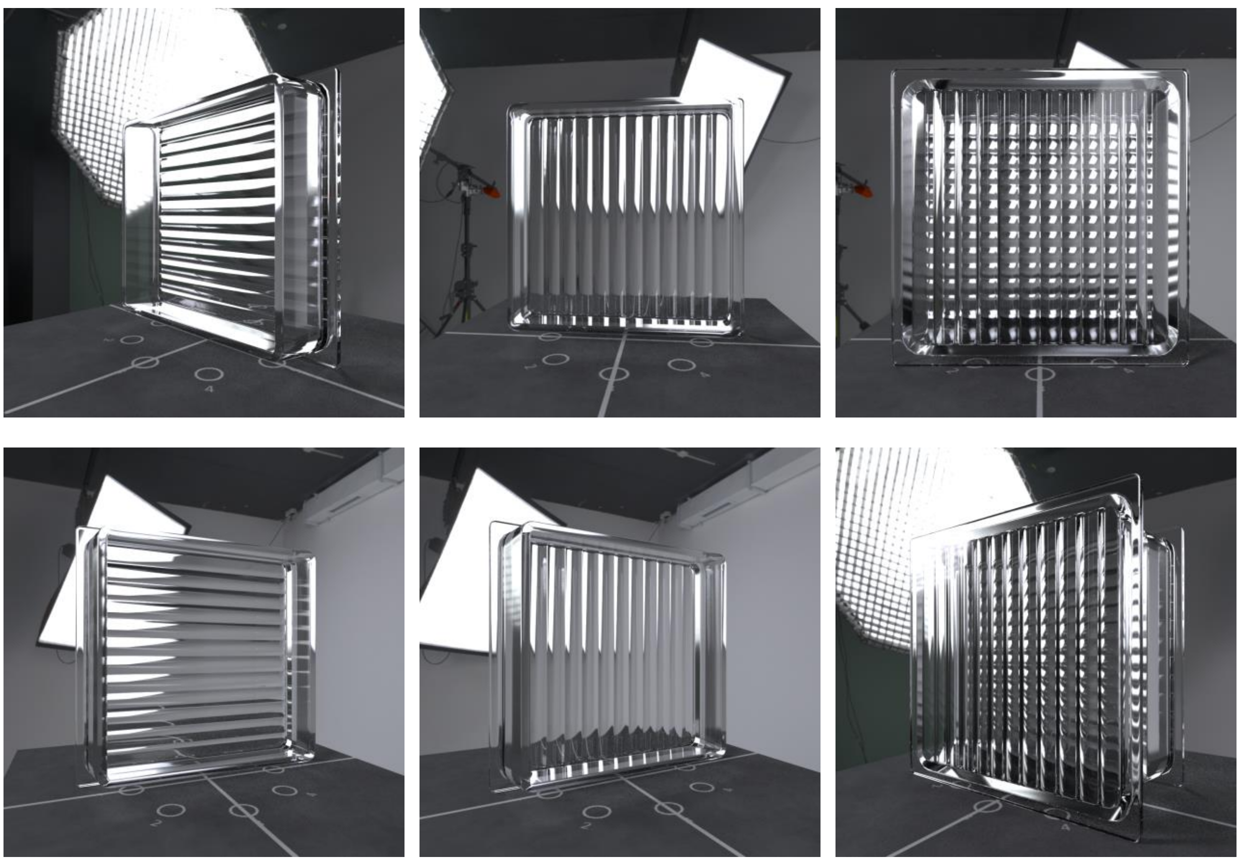


Figure 16. Glass tile exemplar rendered to illustrate repeated geometry, specular response, and appearance under environment lighting.

4.3 Glass bodies

For glass bodies such as bottles, the design problem is often an interplay between profile geometry and material response. The following figures demonstrate quick iteration across alternative bottle forms. The first figure shows a set of candidate bottle geometries rendered under consistent conditions to support shape comparison.

Figure 17. Bottle design variants rendered under the same camera and lighting configuration for geometry-driven comparison.

The second figure extends the comparison with additional designs and/or viewpoints, supporting assessment of silhouette stability and highlight behaviour.

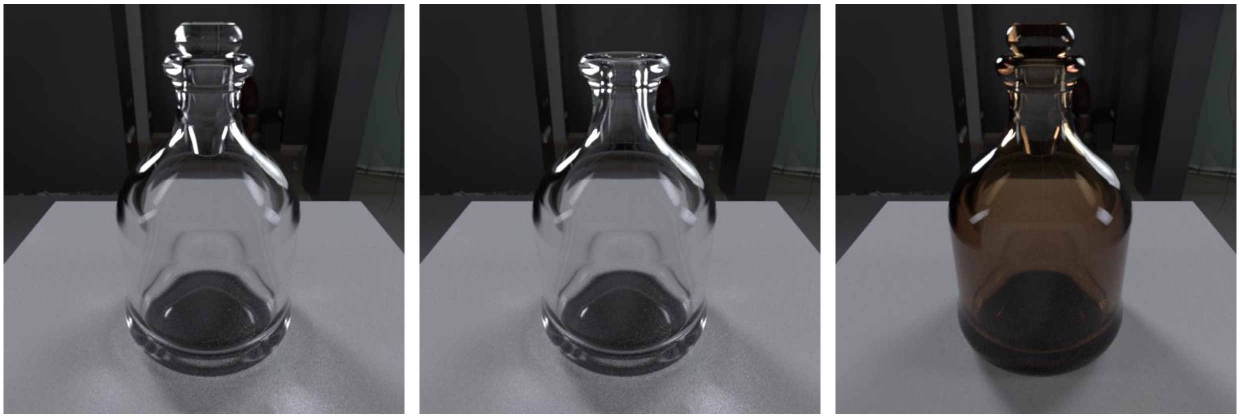


Figure 18. Additional glass bottle design previews (consistent environment lighting; alternative viewpoints and/or shapes).

4.4 Stained glass windows

Stained glass is a particularly demanding visualisation case because it requires modelling coloured transmission and its consequences in context: the window itself, the outdoor illumination, and the projected coloured light patterns within the interior. We therefore provide a specialised stained-glass application that converts a design into a 3D window model, assigns glass-piece colours/materials, and renders the assembled window in a built environment. At a high level, the workflow is:

1. segment an input design image into regions of approximately uniform colour (the current implementation uses [1], but the pipeline is modular),
2. compute a representative colour per region (e.g., in HSV),
3. instantiate the corresponding glass pieces and a supporting frame (with configurable frame material), and
4. render the full scene, including indoor appearance and colour projections due to transmitted light.

The following figure shows two end-to-end examples. For each: we present the input design, a close-up of the window rendering, and a wider interior view to show how the window reads once installed.

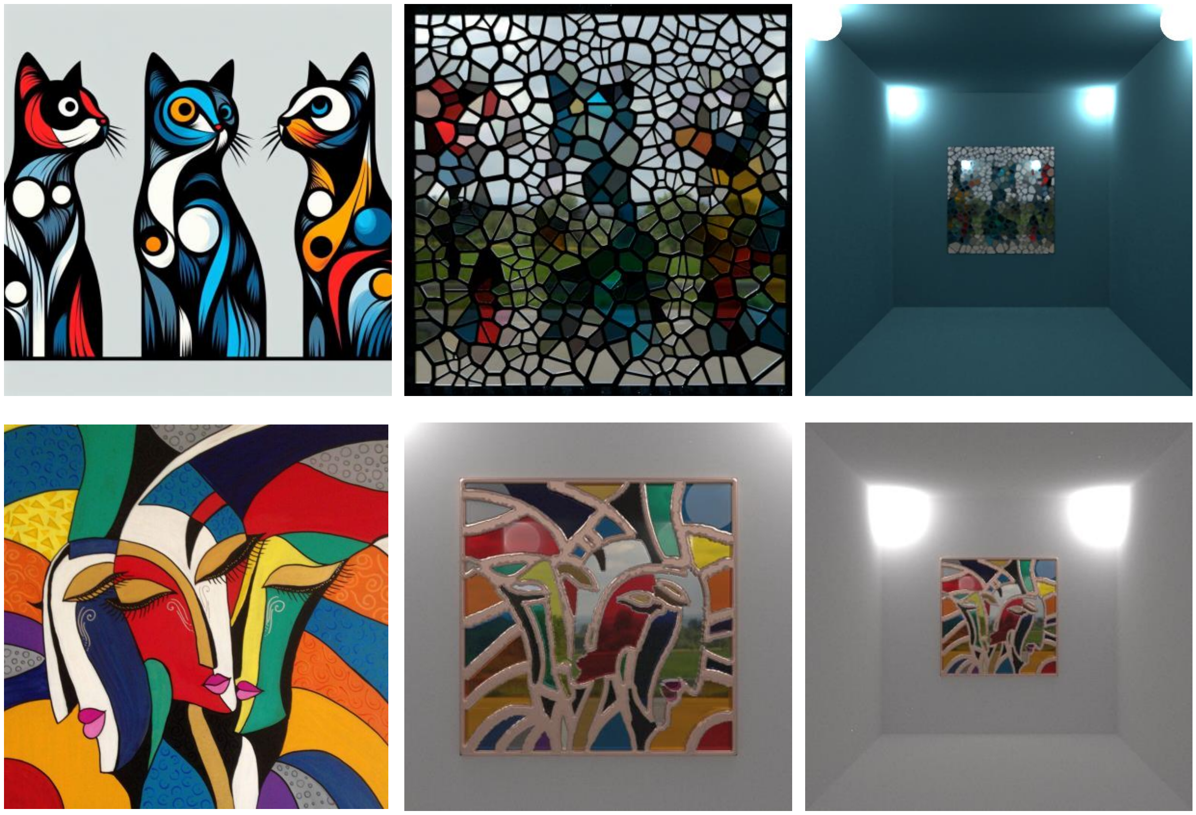


Figure 19. Stained-glass window preview examples. Left: design input. Middle: close-up photorealistic rendering of the window. Right: wider interior view showing the installed window and its lighting context. (Top: printed-plastic frame variant; bottom: rough copper frame variant.)

In addition to full-scene renderings, the designer provides a direct view of the derived piece structure. This supports manual edits and design iteration before photorealistic rendering. 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 20).

Figure 20. Stained-glass designer for glass-piece structure, frame placement, and rendering configuration.

4.5 Tiffany lamps

Tiffany lamps reuse the same core idea—piecewise coloured glass assembled on a frame, but the visual question shifts from “window projection” to ambient lighting: how the shade filters a nearby light source and colours the surrounding space. We therefore provide a variant of the stained-glass workflow configured for lampshade geometry and interior ambience.

The figure demonstrates photorealistic ambience previews for a Tiffany-style lampshade, enabling assessment of colour balance, brightness, and the overall “mood” created in a room.

By creating a variant of the method for the stained-glass windows we can design Tiffany lamps and preview the ambience they create (Figure 21).

Figure 21. Photorealistic renderings of a Tiffany-style lamp in an interior environment. Video: https://www.youtube.com/shorts/Crfac6MLmyQ

4.6 Novel products

Beyond canonical craft categories, the visualisation toolbox supports rapid prototyping of new product concepts by combining material models, textures, and environments. We provide two illustrative examples: (i) planar semi-transparent screens assembled from parts, and (ii) a multi-piece assembly sculpture derived from a 2D artwork.

Figure 22 demonstrates how semi-transparent or translucent components can be evaluated for their light-shaping effects (coloured projections and soft shadowing), and then previewed as a complete artefact viewed from both sides.

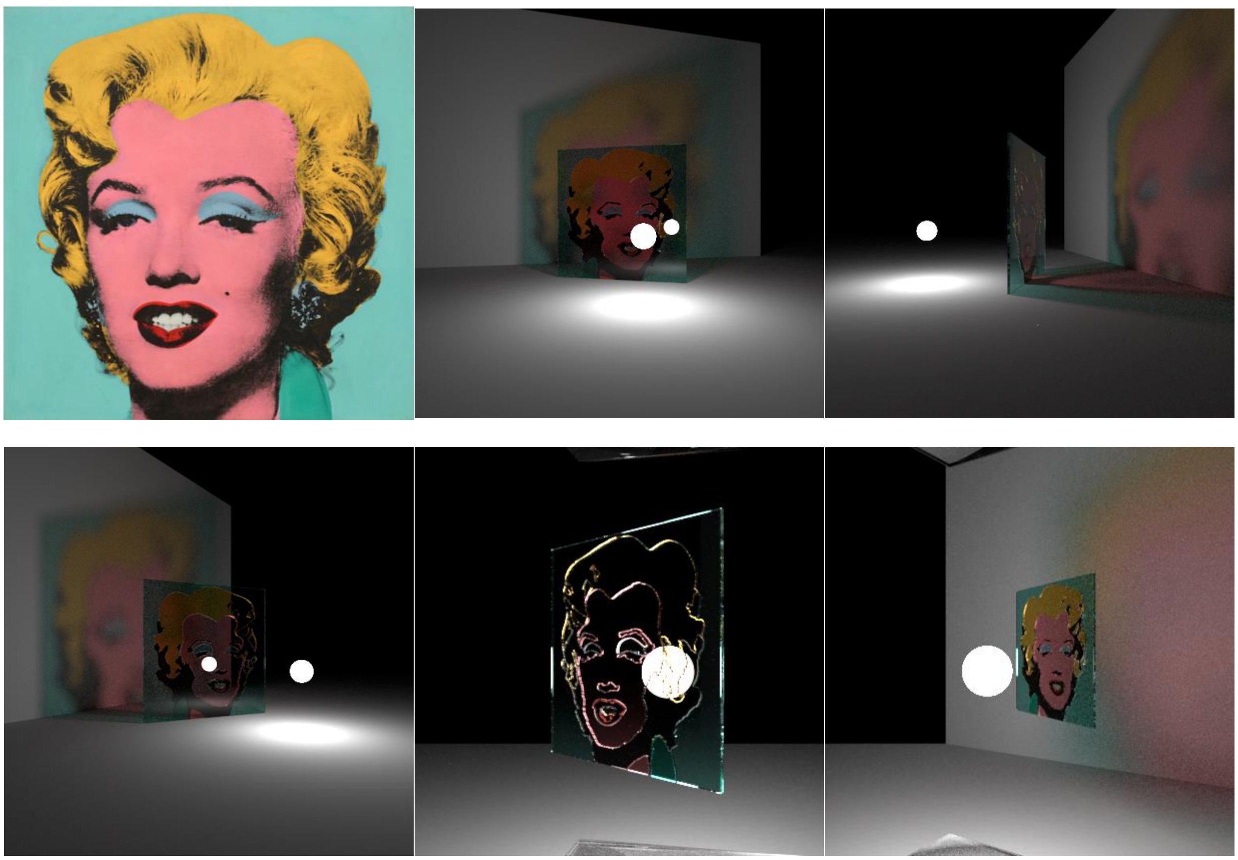


Figure 22. (Top rows) controlled simulation experiments illustrating light interaction with a tilted coloured pane and receiving surfaces. (Bottom row) photorealistic previews of the designed artefact in specific environments, shown from both sides. Video: https://youtu.be/vKlDdEHxMqA

The second example extends the same idea to multi-piece assemblies: a colour-segmented artwork is converted into separate printable solids (one per colour) and previewed both as a filament print and as a higher-fidelity resin print. The assembly sequence is shown to make the practical interlocking constraints explicit.

Figure 23. Multi-piece printed sculpture concept derived from segmented artwork. Top: assembly steps and final result previewed as matte filament prints. Bottom: photorealistic prediction of the same structure as if printed using semi-transparent coloured resins.

4.7 Cane working

Cane working in glassblowing uses coloured rods (canes) that are arranged and twisted to generate intricate, often spiral patterns. Because small parameter changes can substantially alter the perceived pattern, a preview tool is valuable before committing to the physical process.

Figure 24 shows example cane-work designs generated by specifying cane count, layout/shape, dimensions, and a twist parameter, then rendering the resulting object photorealistically.

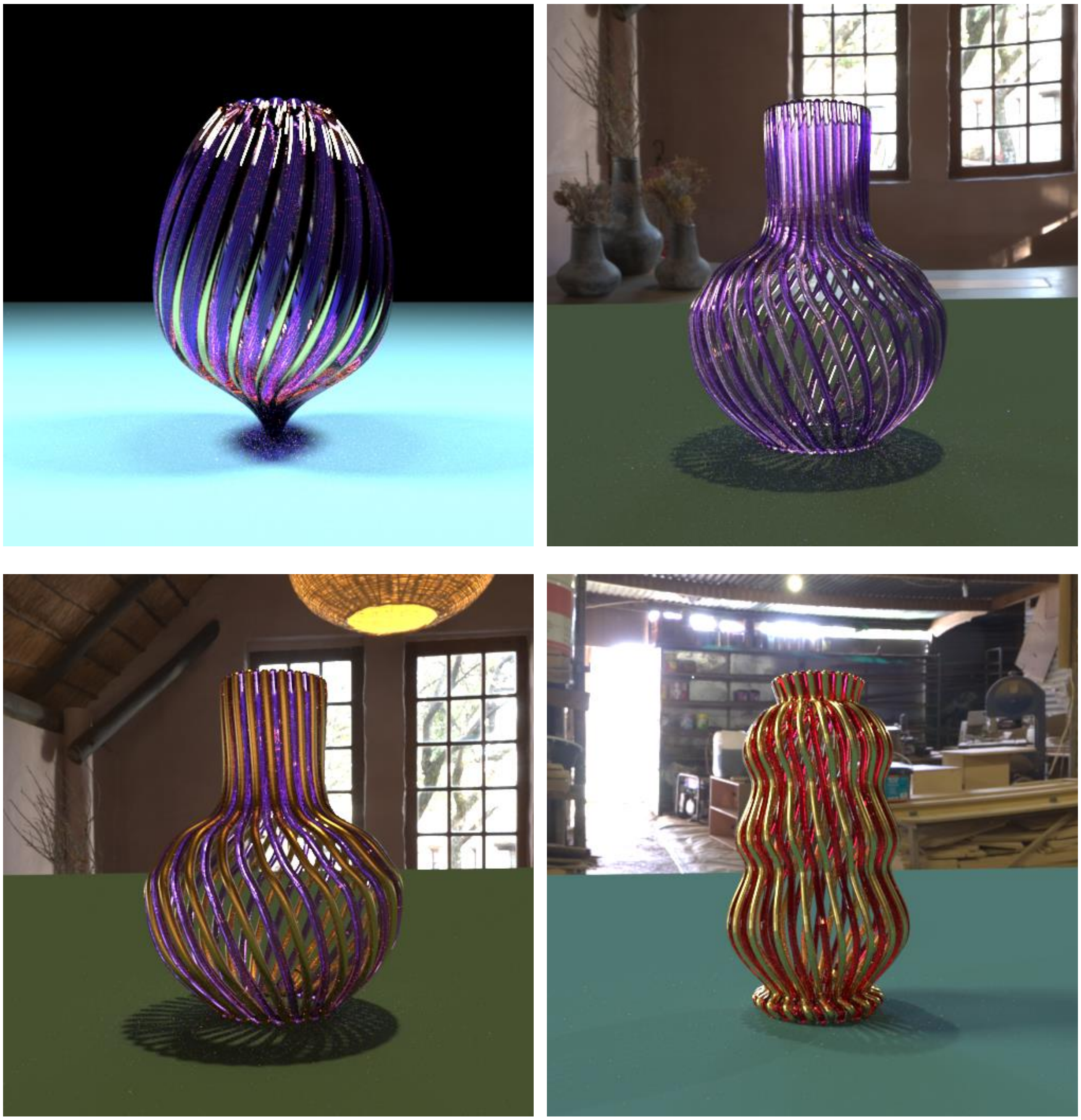


Figure 24. Photorealistic renderings of example cane-work compositions generated from user-specified cane geometry and twisting.

4.8 Metal engraving

Metal engraving is a representative case of design-by-surface-transformation: the designer starts from a 2D motif and controls how it becomes a relief (depth profile) that will be read as engraving on a metal sheet. The Anaglyph Creator supports this by converting a 2D pattern into a 3D engraved model, exposing key parameters in a GUI, and rendering the result in realistic environments and material variants. The figure illustrates the workflow: parameterised engraving in the GUI (top), and photorealistic previews of the engraved sheet in a realistic scene (bottom).

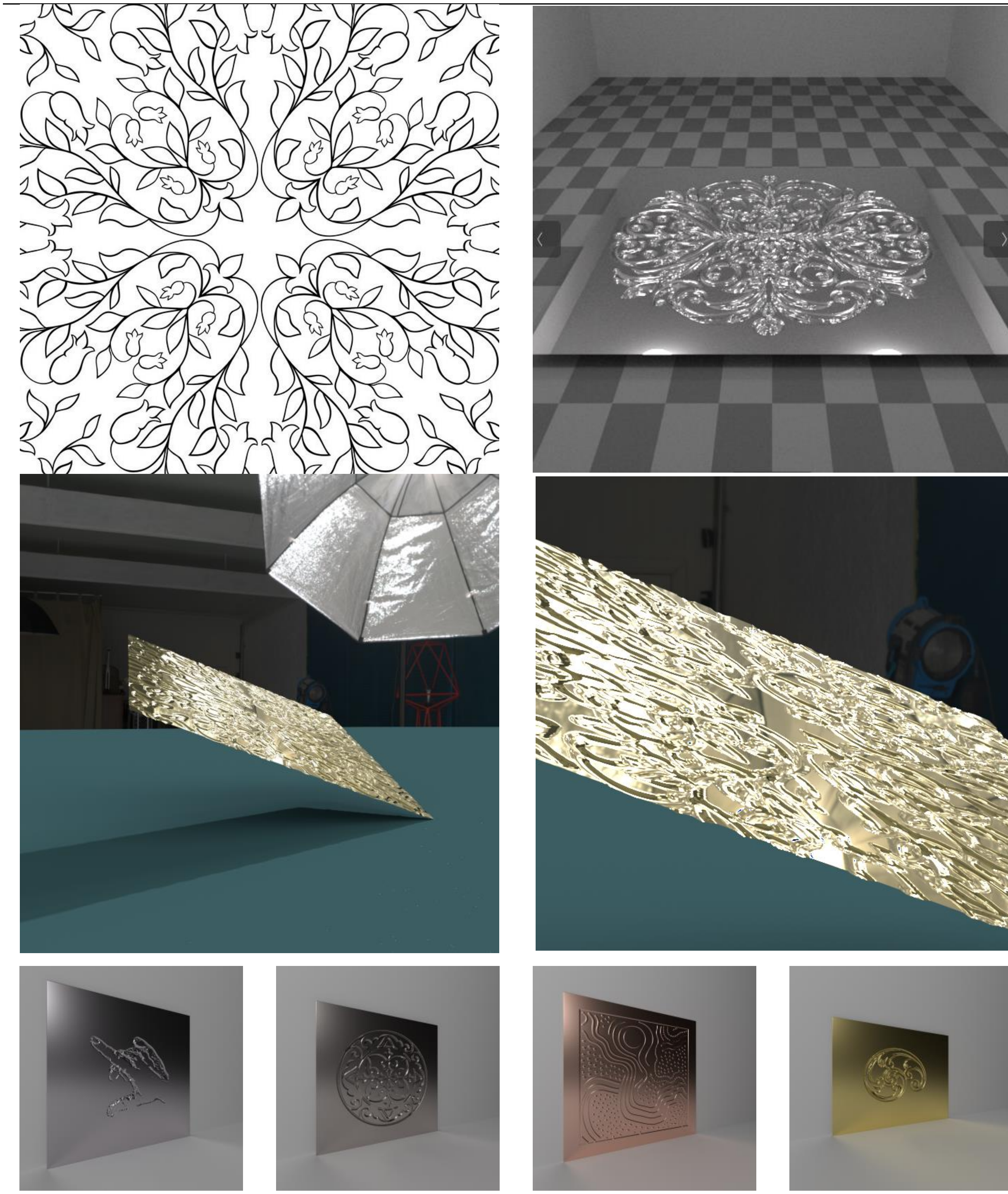


Figure 25. Anaglyph Creator for metal engraving preview: Controls for engraving thickness/depth (top), and photorealistic renderings of the resulting engraved motif on metal (middle, bottom).

4.9 Ceramics and glazes

In ceramics, glazing changes both aesthetics and function, but visually it is dominated by surface optics: specular highlights, micro-roughness, and thin-layer appearance effects. We provide a utility that applies a glaze layer to an existing 3D model and renders the result under controlled lighting, enabling side-by-side comparison of matte vs glazed, and of different glaze roughness and colouration.

Figure 26 demonstrates the same plate geometry under two appearance regimes: smooth glaze, and rough glaze. The comparison emphasises how glazing changes highlight sharpness and perceived material quality.

Figure 26. 3D model of the plate (top-left), rendered only with textured (top-right), with smooth glaze (bottom-left), and with rough glaze (bottom-right).

Figure 27 applies the same glaze concept to a textured vase, showing how even a thin glaze layer changes the perceived curvature through more coherent specular structure.

Figure 27. Porcelain vase appearance: matte rendering (left) and rendering after application of a thin glaze layer (right), under the same lighting.

Glazes may also be coloured. Figure 28 compares a matte clay plate, the same plate with transparent glaze, and a variant with a reddish glaze.

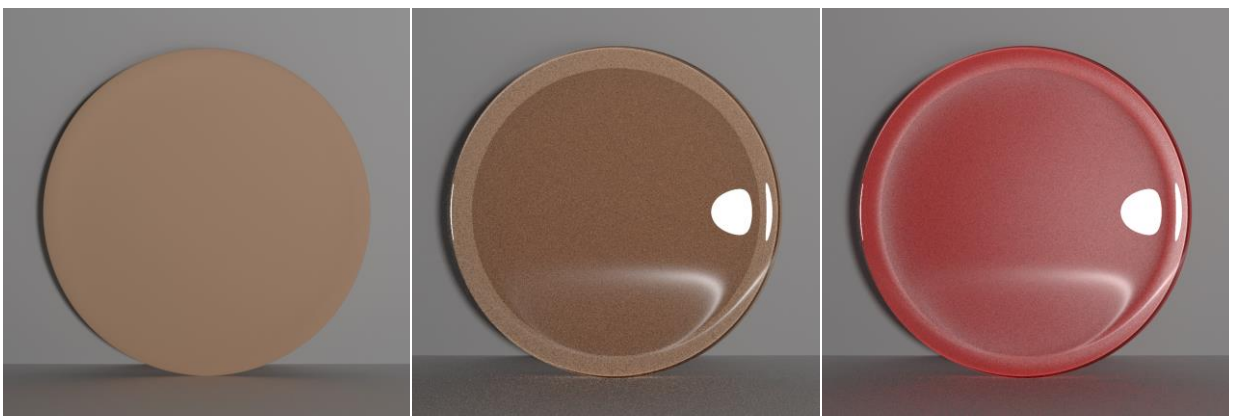


Figure 28. Clay plate variants: matte (left), transparent glaze (middle), and reddish-coloured glaze (right), rendered under identical viewing conditions.

4.10 Showrooms

The showroom tool provides curated interior scenes in which designed artefacts can be placed and inspected. This addresses a recurring user need: to evaluate not only isolated object appearance, but also contextual fit.

The figure shows example virtual showroom scenes used to present craft objects under controlled interior lighting for curation and communication.

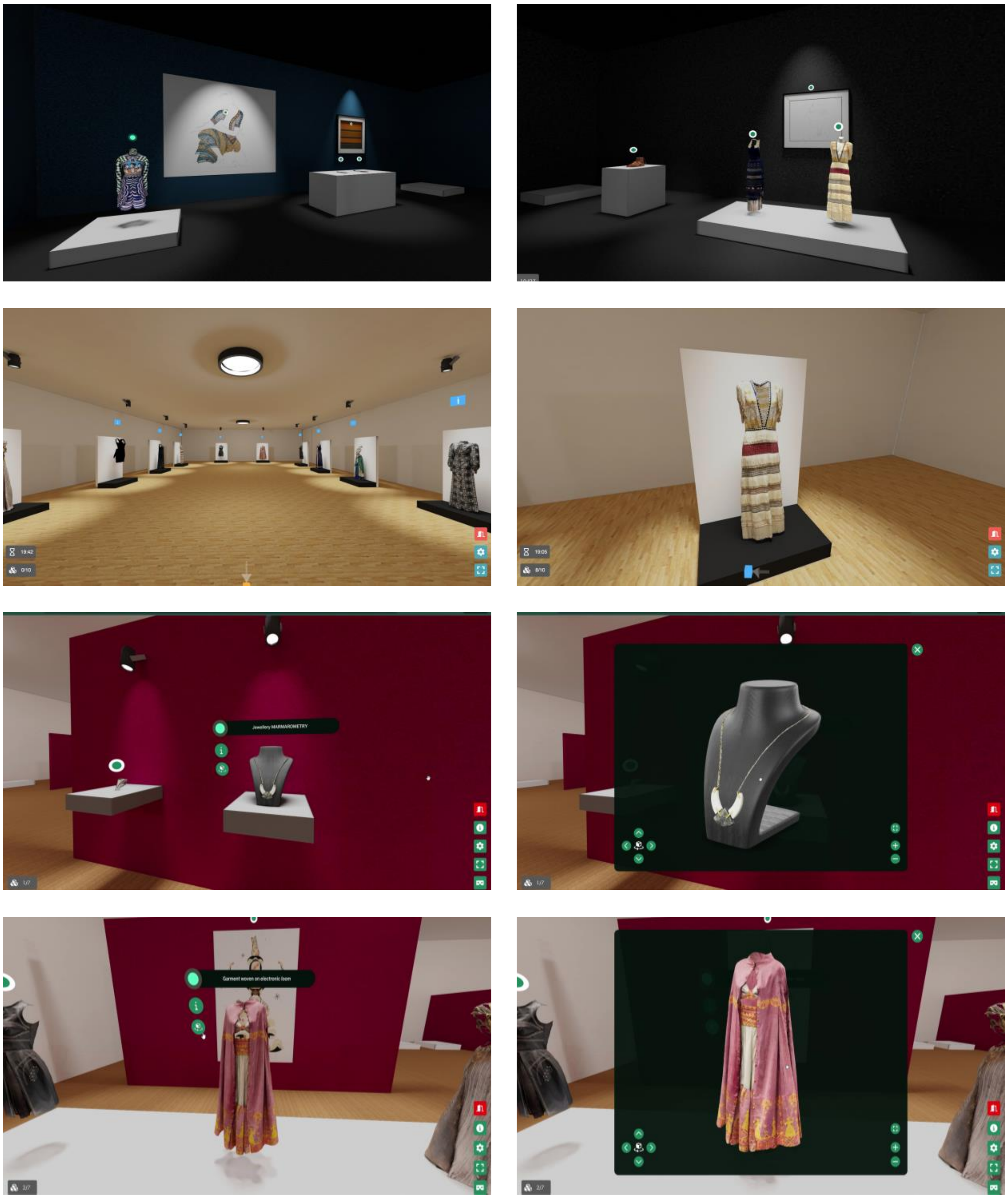


Figure 29. Virtual showroom environments for contextual presentation of designed artefacts.

5. Digital fabrication

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:

1. **Geometric Classes:** These form the foundational entities for the manipulation of 3D models.
2. **Slicing Algorithm:** The algorithm intersects horizontal planes with the model's triangles, creating line segments representing each layer's contours.
3. **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:

1. **Mesh Processing:** Employing numpy-stl for direct operations on the mesh structure.
2. **Vectorized Computations:** Using numpy for enhanced performance in computations.
3. **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).

5.1 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 30 below shows a 3D model and photographs from its 3D printing using the cartesian setup.

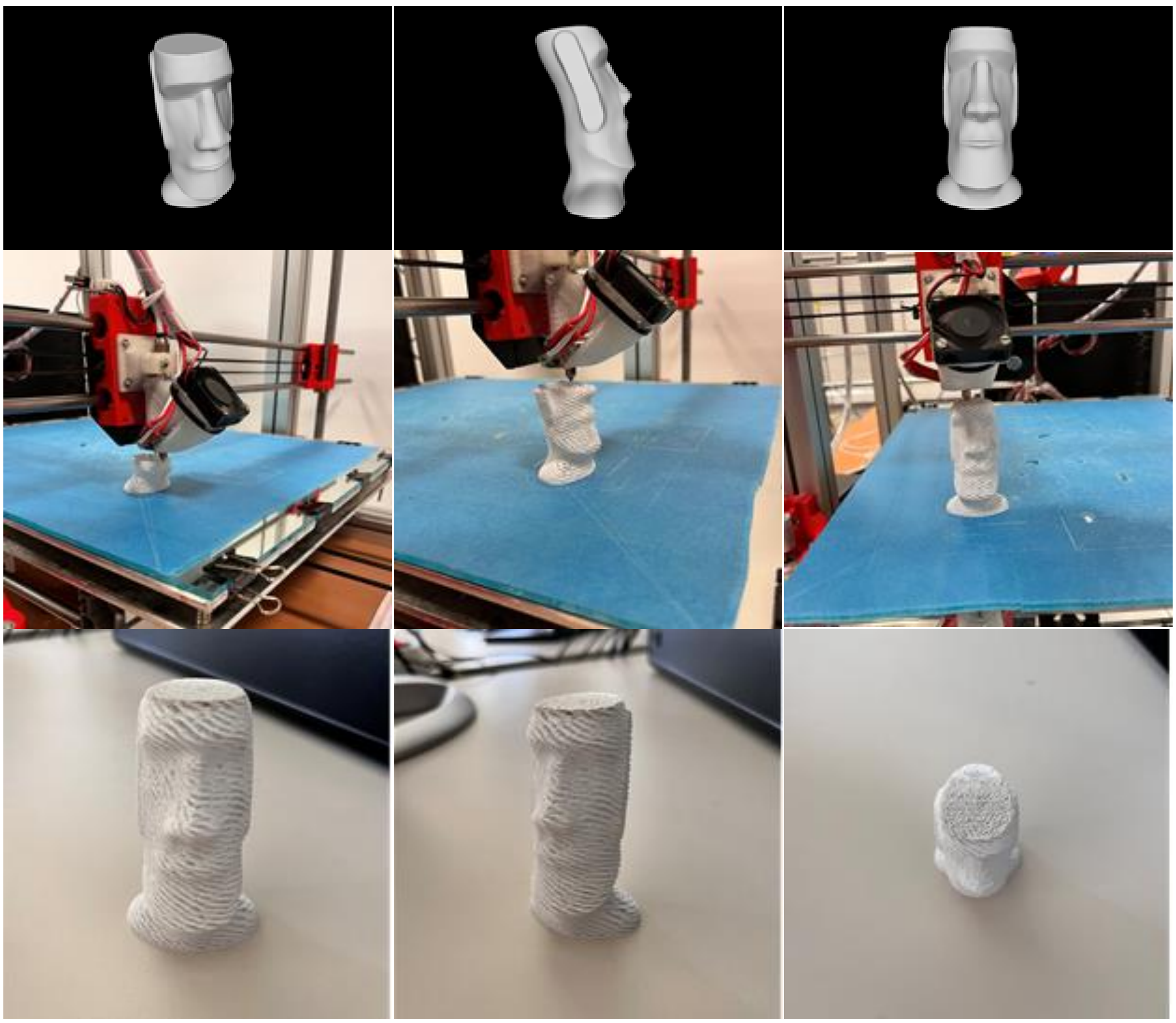


Figure 30. A 3D model, its printing, and the final result.

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.

5.2 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.

5.2.1 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.

5.2.2 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.

5.2.3 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 31. 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.

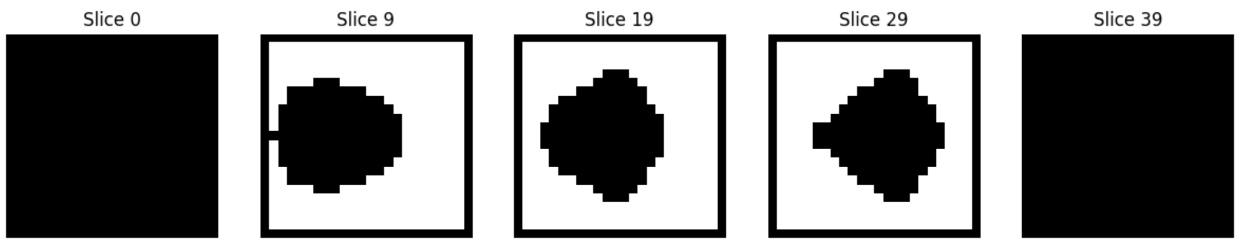


Figure 31. Slices of the 3D voxel grid along the Z-axis. Black regions indicate voxels set to zero, while white regions indicate voxels set to one.

5.2.4 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 32.

Figure 32. Rendering of the mould 3D model using transparency to illustrate its hollow structure.

5.2.5 Results

Finally, the mould was 3D printed as shown in Figure 33. 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.

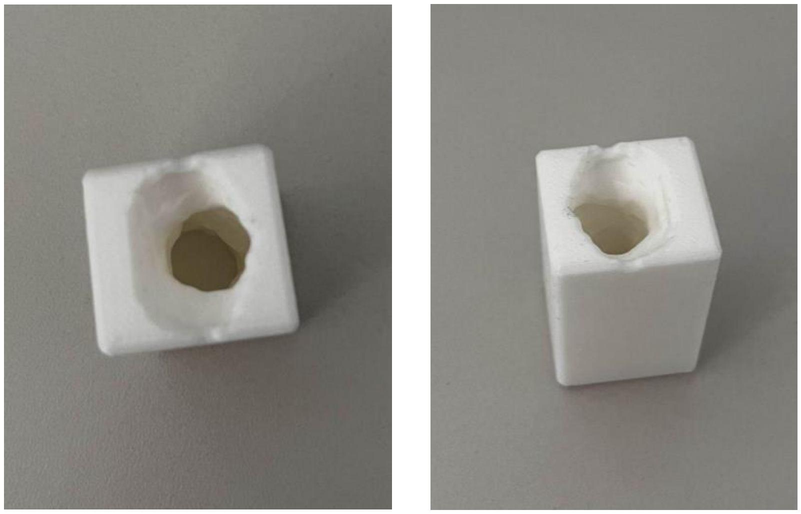


Figure 33. A 3D printed, single-part mould.

However, this mould is usable once, meaning it has to be broken to extract the moulded object. To decrease 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 34.

Figure 34. A two-part mould.

5.3 Laser engraving

Integration with laser engraving equipment is provided as a fabrication-oriented extension of the Design Facilities, enabling the physical realisation of digitally created designs through widely available laser engraving systems. The objective of this component is to establish a direct workflow between digital design environments and affordable, open-source-compatible laser engraving hardware.

Designs created within the Design Facilities, whether geometric patterns, relief structures, decorative motifs, or parametrically generated compositions, are transformed into vector graphics representations suitable for laser processing. Vector formats are preferred because most GRBL-based laser engravers operate on motion instructions derived from vector paths rather than raster images. By converting design outputs into scalable vector graphics (e.g., SVG) and subsequently into G-code, the system ensures compatibility with a broad range of desktop laser engraving machines.

The implemented workflow operates in three main stages. First, the design geometry produced within the Design Facilities is exported in a structured vector format. During this stage, curves, contours, and boundaries are translated into clean vector paths, while depth or shading information can be mapped to engraving parameters such as laser power, speed, or multiple passes. Second, these vector paths are converted into G-code instructions compatible with GRBL firmware, which is widely used in open-source CNC and laser engraving controllers. Finally, the generated G-code is transmitted to the engraving device for execution.

Particular emphasis is placed on compatibility with GRBL-based systems due to their strong association with the open-source hardware movement. GRBL is an open-source firmware widely adopted in low-cost CNC machines and laser engravers. Its openness ensures transparency of operation, modifiability, and broad community support. By aligning the laser engraving workflow with GRBL standards, the Design Facilities support a fabrication ecosystem that is accessible, affordable, and adaptable.

This strategy allows designs developed within Craeft to be realised using a wide variety of commercially available, inexpensive laser engravers. Entry-level diode laser engravers and small-format CNC laser systems can be easily purchased on the market at relatively low cost, making them accessible to individual practitioners, small workshops, educational institutions, and cultural heritage organisations. The reliance on open standards ensures that users are not locked into proprietary hardware or software ecosystems.

From a craft perspective, laser engraving expands the practical applicability of the Design Facilities across multiple materials, including wood, leather, paper, textiles, coated metals, and certain plastics. It enables both surface engraving (marking and decorative carving) and cutting operations, depending on the machine configuration. Designs generated through craft-specific tools, such as ornamental patterns, textile-inspired motifs, engraved metal layouts, or heritage-derived decorative compositions, can therefore be transferred directly to physical substrates with high precision.

The alignment with open-source principles also supports experimentation and customisation. Users can adjust engraving parameters, modify firmware configurations, or integrate the laser engraving workflow into broader fabrication setups that may include 3D printing or CNC milling. This flexibility reinforces the project’s objective of lowering technological barriers for craft practitioners and small-scale producers.

In summary, the laser engraving component establishes a practical bridge between digital design and affordable digital fabrication. By converting designs into vector-based, GRBL-compatible instructions, the Design Facilities enable the exploitation of craft-generated content through widely accessible and low-cost laser engraving systems, consistent with open-source values and the democratisation of digital fabrication technologies.

5.3.1 Software tool

The complete workflow consists of four steps: (1) Digitisation of the motif into vector graphics, (2) Import of the SVG file into the CNC engraving software, (3) Selection of power, speed, and pass parameters according to the material, and (4) Execution of the engraving on wood and aluminium substrates. This process enables reproduction of the same motif across different materials using a single digital representation as input.

The complete workflow can be implemented entirely through open-source software solutions, ensuring transparency, adaptability, and compatibility with low-cost GRBL-based laser engraving systems. The process begins with the digitisation of the motif using an open-source vector graphics editor such as Inkscape. The design, whether manually drawn, derived from scanned material, or exported from the Design Facilities, is converted into clean vector paths and saved in SVG format. Inkscape allows precise control over contours, stroke definitions, and path simplification, ensuring that the geometry is suitable for toolpath generation.

The SVG file is then imported into an open-source CAM environment such as **LaserGRBL** (which is open-source and GRBL-compatible) or alternatively processed using Inkscape extensions that generate G-code directly. Within this stage, vector paths are translated into machine instructions. The user defines engraving parameters including laser power, feed rate (speed), and the number of passes. These parameters are adjusted according to the selected material, for example, lower speeds and multiple passes for aluminium marking, or higher speeds for surface engraving on wood.

Once the parameters are configured, the software generates GRBL-compatible G-code, which is transmitted directly to the laser engraver via USB. The engraver executes the instructions under the control of open-source GRBL firmware installed on its controller board. Because both the CAM software and the firmware are open-source, users retain full visibility and control over the motion logic and engraving parameters.

This fully open-source workflow, from vector design in Inkscape, to G-code generation and machine control via LaserGRBL, to execution through GRBL firmware, enables the consistent reproduction of the same digital motif across different materials while maintaining independence from proprietary ecosystems. It also ensures compatibility with a broad range of affordable, commercially available laser engravers, reinforcing accessibility and alignment with open hardware and open software principles.

5.3.2 Validation

The rosette (*roseta*) is a traditional motif used in woodcarving. To enable its reproduction through computer-controlled engraving, the motif was digitised and represented in a vector graphics format (SVG). The vector format describes the motif in terms of geometric entities such as lines and curves, which can be directly used by digital fabrication systems.

The engraving was performed with a CNC laser engraver equipped with a solid-state diode laser module in the 10-50 W power range. The system operates on a Cartesian X-Y axis configuration, where the workpiece is fixed on a stationary bed and the laser head is mounted on the Y-axis gantry. The laser beam is generated by the diode source, collimated, and focused through a lens assembly onto the material surface. Motion along the X and Y axes is driven by stepper motors with positional control from the engraving software. For wood engraving, the CO_2-free diode laser was used at powers in the range of 10–20 W, with head speeds between 300–600 mm/min, a line spacing of 0.1–0.2 mm, and one to two passes depending on the desired depth. Material removal was achieved through localised heating and vaporisation of wood fibres. For aluminium engraving, higher power settings in the range of 20–50 W were required, with slower head speeds between 100-300 mm/min. The process was executed with multiple passes when necessary to ensure surface marking. Material interaction occurred through localised melting and ablation at the focal spot.

Figure 35. Validation of the software tool with a "rosette" design

6. Design Studio use case implementation

6.1 UX research artefacts and UX/UI design

This section documents UX research artefacts and UX/UI design outputs for the Craeft Design Studio, covering how user and partner requirements were translated into a coherent user journey, consistent workspace patterns, and module-specific interaction models. The purpose of these outputs is twofold: (i) to establish a stable and scalable interface "framework" that can host multiple craft-specific modules over time, and (ii) to ensure that implemented modules reflect craft-relevant workflows while remaining accessible for diverse user groups (students, educators, practitioners, and SMEs).

KHORA's UX and UI work was executed as an iterative cycle of (a) requirements translation, (b) interaction modelling, (c) UI template design, and (d) design validation through internal walkthroughs and alignment sessions with project partners as modules matured from early wireframes (M18) into implemented workspaces (M36). The outputs described below were used directly to guide Unity implementation and to create a consistent experience across Paster Turning, wood carving, and the Visualization Toolbox components.

6.1.1 UX artefacts and design approach

KHORA structured the UX work around three complementary artefact types that together define how users move through the Design Studio and how they act inside each module:

1. **User journey and information architecture.** Defines the end-to-end navigation logic (entry points, module selection, and workspace transitions), ensuring the Design Studio remains understandable for first-time users while supporting repeat workflows for returning users.
2. **Workspace UI templates (layout system).** Defines reusable UI building blocks and panel structures used across modules. This ensures that new craft modules can be integrated without re-learning fundamental navigation patterns.
3. **Interaction models (module behaviour specifications).** Defines how users perform module-specific actions (e.g., shaping or carving), including input mappings, camera behaviour, tool selection logic, and output actions (save/load/export). These models were particularly important in bridging partner requirements with implementable mechanics in Unity.

This approach enabled KHORA to provide both high-level platform consistency and module-level depth, while ensuring that the Design Studio can expand beyond the currently implemented modules.

6.1.2 User journey and information architecture

A central output of the UX research and design process was a clear end-to-end user journey that supports both exploratory and repeat use. The Design Studio navigation is designed to minimise cognitive load by separating early choices (what area do you want to work in?) from later choices (which module or tool do you need?), while ensuring that all modules share the same fundamental "workspace" interaction grammar.

The user journey is structured as:

- **Dashboard / Start:** entry point providing quick access to creating a new project.
- **Area selection:** choice between two top-level areas:
    - **Interactive Simulations** (craft-specific interaction modules)
    - **Visualization Toolbox** (supporting utilities for review and output preparation)
- **Module selection:** users select a specific module (e.g., Paster Turning or wood carving), which establishes the interaction context.
- **Workspace:** users enter a dedicated workspace with consistent layout patterns and controls, including actions for resetting, saving/loading, and exporting where relevant.

This structure was designed to remain robust as more modules are integrated by the consortium, since each module can be introduced at the "module selection" level while reusing the same workspace pattern and navigation expectations.

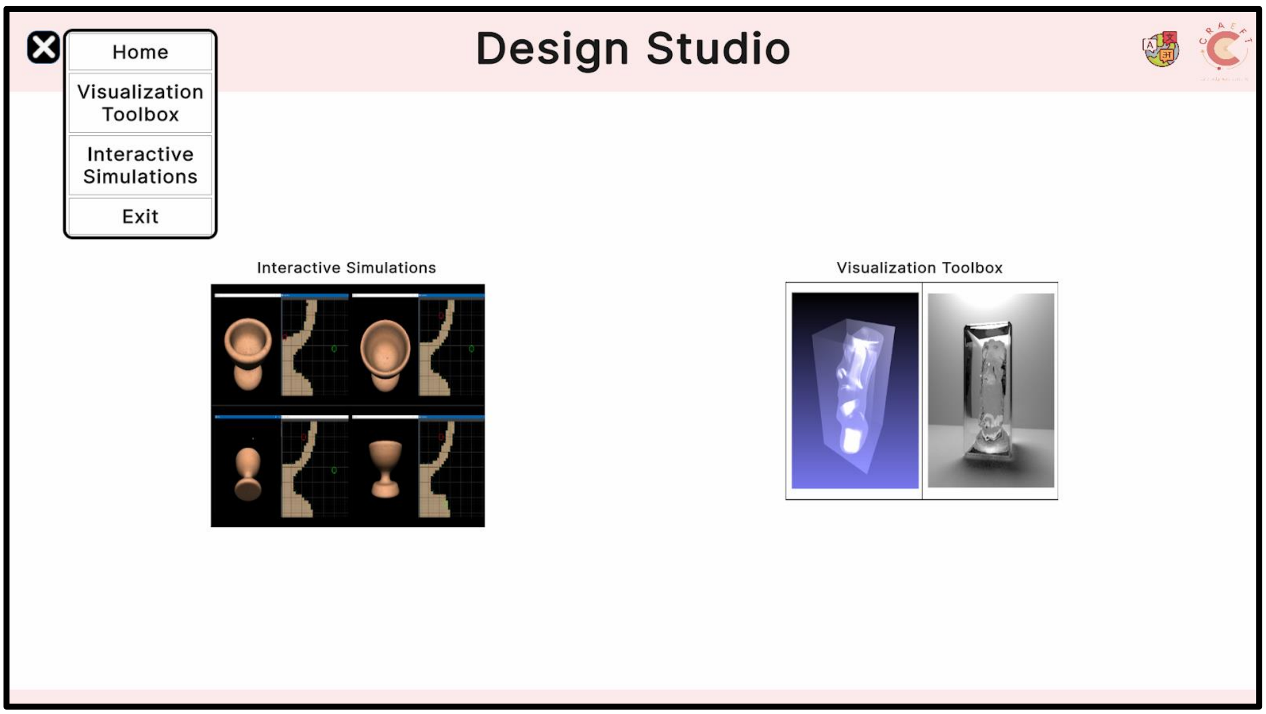


Figure 36. Craeft Design Studio user flow: dashboard → module selection → workspace.

6.1.3 Workspace UI templates and layout system

To support scalability and reduce implementation complexity, KHORA developed UI templates based on a consistent workspace structure. The templates act as a UI "system" that can be reused across current and future modules. The intention is that users feel they are still "inside the same product" when switching modules, while each module can still express domain-specific controls and interactions. The workspace UI pattern is organised into:

- **Top bar (global controls):** module title and primary navigation actions. This top layer anchors user orientation and supports consistent access to menus/settings.

- **Left panel (interaction and tool controls):** primary tool selection and parameter controls, plus camera/inspection controls that are needed frequently while shaping or inspecting artefacts.
- **Right panel (workflow actions and outputs):** turntable/scene controls (where relevant), persistence actions (save/load), and output actions (export, render, documentation outputs). This panel supports the "design-to-output" step of the workflow and allows users to complete work without leaving the workspace.

This layout system was applied across implemented simulator modules and used to define supporting toolbox components, ensuring that a shared UI logic exists even where module functions differ.

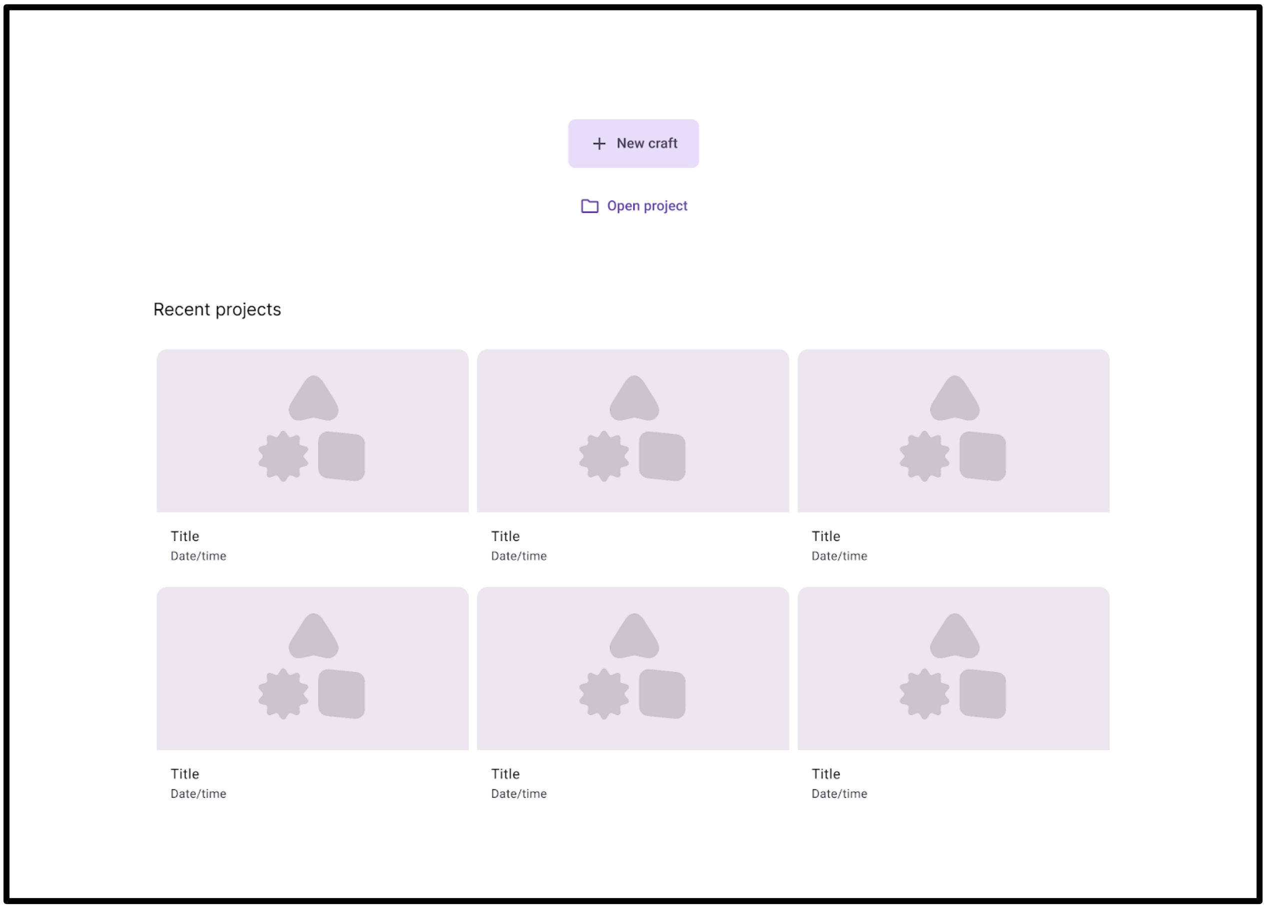
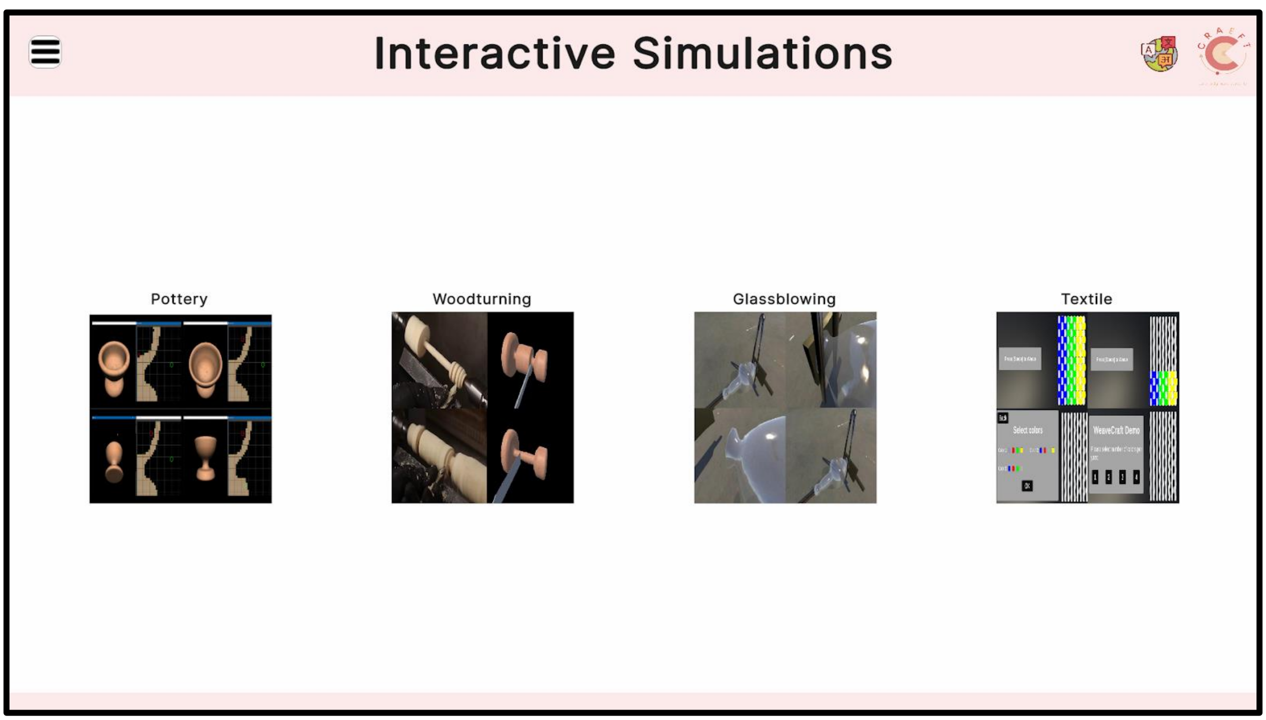


Figure 37. UI templates: Dashboard and entry points.

Figure 38. UI templates: Module selection screens.



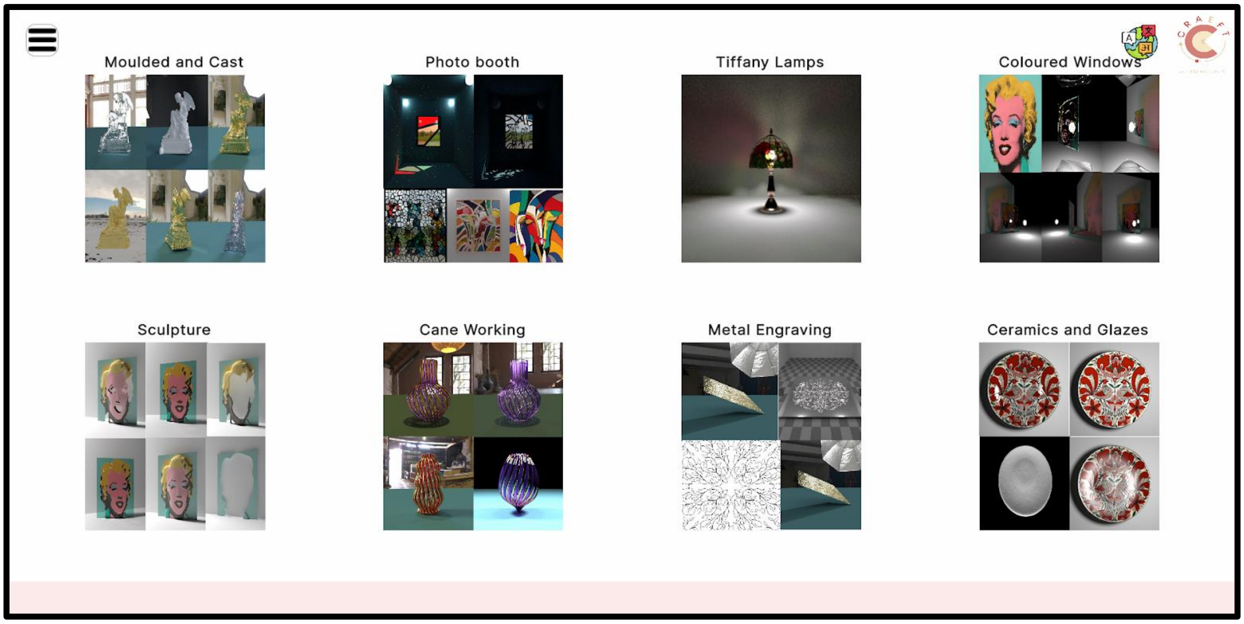


Figure 39. UI templates: Module UI patterns and output actions.

3.4 Interaction model outputs (Plaster Turning and Wood Carving)

KHORA translated partner requirements into interaction models that specify how user inputs map to craft actions and how the environment responds. These interaction models describe camera behaviour, tool selection, input constraints, undo/reset logic where applicable, and output actions (save/load/export). They were used as implementation references to ensure alignment between design intent and Unity behaviour.

Wood Carving interaction model. The Wood Carving interaction model specifies subtractive tool behaviour and inspection logic, including camera orbit/zoom, tool positioning and application, constraint mechanisms that stabilise interaction (e.g., axis/limit logic where relevant), and a repeatable workflow for resetting, saving/loading, and exporting results.

Plaster Turning interaction model. The Plaster Turning interaction model specifies form-shaping interactions suitable for controlled deformation and iterative refinement, including camera inspection controls, parameterised shaping inputs, and a structured iteration loop (apply change → evaluate → adjust). The model also defines the placement and semantics of workflow actions (reset, persistence, output/export) within the shared workspace UI pattern, ensuring consistency with other modules.

	Function	Interaction
Camera		
	Orbit	While pressing: • Middle mouse OR • Shift + mousedown Dragging on 3D gizmo, either freely or along axes
	Zoom in/out	Scroll up/down
Chisel		
	Position	Follow mousePos
	Carve wood	While pressing: • Left mouse
	Lock movement to X, Y, Z axis	Press X, Y, Z on keyboard
	Angle	While pressing • Right mouse
	Change size	CTRL + mousewheel OR Select on GUI

Figure 40. Plaster turning interaction model

3.5 Visualization Toolbox UX/UI specification (incl. Photo Booth screen design)

KHORA produced UX/UI specifications for a set of supporting utilities grouped under the **Visualization Toolbox**. The toolbox is designed to complement the Interactive Simulations by enabling users to review outcomes across iterations, document results, and prepare outputs in consistent formats for critique, sharing, and downstream workflows.

Within this toolbox, KHORA specified the **Photo Booth** screen concept as a standardized "output station" interaction pattern. The Photo Booth UX/UI specification defines a clear, stepwise user flow—configuration choices, input selection, execution, and output access—presented in a predictable layout aligned with the broader Design Studio UI system. The intent is to reduce friction for non-technical users and provide reproducible outputs across users and sites.

3.6 Summary of UX/UI outputs and readiness for implementation

By M36, KHORA's UX/UI outputs provide:

- a coherent **user journey** and information architecture that supports scalability
- reusable **UI templates and workspace layout patterns** used across modules
- interaction model artefacts that translate craft requirements into implementable behaviours
- toolbox UX/UI patterns supporting review, documentation, and output preparation

These outputs formed the basis for implementation of Paster Turning and wood carving workspaces in Unity, and provide a stable foundation for further module integration by the consortium.

6.2 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.

In M36, KHORA implemented and integrated the following within the Design Studio runtime:

- **Plaster Turning** (interactive simulation)
- **Wood Carving** (interactive simulation)

- **Photo Booth** (Visualization Toolbox component), UI integration status documented here; pipeline integration documented where available

6.2.1 Implementation principles and shared module architecture

KHORA's Unity implementation follows a modular architecture designed to support multiple craft simulations and supporting utilities without redesigning the full application for each new feature. The key principles applied across modules are:

- **Common navigation and routing:** Modules are accessed through a shared Design Studio entry flow (dashboard → area selection → module selection → workspace), enabling predictable transitions and reducing fragmentation.
- **Reusable workspace layout:** Modules share a consistent UI structure (top bar + left tool panel + right workflow/output panel), enabling users to transfer skills between modules.
- **Clear separation of concerns:** UI layout, interaction layer, and simulation logic are separated to allow module-specific behaviours to evolve without impacting the global UI and navigation framework.
- **Consistent workflow actions:** Reset, save/load, and output/export actions are presented consistently across modules, even when the underlying implementation differs.
- **Scalable module packaging:** Each module is integrated as a discrete unit that can be enabled/disabled and extended over time as additional craft instances and capabilities are added by the consortium.

6.2.2 Unity UI layout and UI Toolkit integration

The Design Studio UI is implemented using Unity's UI system in a way that mirrors the UX/UI templates defined in the design artefacts. The UI layout is structured to ensure both usability and implementation efficiency:

- **Top bar (global context):** Provides module identification and consistent access to primary navigation and system actions.
- **Left panel (tools and interaction controls):** Hosts tool selection and frequently-used controls that directly affect user manipulation of the craft object or workspace inspection.
- **Right panel (workflow, outputs, and context):** Hosts actions for persistence and outputs (e.g., save/load/export/render) and module-specific workflow controls (e.g., turntable/scene controls where relevant).

A key implementation goal is that module teams can add new craft behaviours while reusing the same UI "shell," limiting per-module UI redesign and enabling cross-module consistency.

6.3 Compatibility/Integration with Craeft components

This section describes how the Design Studio elements delivered by KHORA (UX/UI system, Plaster Turning, Wood Carving, and Visualization Toolbox UI components) integrate with, or are designed to integrate with, other Craeft components developed by the consortium. The intention is to make integration points explicit and actionable, so that partner-developed capabilities can be connected to the

Design Studio consistently, without rework of navigation patterns, UI logic, or data handling. The Design Studio is structured as a modular environment where craft-specific capabilities can be integrated as discrete modules while sharing a common user journey and workspace shell. Integration therefore occurs at three main levels:

1. **User-facing integration:** shared navigation, naming conventions, and consistent user interaction patterns across modules.
2. **Technical integration:** runtime interfaces, dependency management, and module loading.
3. **Data integration:** formats, persistence, and exchange of assets between modules and external toolchains.

6.3.1 Integration model and interface principles

To support incremental integration, the Design Studio follows interface principles that reduce coupling between modules:

- **Stable "shell" + modular "content":** The Design Studio provides a stable application frame (navigation and workspace UI), while craft capabilities plug in as module content.
- **Consistent interaction grammar:** Core controls (navigation, camera inspection, workspace actions) behave consistently across modules, even when craft logic differs.
- **Explicit module entry/exit:** Each module has a defined entry state (loaded content + default tools) and exit state (saved state and safe navigation back to selection screens).
- **Versionable dependencies:** External libraries and simulation runtimes are integrated via explicit dependency definitions so that updates can be managed without breaking the platform.

6.3.2 Integration with craft-specific simulators and feasibility components (WP3)

The Design Studio is designed to act as the primary user-facing entry point for craft-specific simulators developed within Craeft. Within this integration model, simulators are expected to:

- expose an interaction loop that maps to craft-relevant actions and constraints
- provide hooks for persistence (save/load) and outputs (export/asset handover)
- comply with the Design Studio workspace UI patterns to preserve a coherent user experience

KHORA's Plaster Turning and Wood Carving modules follow this integration model and act as reference implementations for how craft simulators can be connected to the platform. Additional simulators and feasibility components integrate through the same module framework.

6.3.3 Integration with design assets, CAD/AI toolchains, and content pipelines

The Design Studio is intended to integrate with toolchains that support design creation, transformation, and enhancement (e.g., CAD pipelines and AI-assisted design). This includes import/export of 3D assets, transformation of assets between tools, and consistency of scale and coordinate conventions across modules.

Key integration considerations include:

- asset interchange formats (e.g., mesh formats, material/texture handling)
- scale, unit systems, and coordinate conventions to ensure consistent behaviour across modules
- versioning of assets and maintaining traceability between iterations
- linking assets generated in one capability (e.g., design tools) to simulation modules for feasibility exploration

6.3.4 Integration with visualization and output-generation components (Visualization Toolbox)

Visualization Toolbox utilities are intended to provide platform-wide support for documenting and preparing outputs. Integration at this level focuses on:

- reusing shared UI patterns so that “output preparation” feels like part of the same platform
- consistent output naming and structure to support comparison across iterations and users
- output storage conventions that support educational critique workflows and professional sharing

The Photo Booth screen concept and its Design Studio integration are designed to function as a standardised output pathway for assets originating from simulations and other design components.

6.3.5 Integration with digital fabrication workflows (additive/subtractive production)

A core Craeft ambition is to support pathways from digital exploration to physical prototyping and production. In the Design Studio context, this requires:

- clean handover artefacts (e.g., exportable models suitable for fabrication)
- metadata and constraint information where relevant (e.g., thickness constraints, mould logic, material assumptions)
- clear “ready for fabrication” states and user guidance to reduce fabrication failure modes

6.3.6 Cross-module data handling and persistence conventions

To ensure that users can move between modules without losing context, the Design Studio requires consistent approaches to:

- saving and reloading module states
- storing exported assets and derivative outputs
- preserving links between a project and its generated variants
- maintaining comparability between iterations (e.g., consistent camera presets or output formats)

These conventions are particularly important for training contexts, where instructors and students need to review progression and compare outcomes across sessions.

6.3.7 Integration risks and mitigation measures

Key integration risks include:

- mismatch between module-specific assumptions (units, scale, coordinate systems)
- inconsistent input/output formats leading to broken handovers
- dependency conflicts between simulation libraries
- divergence in UX patterns if modules implement custom UI outside the shared templates

Mitigation is achieved through the Design Studio's shared UI system, explicit module interfaces, and agreed data conventions, supported by integration testing as new components are added.

6.4 Craeft components integration

6.4.1 Plaster Turning (implemented simulation module)

The **Plaster Turning** module is implemented as an interactive simulation workspace that allows users to explore craft-relevant shaping and form development through controlled manipulation. The module supports iterative experimentation by enabling users to apply successive shaping actions, inspect results, and maintain continuity across iterations.

Workspace structure. Plaster Turning uses the shared Design Studio workspace layout:

- top bar for module context and navigation
- left panel for tool selection and interaction controls
- right panel for workflow actions and outputs, aligned with iterative exploration

Core interaction loop. The interaction loop is designed to support the typical craft design cycle of "apply change → evaluate → adjust." The implementation supports:

- applying shaping actions to evolve the form
- inspection via camera controls and viewpoint adjustment
- parameter adjustment for controlled variation
- reset and iteration support for learning and exploration

Persistence and outputs. The module supports iterative work by providing structured actions for:

- retaining work states between sessions (save/load)
- exporting outputs for review and documentation (export actions)
- producing comparable outputs across iterations (alignment with toolbox conventions)

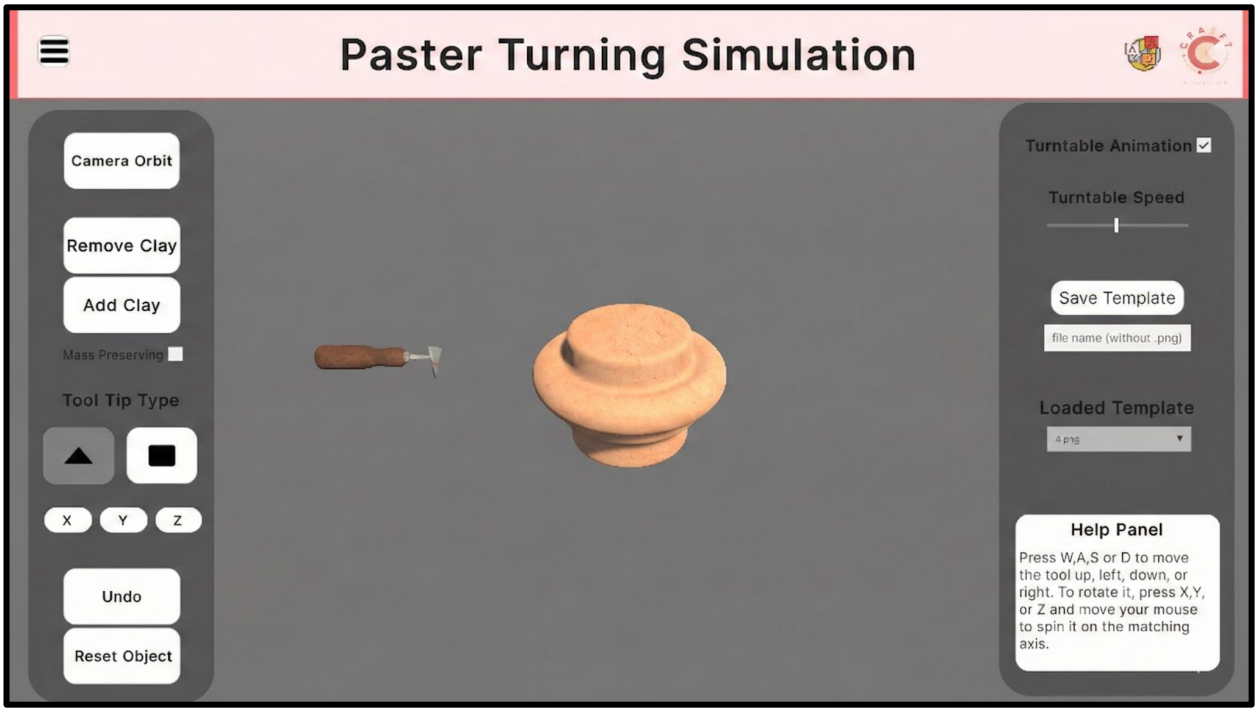


Figure 41. Paster Turning simulation workspace implemented in Unity.

6.4.2 Wood Carving (implemented simulation module)

The **Wood Carving** module is implemented as an interactive simulation workspace focused on subtractive shaping processes. The implementation translates the Wood Carving interaction specification into functional Unity behaviours, enabling users to perform carving actions with structured controls and predictable constraints suitable for craft-grounded experimentation.

Workspace structure. Wood Carving follows the shared workspace layout and integrates module-specific controls into the left and right panels while preserving the global UI grammar.

Interaction model implementation. The module supports a structured carving workflow including:

- camera orbit and zoom to support inspection of both fine detail and overall silhouette
- tool-based carving actions aligned with subtractive shaping
- constraint and control mechanisms that stabilise interaction (e.g., controlled axes/limits where relevant)
- tool parameter controls enabling exploration of different carving outcomes

Iteration, persistence, and outputs. The module supports iterative progression by enabling users to:

- perform multiple carving passes and compare outcomes
- save and reload states to continue development across sessions
- export outputs for critique, documentation, and downstream workflows

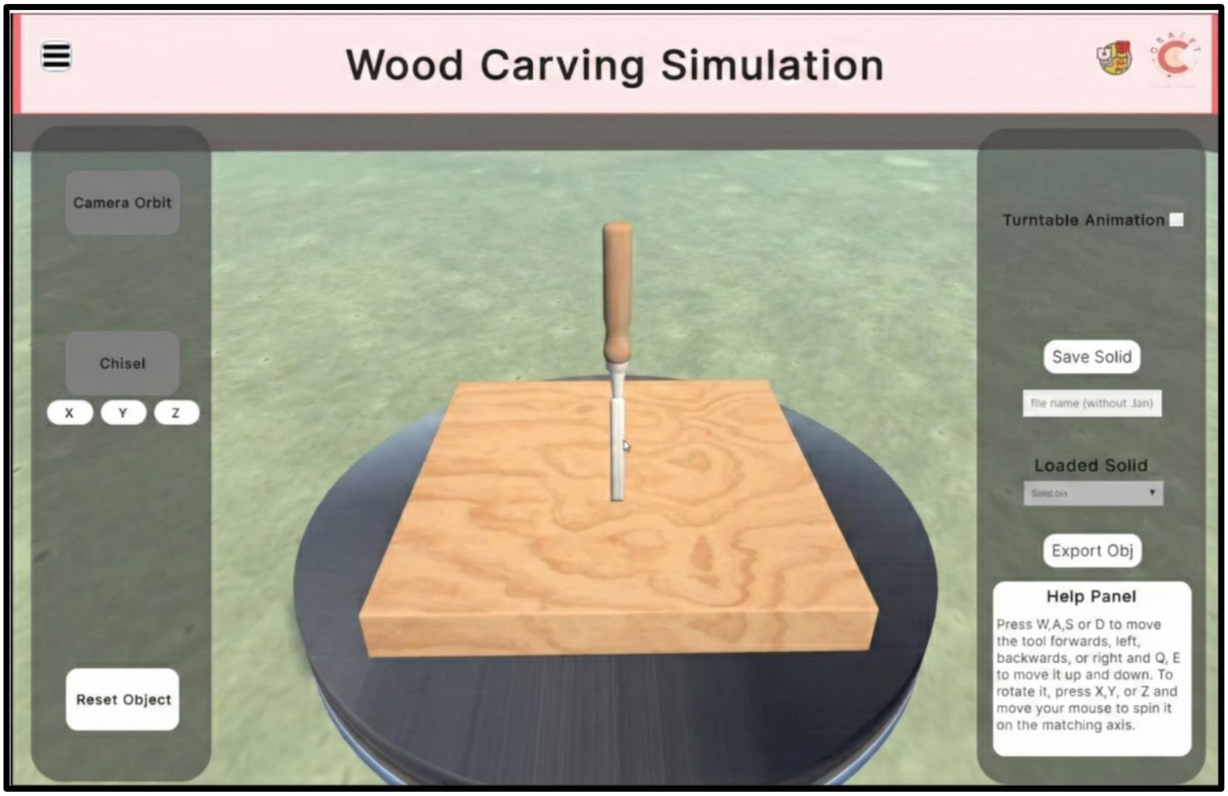


Figure 42. wood carving simulation workspace implemented in Unity.

6.4.3 Photo Booth

The **Photo Booth** component is integrated within the **Visualization Toolbox** as a dedicated workspace for producing consistent outputs from Design Studio assets. It supports the transition from interactive exploration to shareable and reusable artefacts, enabling users to generate comparable outputs across iterations and modules.

Workspace structure. Photo Booth is implemented as a configuration-and-execution workspace with three main areas:

- **Configuration:** Users select a **renderer mode** (CPU-based or GPU-based) and an **output preset** (e.g., Simple Obj or Textured Obj).
- **Execution and status:** Users select input files, receive immediate selection feedback (e.g., number of files selected), and trigger the processing step.
- **Results:** The workspace provides access to generated outputs and a dedicated area for reviewing results in-session.

User workflow. The module follows a clear sequence: select renderer mode → select preset → select input file(s) → run output generation → open/review results. Controls for restarting the processing environment are provided to support repeated runs.

Implementation status at M36. At M36, Photo Booth is integrated into the Design Studio as a Visualization Toolbox component with a complete UI-level workflow (renderer selection, preset selection, file input handling, execution controls, and output access). Details regarding the underlying rendering pipeline and output structuring are documented in the project repository and/or partner technical documentation.

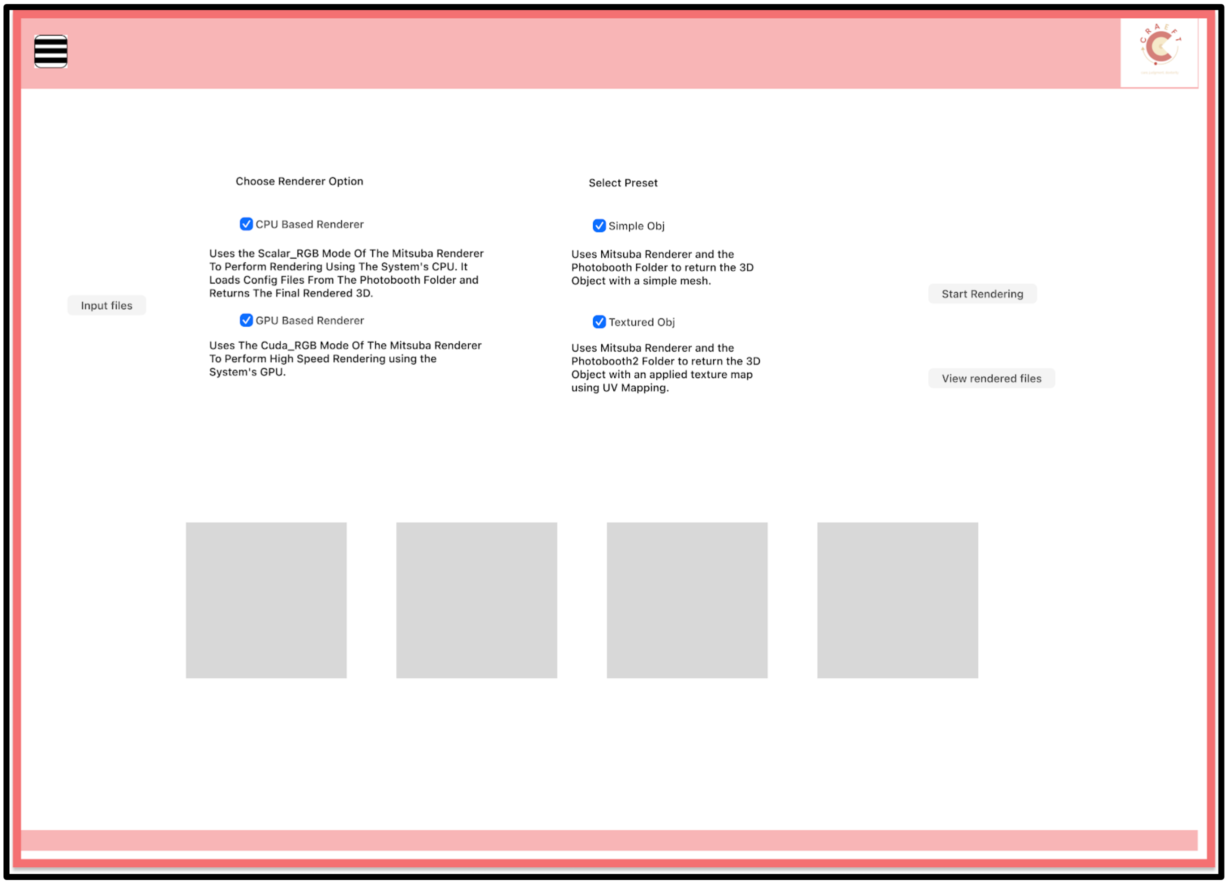


Figure 43. Photo Booth UI specification: renderer selection, presets, and output handling.

6.5 Integration points, simulation dependencies, and supporting libraries

The implementation integrates craft simulation behaviours and supporting dependencies required for interactive shaping, inspection, and output workflows. Integration points include:

- shared navigation and module routing
- shared UI template bindings and panel logic
- input handling and interaction abstraction to support consistent user control schemes
- persistence and output actions that align with cross-module workflows

6.6 Build, packaging, and runtime considerations

The Design Studio implementation considers deployment contexts where the platform must remain usable in educational and professional environments, including:

- consistent module load behaviour and predictable startup states
- performance considerations for interactive shaping and inspection
- packaging of required dependencies for module runtime
- output location and file handling suitable for end-user workflows

6.7 Implementation status, limitations, and readiness (M36)

At M36, KHORA has delivered:

- implemented Unity workspaces for **Plaster Turning** and **Wood Carving**, aligned with the Design Studio UX/UI templates and navigation flow
- **Photo Booth** integrated at UX/UI level within the Design Studio structure, with pipeline integration documented where available

Outstanding elements, limitations, and remaining integration tasks will be addressed in consortium-wide validation and the relevant technical work packages.

6.8. Evaluation

This section reports results from the end-of-project questionnaire. The purpose of the evaluation is to document the usability and perceived fit of the implemented Design Studio baseline at project end. The findings provide evidence for the delivered solution and create a record of observed strengths and limitations that can support future uptake or further development beyond the project.

6.8.1 Data handling and respondent context

Responses were collected anonymously. The questionnaire requested respondents to indicate their role and, optionally, their organisation or partner affiliation. These fields were used only to contextualise the dataset at an aggregate level and are not reported in a way that allows individual attribution. Where quotes are used in Craeft reporting, they are included only when explicit permission was granted and are presented without identifying metadata.

6.8.2 Method

Participants completed a structured questionnaire combining overall UX statements scored on a five-point agreement scale with task-based questions for three representative modules: Plaster Turning, Wood Carving, and Photo Booth. Participants also provided free-text comments describing issues encountered and suggestions. Not every participant tested every module. This produced varying response counts across the module questions. In some module questions, only three responses were recorded. The results should therefore be interpreted as indicative evidence rather than a statistically representative benchmark.

6.8.3 Sample

A total of seven questionnaire submissions were received. The respondent group was dominated by technical profiles, with four participants identifying as researchers or engineers. In addition, the sample included one craft practitioner, one educator or trainer, and one respondent selecting “other.” Responses were submitted anonymously, but participants were asked to indicate their organisation or affiliation to contextualise the dataset at an aggregate level. Two respondents did not specify an affiliation, while the remaining submissions were associated with PIOP (two responses), CERFAV (one), CETEM (one), and one listed simply as “partner.” Testing was carried out on a mix of desktop and laptop computers, with three respondents using a desktop PC and three using a laptop, while one respondent indicated both. Where session duration was reported, time-on-task ranged from 20 to 60 minutes, with a median session length of 30 minutes.

6.8.4 Overall UX Results

Across the overall UX statements, respondents most strongly agreed that they understood where they were in the Design Studio. The average rating for navigation and contextual understanding was 4.43 out of 5, based on 7 responses. Respondents also rated consistency of the UI layout positively. The average rating for layout consistency was 4.00 out of 5, based on 7 responses. Clarity of the end-to-end flow and support for iterative work were rated more moderately. This suggests that the baseline supports exploration but would benefit from clearer cues around state, outputs, and repeat and compare workflows. Performance was rated lowest across the overall items. The average performance rating was 3.14 out of 5, based on 7 responses. This indicates that responsiveness and rendering feedback remain key factors for user confidence.

Respondents also rated whether they would recommend the Design Studio to a peer on a ten-point scale. The average recommendation score was 5.57 out of 10 and the median score was 6. This item was answered by 7 respondents. This result should be read as end-of-project directional evidence rather than a final adoption metric.

6.8.5 Module tasks Results

For Plaster Turning, respondents generally managed to start the module and perform a basic action. Task 1 completion was 100 percent, based on 6 responses. Inspection and discovery of key controls were also typically achieved. Task 2 completion was 100 percent, based on 6 responses. Completion decreased when participants were asked to persist or externalise results. Saving and later reloading work had a completion rate of 67 percent, based on 6 responses. Exporting or producing an output had a completion rate of 50 percent, based on 6 responses.

For Wood Carving, the same overall pattern was observed. Starting the module and performing a basic interaction had a completion rate of 80 percent, based on 5 responses. Inspection and discovery of key controls had a completion rate of 80 percent, based on 5 responses. Saving and exporting were more challenging. Saving and later reloading work had a completion rate of 40 percent, based on 5 responses. Exporting or producing an output had a completion rate of 20 percent, based on 5 responses. This indicates that exploration is achievable, while the output lifecycle requires clearer affordances and more reliable execution.

For Photo Booth, configuration steps were largely successful. Selecting a renderer mode and preset had a completion rate of 100 percent, based on 6 responses. Completion decreased when respondents attempted to run output generation and then locate the generated files. Running output generation had a completion rate of 50 percent, based on 6 responses. Locating and opening generated outputs had a completion rate of 33 percent, based on 6 responses. This indicates that the module would benefit from clearer run-state feedback and explicit guidance on where outputs are stored.

6.8.6 Qualitative synthesis

Free-text comments reinforced the quantitative results. Positive feedback highlighted that the baseline is approachable and that it is possible to start exploring tools without extensive onboarding. However, several respondents reported breakdowns that reduced confidence during testing. In Wood Carving, respondents described cases where the tool did not affect the object and cases where the Help Panel did not appear. Across modules, participants requested greater precision for small adjustments when positioning tools using the keyboard mappings. Respondents also reported uncertainty about whether saves, exports, and renders had executed successfully.

A recurring theme concerned outputs. Respondents had difficulty understanding where saved assets and generated outputs were stored and how they should be retrieved. This reduced perceived usefulness for iterative workflows and for critique and teaching contexts. For Photo Booth, respondents also noted confusion around CPU and GPU options, and reported cases where outputs appeared visually degraded, which reduced trust in the rendering pipeline. Finally, comments on craft fidelity were mixed. Some respondents valued a digital space to explore form and appearance, while others emphasised that material behaviour and surface realism require further refinement to support expert practice.

6.8.7 Interpretation

These findings are reported as the end-of-project evaluation record. They do not imply additional implementation within the project period. Instead, the results document the degree to which the delivered baseline supports first-time exploration, and they identify where limitations affected task completion and user confidence. Because the codebase is open source, the evaluation can be used as an evidence base by any future team that chooses to continue development, prioritise deferred requirements, or adapt the tools for specific craft or educational contexts.

6.8.8 Directions for future use

If the Design Studio baseline is reused or extended beyond the project, the evaluation evidence indicates three high-impact improvement directions:

- Make output locations explicit and verifiable, including clear naming, in-UI confirmation, and a direct option to open the target folder after save, export, or render.
- Improve reliability and state visibility in Wood Carving and Photo Booth by adding status indicators, clear error messages, and recovery paths when a tool fails to respond.

- Provide additional in-context guidance for precise positioning and axis-selected rotation by adding short first-run hints and tooltips aligned with the Help Panel.

7. Innovation

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.

7.1 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.

7.2 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.

7.3 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.

8. Conclusion

This deliverable, submitted at Month 36 (M36) as the final version of D5.1 "Craft Design Revisited," documents the complete design, development, and evaluation of a suite of craft-oriented digital services and their integration into a practitioner-facing demonstrator within the Craeft project. The work presented here represents the culmination of a three-year effort involving close collaboration between technical partners, craft domain experts, and Representatives of Craft Instances (RCIs) from across Europe.

8.1 Contributions at a Glance

The primary technical contributions of this deliverable are the **craft-specific design services** (Section 3) and **visualisation services** (Section 4), developed as modular, independently deployable components aligned with the architecture of the European Collaborative Cloud for Cultural Heritage (ECCH). These services were not conceived as features of a single application but as reusable computational resources that can be accessed, combined, and deployed independently by cultural heritage institutions, craft educators, researchers, and practitioners through shared digital infrastructure. This framing represents a deliberate and meaningful departure from monolithic software development, and it ensures that the outputs of this work remain exploitable well beyond the lifetime of the Craeft project.

The design services developed in Section 3 cover a range of craft-relevant geometric operations, additive construction, subtractive shaping through solids of revolution, transformation, and interlocking structures, implemented through interactive simulators that embed craft-specific constraints directly into the design process. Critically, these simulators are coupled with the craft-specific simulation engines developed under WP3 (D3.1), ensuring that designs produced through them are physically grounded in the material behaviours and technique constraints of their respective craft domains. The visualisation services in Section 4 provide material-accurate rendering environments across a broad and diverse set of craft domains: moulded and sculpted objects, stained glass windows, Tiffany lamps, caneworking, metal engraving, and ceramics with glaze simulation. Across all these domains, the guiding principle has been that a design preview must be trustworthy, realistic enough for practitioners to make genuine design decisions on the basis of what they see.

Section 5 extended the scope of the deliverable to additive and subtractive manufacturing, presenting services for solid 3D printing, automated mould generation, and laser engraving pattern transfer. These manufacturing preparation utilities follow the same service-oriented architecture as the design and visualisation components, and provide a concrete pathway from digital design to physical craft production, reducing material waste and supporting rapid, cost-effective iteration.

8.2 The Design Studio as Demonstrator

The Design Studio, documented in Section 6, was developed as a **reference implementation** illustrating how the services described above can be assembled into a coherent, end-to-end workspace for craft practitioners. Its Unity-based architecture, dashboard-led UX, and two-family tool taxonomy (Interactive Simulations and Visualisation Toolbox) provide a concrete template for future ECCH-oriented deployments. The integration of Plaster Turning and Wood Carving simulation modules, the Photo Booth visualisation component, and the shared interaction grammar across tools demonstrates that modular craft services can be unified within a single, accessible environment without sacrificing craft specificity or domain depth.

8.3 What the Evaluation Tells Us

The end-of-project evaluation (Section 6.8), conducted with seven participants from across the consortium, provides directional evidence about the state of the delivered baseline. Results indicate that the core navigation and contextual orientation of the Design Studio are well-received, with navigation and contextual understanding rated 4.43 out of 5. UI layout consistency was also positively assessed at 4.00 out of 5. However, the evaluation also surfaces areas where the current implementation falls short of full production readiness. Performance was rated lowest across all overall UX items at 3.14 out of 5, and task completion rates for output persistence and file export were notably lower than for exploration tasks, with export completion reaching only 50% in Plaster Turning and 20% in Wood Carving. The median peer recommendation score of 6 out of 10 should be read as consistent with an early-stage research prototype: the foundation is approachable and the tools are usable for exploratory purposes, but the output lifecycle and rendering reliability require further refinement before the platform could be recommended for sustained professional or educational use.

These findings are reported here as the definitive end-of-project evaluation record. They do not imply additional development within the project, but they constitute a documented evidence base for any future team choosing to build on, adapt, or integrate the tools. The codebase is open source, and the evaluation identifies three concrete high-priority improvement directions: making output locations explicit and verifiable; improving reliability and state visibility in Wood Carving and Photo Booth; and providing additional in-context guidance for precise tool positioning.

8.4 Requirements Coverage

A review of the consolidated requirements set (Section 2 and Annex B) against the implemented deliverables confirms that the core functional and architectural requirements were addressed by M36. Interactive 3D design and modification, realistic material rendering, craft-specific feasibility grounding, modular architecture, standardised data exchange, and accessible UX patterns were all delivered. Requirements relating to gesture recording and playback (REQ-INT-CNAM-01, -02) and extended VR-native interaction (REQ-INT-CER-04) remain partially addressed at the platform level and are identified as natural candidates for post-project extension, particularly in the context of future ECCH service deployments.

8.5 Towards ECCH Integration

The work presented in this deliverable directly supports Craeft's broader ambition of contributing to European open digital infrastructure for cultural heritage. The design and visualisation services developed here are architecturally ready for cloud deployment: they are self-contained, use standardised data formats, and are decoupled from any specific application shell. A material rendering service, a glaze simulation tool, a mould-generation utility, or a weaving pattern simulator could each be made independently accessible through the ECCH to cultural heritage institutions, educators, and craft communities across Europe, extending the reach and impact of this work far beyond the consortium that produced it.

The Design Studio demonstrator provides a worked example of how such services can be surfaced to practitioners. Future work could build on this foundation to develop additional craft modules, extend the VR interaction layer, improve the output and persistence pipeline, and carry out broader user studies with more diverse practitioner groups. The evaluation evidence gathered in this deliverable provides the starting point for that work.

References

1. Guru Prashanth Balasubramanian, Eli Saber, Vladimir Misic, Eric Peskin, Mark Shaw, Unsupervised color image segmentation using a dynamic color gradient thresholding algorithm, Volume 6806, Human Vision and Electronic Imaging XIII; 68061H (2008) https://doi.org/10.1117/12.766184

Annex A. Control Mapping for Simulation Tools

This annex documents the baseline input mapping implemented in the interactive simulations, as surfaced through the in-tool Help Panels. The mapping is limited to tool translation and axis-selected tool rotation. All other on-screen UI controls and tool-specific buttons are unchanged.

A.1 Plaster Turning

Tool translation: W/A/S/D moves the active tool Up/Left/Down/Right (screen-aligned planar positioning).

Tool rotation: Press X, Y, or Z to select the rotation axis; move the mouse to rotate the tool about the selected axis.

Note: Tool-specific UI controls (e.g., add/remove material, mass-preserving manipulation, save/load template, turntable options) remain unchanged.

A.2 Wood Carving

Tool translation: W/A/S/D moves the active tool Forwards/Left/Backwards/Right; Q/E moves the tool Up/Down.

Tool rotation: Press X, Y, or Z to select the rotation axis; move the mouse to rotate the tool about the selected axis.

Note: Tool-specific UI controls (e.g., chisel selection, reset object, save solid, export OBJ) remain unchanged.

Annex B. Requirements Catalogue

This annex lists interview-derived requirements in consolidated form for convenient reference. Requirement identifiers align with Section 3.2.

CERFAV

- REQ-INT-CER-01 The Design Studio shall provide an interactive toolset enabling students to shape and refine ideas in 3D.
- REQ-INT-CER-02 The Design Studio shall provide an open palette of VR-friendly tools for creating and modifying shapes (freeform and constrained edits).
- REQ-INT-CER-03 The Design Studio shall provide critique-ready visualisation controls (rotate/scale/inspect) and a 3D viewer mode suitable for peer and instructor review.
- REQ-INT-CER-04 The Design Studio shall support VR-native creative engagement (e.g., gesture-based interaction) where appropriate to the learning context.
- REQ-INT-CER-05 The Design Studio shall provide mould design support appropriate for students (templates, guidance, and/or checks).
- REQ-INT-CER-06 The Design Studio should support exercises that help students practice shape creation from memory (e.g., reconstruction tasks).

CNAM

- REQ-INT-CNAM-01 The Design Studio shall provide gesture recording for technical craft gestures, capturing 'ghost gestures' involving body, tools, and material interaction.
- REQ-INT-CNAM-02 The Design Studio shall enable playback and visualisation of recorded gestures to support analysis, learning, and design review.
- REQ-INT-CNAM-03 The Design Studio shall support co-design and iterative refinement cycles with practitioners, designers, and consortium partners.
- REQ-INT-CNAM-04 The Design Studio shall provide a mechanism to check feasibility of proposed designs.

PIOP

- REQ-INT-PIOP-01 The Design Studio shall be simple and intuitive, minimising setup effort and reducing interface complexity for newcomers.
- REQ-INT-PIOP-02 The Design Studio shall provide digital drawing/design aids that help new entrants externalise and communicate ideas.
- REQ-INT-PIOP-03 The Design Studio shall support testing designs prior to presentation to craftspeople, enabling iteration without material waste.
- REQ-INT-PIOP-04 The Design Studio should embed a heritage lens where relevant (support for traditional design references for silver and marble crafts).
- REQ-INT-PIOP-05 The Design Studio shall explicitly support resource-efficient iteration (material/time saving use cases).
- REQ-INT-PIOP-06 The Design Studio should support educational collaboration scenarios (e.g., integration into arts education contexts).

MadInEurope

- REQ-INT-MIE-01 The Design Studio shall provide methodological support for craft design that bridges traditional practice and future-oriented making.
- REQ-INT-MIE-02 The Design Studio should include features that promote self-awareness of skills/capabilities and support innovation (reflection and learning loops).
- REQ-INT-MIE-03 The Design Studio shall support cross-disciplinary craft practice by enabling representations and workflows that can be shared across disciplines.
- REQ-INT-MIE-04 The Design Studio should support inspiration and learning for younger practitioners, including integration of 3D scanning and showcase/sharing practices.

FORTH

- REQ-INT-FORTH-01 The Design Studio shall provide material/technique feasibility evaluation from early design inputs (including sketches), particularly for wood carving.
- REQ-INT-FORTH-02 The Design Studio shall provide realistic rendering of 3D models to support trustworthy previews.
- REQ-INT-FORTH-03 The Design Studio shall include a pottery simulator focused on shape modification.
- REQ-INT-FORTH-04 The Design Studio shall include woodturning and wood carving simulators.

Annex C. Evaluation Questionnaire Responses

This annex reproduces the collected questionnaire responses as provided, organised per respondent. Responses were collected anonymously. Respondents were asked to state their role and, optionally, their organisation or affiliation to contextualise the dataset. No personal identifiers were collected or reported.

The questionnaire contains a mix of binary and numeric response types. Numeric responses use consistent directionality so that higher values reflect a more positive assessment, except for difficulty where higher values indicate greater difficulty. The following conventions apply:

- Agreement and consistency items use a 1 to 5 scale. A value of 1 indicates the least positive evaluation, and a value of 5 indicates the most positive evaluation.
- Clarity items use a 1 to 5 scale. A value of 1 indicates low clarity, and a value of 5 indicates high clarity.
- Difficulty items use a 1 to 5 scale. A value of 1 indicates low difficulty, and a value of 5 indicates high difficulty.
- Craft relevance and constraint helpfulness items use a 1 to 5 scale. A value of 1 indicates low alignment or low helpfulness, and a value of 5 indicates strong alignment or high helpfulness.
- Recommendation uses a 0 to 10 scale, where 0 indicates not at all and 10 indicates absolutely.
- Task completion items use Yes or No.

Blank entries indicate that the respondent did not provide an answer for that item.

R01

Item	Response
Respondent context	
Role	Craft practitioner
Organisation / affiliation (optional)	Not provided
Platform tested on	PC / Desktop
Approx. time spent (minutes)	Not provided
Did anything break, crash, or get stuck during your session?	No
May we quote your feedback anonymously in Craeft reporting?	Yes
Overall UX responses	
I understood where I was in the Design Studio (navigation & context).	4
The overall user flow is clear (start → select → work → output).	4
The UI layout is consistent across screens and workspaces.	4
I could recover from mistakes (back/reset/restart) without stress.	4
The application supports iterative work (repeat, compare, continue).	4
Performance felt acceptable for the tasks I did.	4

Overall: Would you recommend the Design Studio to a peer? (0 = not at all, 10 = absolutely)	8

R02

Item	Response
Respondent context	
Role	Researcher / engineer
Organisation / affiliation (optional)	Partner
Platform tested on	PC / Desktop, Laptop
Approx. time spent (minutes)	30
Did anything break, crash, or get stuck during your session?	Yes
May we quote your feedback anonymously in Craeft reporting?	Yes
Overall UX responses	
I understood where I was in the Design Studio (navigation & context).	4
The overall user flow is clear (start → select → work → output).	3
The UI layout is consistent across screens and workspaces.	4
I could recover from mistakes (back/reset/restart) without stress.	3
The application supports iterative work (repeat, compare, continue).	3
Performance felt acceptable for the tasks I did.	3
Overall: Would you recommend the Design Studio to a peer? (0 = not at all, 10 = absolutely)	5
Plaster Turning module responses	
Plaster Turning – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Plaster Turning – Task 1: How clear was it what to do?	5.0
Plaster Turning – Task 1: How difficult was it?	1.0
Plaster Turning – Task 1: What was confusing or blocked you (if anything)?	the colour and texture not corresponing to plaster and the combination of different ceramic techniques within the same device
Plaster Turning – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Plaster Turning – Task 2: How consistent did the layout feel (panels, buttons, placement)?	4.0
Plaster Turning – Task 2: Any usability issues you noticed?	it was difficult to move the tools using XYZ coordinate on the keyboard

Plaster Turning – Task 3: Could you save and later reload your work state?	Yes
Plaster Turning – Task 3: How clear were save/load actions?	3.0
Plaster Turning – Task 3: What should change about save/load?	it is not very clear where the saved file arrives
Plaster Turning – Task 4: Could you export or produce an output (file/result) successfully?	No
Plaster Turning – Task 4: How clear were export/output actions?	2.0
Plaster Turning – Craft relevance: Does the interaction feel aligned with craft logic?	2.0
Plaster Turning – Constraints: Do constraints help prevent unrealistic outcomes?	3.0
Plaster Turning – Craft fidelity notes: What felt realistic / what felt off?	it doesnt seem to correspond to Plaster turning
Wood Carving module responses	
Wood Carving – Task 1: Could you start the module and perform a basic action (shape/carve)?	No
Wood Carving – Task 1: How clear was it what to do?	3.0
Wood Carving – Task 1: How difficult was it?	3.0
Wood Carving – Task 1: What was confusing or blocked you (if anything)?	Tool manipulation was confusing | what is the use of the "Economisez solide" function?
Wood Carving – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Wood Carving – Task 2: How consistent did the layout feel (panels, buttons, placement)?	3.0
Wood Carving – Task 2: Any usability issues you noticed?	I was able to move to tool but not to shape or carve
Wood Carving – Task 3: Could you save and later reload your work state?	No
Wood Carving – Task 3: How clear were save/load actions?	3.0
Wood Carving – Task 3: What should change about save/load?	it is not clear where you are saving the files
Wood Carving – Task 4: Could you export or produce an output (file/result) successfully?	No
Wood Carving – Task 4: How clear were export/output actions?	3.0
Wood Carving – Craft relevance: Does the interaction feel aligned with craft logic?	3.0
Wood Carving – Constraints: Do constraints help prevent unrealistic outcomes?	3.0

Wood Carving – Craft fidelity notes: What felt realistic / what felt off?	texture and tool orientation (+)
Photo Booth module responses	
Photo Booth – Task 1: Could you select renderer mode and preset?	Yes
Photo Booth – Task 1: How clear were renderer/preset choices?	3.0
Photo Booth – Task 2: Could you select input file(s) and run output generation?	No
Photo Booth – Task 2: How clear was the run/execution step?	2.0
Photo Booth – Task 2: Any issues during running / processing?	it didnt work
Photo Booth – Task 3: Could you locate/open the generated outputs?	No
Photo Booth – Task 3: How clear was how to access results?	2.0
Photo Booth – Output usefulness: Are outputs useful for documentation/critique?	3.0
Photo Booth – Output notes: What formats/presets are missing?	I wasn't able to evaluate it in that detail
Open comments	
What worked best in the application overall?	interface simplicity
What was the biggest friction point in the application overall?	unresponsive tools
Top 3 improvements you would make (bullet style is fine).	1. change plaster simulator name, 2. remove turning tools 3. improve tool handling

R03

Item	Response
Respondent context	
Role	Researcher / engineer
Organisation / affiliation (optional)	PIOP
Platform tested on	Laptop
Approx. time spent (minutes)	30min
Did anything break, crash, or get stuck during your session?	No
May we quote your feedback anonymously in Craeft reporting?	Yes
Overall UX responses	
I understood where I was in the Design Studio (navigation & context).	5
The overall user flow is clear (start → select → work → output).	4
The UI layout is consistent across screens and workspaces.	3

I could recover from mistakes (back/reset/restart) without stress.	5
The application supports iterative work (repeat, compare, continue).	5
Performance felt acceptable for the tasks I did.	4
Overall: Would you recommend the Design Studio to a peer? (0 = not at all, 10 = absolutely)	8
Plaster Turning module responses	
Plaster Turning – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Plaster Turning – Task 1: How clear was it what to do?	5.0
Plaster Turning – Task 1: How difficult was it?	2.0
Plaster Turning – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Plaster Turning – Task 2: How consistent did the layout feel (panels, buttons, placement)?	4.0
Plaster Turning – Task 2: Any usability issues you noticed?	I couldn't save the photos of the object
Plaster Turning – Task 3: Could you save and later reload your work state?	No
Plaster Turning – Task 3: How clear were save/load actions?	2.0
Plaster Turning – Task 4: Could you export or produce an output (file/result) successfully?	No
Plaster Turning – Task 4: How clear were export/output actions?	2.0
Plaster Turning – Craft relevance: Does the interaction feel aligned with craft logic?	4.0
Plaster Turning – Constraints: Do constraints help prevent unrealistic outcomes?	5.0
Wood Carving module responses	
Wood Carving – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Wood Carving – Task 1: How clear was it what to do?	1.0
Wood Carving – Task 1: How difficult was it?	4.0
Wood Carving – Task 1: What was confusing or blocked you (if anything)?	The help panel does not appear
Wood Carving – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	No
Wood Carving – Task 2: How consistent did the layout feel (panels, buttons, placement)?	2.0

Wood Carving – Task 3: Could you save and later reload your work state?	No
Wood Carving – Task 3: How clear were save/load actions?	2.0
Wood Carving – Task 3: What should change about save/load?	Chisel is not working
Wood Carving – Task 4: Could you export or produce an output (file/result) successfully?	No
Wood Carving – Task 4: How clear were export/output actions?	3.0
Wood Carving – Craft relevance: Does the interaction feel aligned with craft logic?	3.0
Wood Carving – Constraints: Do constraints help prevent unrealistic outcomes?	3.0
Photo Booth module responses	
Photo Booth – Task 1: Could you select renderer mode and preset?	Yes
Photo Booth – Task 1: How clear were renderer/preset choices?	5.0
Photo Booth – Task 2: Could you select input file(s) and run output generation?	No
Photo Booth – Task 2: How clear was the run/execution step?	2.0
Photo Booth – Task 2: Any issues during running / processing?	not able to find the photo
Photo Booth – Task 3: Could you locate/open the generated outputs?	No
Photo Booth – Task 3: How clear was how to access results?	2.0
Photo Booth – Output usefulness: Are outputs useful for documentation/critique?	2.0
Open comments	
What worked best in the application overall?	wood curving
What was the biggest friction point in the application overall?	saving photos
Any final comments (optional)	Cause of the problems i faced (chisel not appear, help panel not appear, unable to save photos and i couldn't explore the photo booth

R04

Item	Response
Respondent context	
Role	Researcher / engineer
Organisation / affiliation (optional)	PIOP
Platform tested on	Laptop
Approx. time spent (minutes)	60

Did anything break, crash, or get stuck during your session?	No
May we quote your feedback anonymously in Craeft reporting?	Yes
Overall UX responses	
I understood where I was in the Design Studio (navigation & context).	5
The overall user flow is clear (start → select → work → output).	3
The UI layout is consistent across screens and workspaces.	4
I could recover from mistakes (back/reset/restart) without stress.	5
The application supports iterative work (repeat, compare, continue).	5
Performance felt acceptable for the tasks I did.	2
Overall: Would you recommend the Design Studio to a peer? (0 = not at all, 10 = absolutely)	3
Plaster Turning module responses	
Plaster Turning – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Plaster Turning – Task 1: How clear was it what to do?	5.0
Plaster Turning – Task 1: How difficult was it?	1.0
Plaster Turning – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Plaster Turning – Task 2: How consistent did the layout feel (panels, buttons, placement)?	4.0
Plaster Turning – Task 3: Could you save and later reload your work state?	No
Plaster Turning – Task 3: How clear were save/load actions?	1.0
Plaster Turning – Task 4: Could you export or produce an output (file/result) successfully?	No
Plaster Turning – Task 4: How clear were export/output actions?	1.0
Plaster Turning – Craft relevance: Does the interaction feel aligned with craft logic?	4.0

Plaster Turning – Constraints: Do constraints help prevent unrealistic outcomes?	3.0
Wood Carving module responses	
Wood Carving – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Wood Carving – Task 1: How clear was it what to do?	1.0
Wood Carving – Task 1: How difficult was it?	1.0
Wood Carving – Task 1: What was confusing or blocked you (if anything)?	Help panel did not show anything, chisel did not work
Wood Carving – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Wood Carving – Task 2: How consistent did the layout feel (panels, buttons, placement)?	3.0
Wood Carving – Task 3: Could you save and later reload your work state?	No
Wood Carving – Task 3: How clear were save/load actions?	1.0
Wood Carving – Task 4: Could you export or produce an output (file/result) successfully?	No
Wood Carving – Task 4: How clear were export/output actions?	1.0
Wood Carving – Craft relevance: Does the interaction feel aligned with craft logic?	4.0
Wood Carving – Constraints: Do constraints help prevent unrealistic outcomes?	4.0
Photo Booth module responses	
Photo Booth – Task 1: Could you select renderer mode and preset?	Yes
Photo Booth – Task 1: How clear were renderer/preset choices?	1.0
Photo Booth – Task 2: Could you select input file(s) and run output generation?	No
Photo Booth – Task 2: How clear was the run/execution step?	1.0
Photo Booth – Task 3: Could you locate/open the generated outputs?	No
Photo Booth – Task 3: How clear was how to access results?	1.0

Photo Booth – Task 3: What would make results access clearer?	not able to attach files
Photo Booth – Output usefulness: Are outputs useful for documentation/critique?	3.0
Open comments	
What worked best in the application overall?	Plastic Turning Simulation
What was the biggest friction point in the application overall?	the wood curving did not work properly (chisel, help panel and save option did not work), photobooth not clear at all
Top 3 improvements you would make (bullet style is fine).	- the app should be more user friendly and easy to understand - more clarity what the photobooth is used for and how it works - it should be easier to save and upload images

R05

Item	Response
Respondent context	
Role	Educator / trainer
Organisation / affiliation (optional)	Partner Cerfav
Platform tested on	PC / Desktop
Approx. time spent (minutes)	30 minutes
Did anything break, crash, or get stuck during your session?	Yes
May we quote your feedback anonymously in Craeft reporting?	Yes
Overall UX responses	
I understood where I was in the Design Studio (navigation & context).	4
The overall user flow is clear (start → select → work → output).	4
The UI layout is consistent across screens and workspaces.	3
I could recover from mistakes (back/reset/restart) without stress.	2
The application supports iterative work (repeat, compare, continue).	1
Performance felt acceptable for the tasks I did.	1
Overall: Would you recommend the Design Studio to a peer? (0 = not at all, 10 = absolutely)	0
Plaster Turning module responses	

Plaster Turning – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Plaster Turning – Task 1: How clear was it what to do?	2.0
Plaster Turning – Task 1: How difficult was it?	4.0
Plaster Turning – Task 1: What was confusing or blocked you (if anything)?	Keyboard interface is not intuitive, no precision on tools usage.
Plaster Turning – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Plaster Turning – Task 2: How consistent did the layout feel (panels, buttons, placement)?	3.0
Plaster Turning – Task 2: Any usability issues you noticed?	No help bubble, for example, I figured out by chance how to rotate the piece.
Plaster Turning – Task 3: Could you save and later reload your work state?	Yes
Plaster Turning – Task 3: How clear were save/load actions?	3.0
Plaster Turning – Task 3: What should change about save/load?	No tryed
Plaster Turning – Task 4: Could you export or produce an output (file/result) successfully?	Yes
Plaster Turning – Task 4: How clear were export/output actions?	3.0
Plaster Turning – Task 4: What output would you need next?	not tryed
Plaster Turning – Craft relevance: Does the interaction feel aligned with craft logic?	1.0
Plaster Turning – Constraints: Do constraints help prevent unrealistic outcomes?	1.0
Plaster Turning – Craft fidelity notes: What felt realistic / what felt off?	Our impression and that this is too far removed from the actual experience.
Wood Carving module responses	
Wood Carving – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Wood Carving – Task 1: How clear was it what to do?	2.0
Wood Carving – Task 1: How difficult was it?	4.0

Wood Carving – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Wood Carving – Task 2: How consistent did the layout feel (panels, buttons, placement)?	4.0
Wood Carving – Task 3: Could you save and later reload your work state?	Yes
Wood Carving – Task 3: How clear were save/load actions?	3.0
Wood Carving – Task 3: What should change about save/load?	Not tryed
Wood Carving – Task 4: Could you export or produce an output (file/result) successfully?	Yes
Wood Carving – Task 4: How clear were export/output actions?	3.0
Wood Carving – Task 4: What output would you need next?	Not tryed
Wood Carving – Craft relevance: Does the interaction feel aligned with craft logic?	2.0
Wood Carving – Constraints: Do constraints help prevent unrealistic outcomes?	1.0
Wood Carving – Craft fidelity notes: What felt realistic / what felt off?	For example, it is very difficult to measure the depth of the chisel in the material, and the chisel does not stop on the support plate.
Photo Booth module responses	
Photo Booth – Task 1: Could you select renderer mode and preset?	Yes
Photo Booth – Task 1: How clear were renderer/preset choices?	3.0
Photo Booth – Task 1: What was confusing about configuration (if anything)?	One only is available "photo cabine"
Photo Booth – Task 2: Could you select input file(s) and run output generation?	Yes
Photo Booth – Task 2: How clear was the run/execution step?	2.0
Photo Booth – Task 3: Could you locate/open the generated outputs?	Yes
Photo Booth – Task 3: How clear was how to access results?	2.0
Photo Booth – Task 3: What would make results access clearer?	The instructions are intended for individuals who are highly familiar with computers, not for everyday users.
Photo Booth – Output usefulness: Are outputs useful for documentation/critique?	1.0

Photo Booth – Output notes: What formats/presets are missing?	Resulting in a uniform grey colour....
Open comments	
What was the biggest friction point in the application overall?	Photobooth Only photo cabine is available Trial of 3D object rendered a gray background 3D plaster turning Navigating with the keyboard keys is inconvenient and does not allow for precise work on the object. Remove / add mater tool is not reponsive and precise Wood carving As with plaster turning, the orientation of the chisel and the depth are difficult to control when using the keys. Overall, the foundations have been laid and the camera orbit settings follow the usual codes for 3D visualisation. However, the user interface needs to be improved to make it more user-friendly.
Any final comments (optional)	Although this tool provides a good general basis, the results obtained are still too far removed from the actual work on a part to be useful to a practitioner.

R06

Item	Response
Respondent context	
Role	Researcher / engineer
Organisation / affiliation (optional)	CETEM
Platform tested on	Laptop
Approx. time spent (minutes)	30
Did anything break, crash, or get stuck during your session?	No
May we quote your feedback anonymously in Craeft reporting?	Yes
Overall UX responses	
I understood where I was in the Design Studio (navigation & context).	4
The overall user flow is clear (start → select → work → output).	3
The UI layout is consistent across screens and workspaces.	4
I could recover from mistakes (back/reset/restart) without stress.	5
The application supports iterative work (repeat, compare, continue).	4
Performance felt acceptable for the tasks I did.	4
Overall: Would you recommend the Design Studio to a peer? (0 = not at all, 10 = absolutely)	9
Plaster Turning module responses	
Plaster Turning – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes

Plaster Turning – Task 1: How clear was it what to do?	5.0
Plaster Turning – Task 1: How difficult was it?	1.0
Plaster Turning – Task 1: What was confusing or blocked you (if anything)?	mix the use of the keyboard and mouse
Plaster Turning – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Plaster Turning – Task 2: How consistent did the layout feel (panels, buttons, placement)?	3.0
Plaster Turning – Task 3: Could you save and later reload your work state?	Yes
Plaster Turning – Task 3: How clear were save/load actions?	4.0
Plaster Turning – Task 4: Could you export or produce an output (file/result) successfully?	Yes
Plaster Turning – Task 4: How clear were export/output actions?	3.0
Plaster Turning – Craft relevance: Does the interaction feel aligned with craft logic?	4.0
Plaster Turning – Constraints: Do constraints help prevent unrealistic outcomes?	4.0
Plaster Turning – Craft fidelity notes: What felt realistic / what felt off?	overall is realistic, maybe the process of adding/delete clary is bit different
Photo Booth module responses	
Photo Booth – Task 1: Could you select renderer mode and preset?	Yes
Photo Booth – Task 1: How clear were renderer/preset choices?	3.0
Photo Booth – Task 1: What was confusing about configuration (if anything)?	we need to select our own object
Photo Booth – Task 2: Could you select input file(s) and run output generation?	Yes
Photo Booth – Task 2: How clear was the run/execution step?	4.0
Photo Booth – Task 3: Could you locate/open the generated outputs?	No
Photo Booth – Task 3: How clear was how to access results?	2.0
Photo Booth – Output usefulness: Are outputs useful for documentation/critique?	3.0
Open comments	
What worked best in the application overall?	Selection of objtecs
What was the biggest friction point in the application overall?	Understand the menu options of CPU/GPU and the procedure
Top 3 improvements you would make (bullet style is fine).	Short FAQs or user guide. Explanatory texts on different options.

R07

Item	Response

Respondent context	
Role	Other
Organisation / affiliation (optional)	Not provided
Platform tested on	PC / Desktop
Approx. time spent (minutes)	20
Did anything break, crash, or get stuck during your session?	No
May we quote your feedback anonymously in Craeft reporting?	Yes
Overall UX responses	
I understood where I was in the Design Studio (navigation & context).	5
The overall user flow is clear (start → select → work → output).	4
The UI layout is consistent across screens and workspaces.	5
I could recover from mistakes (back/reset/restart) without stress.	4
The application supports iterative work (repeat, compare, continue).	4
Performance felt acceptable for the tasks I did.	4
Overall: Would you recommend the Design Studio to a peer? (0 = not at all, 10 = absolutely)	6
Plaster Turning module responses	
Plaster Turning – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Plaster Turning – Task 1: How clear was it what to do?	5.0
Plaster Turning – Task 1: How difficult was it?	3.0
Plaster Turning – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Plaster Turning – Task 2: How consistent did the layout feel (panels, buttons, placement)?	5.0
Plaster Turning – Task 3: Could you save and later reload your work state?	Yes
Plaster Turning – Task 3: How clear were save/load actions?	4.0
Plaster Turning – Task 4: Could you export or produce an output (file/result) successfully?	Yes
Plaster Turning – Task 4: How clear were export/output actions?	4.0
Plaster Turning – Craft relevance: Does the interaction feel aligned with craft logic?	2.0
Plaster Turning – Constraints: Do constraints help prevent unrealistic outcomes?	3.0
Wood Carving module responses	
Wood Carving – Task 1: Could you start the module and perform a basic action (shape/carve)?	Yes
Wood Carving – Task 1: How clear was it what to do?	4.0
Wood Carving – Task 1: How difficult was it?	4.0
Wood Carving – Task 2: Could you inspect the object (camera/orbit/zoom) and find key controls?	Yes
Wood Carving – Task 2: How consistent did the layout feel (panels, buttons, placement)?	5.0
Wood Carving – Task 3: Could you save and later reload your work state?	Yes
Wood Carving – Task 3: How clear were save/load actions?	5.0
Wood Carving – Task 4: Could you export or produce an output (file/result) successfully?	No
Wood Carving – Task 4: How clear were export/output actions?	3.0
Wood Carving – Craft relevance: Does the interaction feel aligned with craft logic?	4.0

Wood Carving – Constraints: Do constraints help prevent unrealistic outcomes?	3.0
Photo Booth module responses	
Photo Booth – Task 1: Could you select renderer mode and preset?	Yes
Photo Booth – Task 1: How clear were renderer/preset choices?	2.0
Photo Booth – Task 2: Could you select input file(s) and run output generation?	Yes
Photo Booth – Task 2: How clear was the run/execution step?	3.0
Photo Booth – Task 3: Could you locate/open the generated outputs?	Yes
Photo Booth – Task 3: How clear was how to access results?	4.0
Photo Booth – Output usefulness: Are outputs useful for documentation/critique?	4.0