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The integration of critical thinking and digital manufacturing in interior design product development

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Abstract

In recent years, digital fabrication has become an increasingly popular tool in the design field. By integrating digital manufacturing techniques into the design process, designers can produce more innovative and sustainable products while minimising material waste. In this paper, we present a model of approach that incorporates digital fabrication into the prototyping of interior design products using Origami-based techniques. Origami, the antique art of paper folding, has long been admired for its beauty and precision. One of the main benefits of Origami-based techniques is that they provide a way to create complex forms using only simple folds, transforming a bi-dimensional surface into a 3D object. This makes them particularly useful for projecting design objects, such as room dividers, which must be functional and visually appealing. The study involved a group of students who were allowed to study digital fabrication techniques and apply them to the singularity of their product through design thinking and reverse engineering. The study is a pilot for a master's thesis, focusing on the integration of folding in digital fabrication, therefore this project allows the preliminary collection of data that can be used to implement the outcome of the thesis.

By merging activities such as folding, digital fabrication, and prototyping, students could focus on art and design, problem-solving, and critical thinking. By combining wood, paper, silicone, and 3D printing filament, the students were able to create room dividers that were both functional and visually striking. The study emphasised the importance of integrating critical thinking and digital manufacturing throughout the design process and in doing so, allowed the participants to identify potential problems and come up with innovative solutions. The students could quickly and efficiently produce prototypes using digital manufacturing techniques, allowing them to test their designs and make necessary adjustments.

The paper provides a framework for integrating critical thinking and digital manufacturing in interior design product development, from ideation to prototyping. It provides examples of how these approaches can be used at each stage to produce more innovative and sustainable products. The study also highlights the versatility of Origami-based techniques, particularly in creating double-purpose room dividers adaptable to the space's visual needs. The folds can also be used as an integral feature of the product, providing stability and structural needs. Origami-based techniques were revealed to be a perfect way of creating a double-purpose room divider, which is also adaptable to the visual needs of the space.

Keywords: 4IR, computational origami, critical thinking, digital manufacturing, interior design.

Introduction

Figure 1, Author (Photographer), final outcomes examples, 2022

Origami, from the Japanese “the art of folding paper”(Richman-Abdou 2022), in the last 20 years has been gaining ground in fields such as architecture, industrial, interior, and fashion design, among many others (Morrison 2019). Not only has the antique art of folding improved those disciplines but it has also been used to learn mathematics and physics fundaments and apply them to different scales and innovative solutions. One of the many examples is the astronomist Koryo Miura and his homonymous folding pattern, thanks to which there has been a consistent increase in origami for outer space and shuttles (‘Folding Physics: The Mathematics of Origami’ 2017). Origami in design can be seen as a tool to satisfy needs such as flat packing, material savings, manufacturing process, structural stability, rigidity, and last but not least, aesthetic requirements. The 3D origami pattern, together with the folding crease of textile and paper, creates games of shadows and light, given by mountain and valley pleats, which improve the exterior of the outcome alongside the overall aspect. Besides these features, origami helps the design meet the requirements of the fabrication process that have become fundamental in the present day: energy and material saving, sustainability of each component including fasteners, glues, resins, and budget limitations. As with every other discipline, folding techniques and digital fabrication can only be used in their entirety if well understood, This is why introducing such topics in third years can be a game changer for the way students perceive ideation and prototyping of models. A big issue in the production of outcomes for learners is the fabrication itself. Usually in this phase, many doubts are raised about materials, cutting, and assembly, driving students to choose easier designs that they feel more comfortable producing. Origami and digital fabrication open a whole new chapter for university making, consistently increasing the number of prototypes, manufacturing process, and therefore size and quality of the outcomes (Figure 1).

Context

As expressed in the previous paragraph, origami can be a fundamental tool if integrated into the design process, but to understand it and benefit from it in a teaching and learning context, we go back to one of the most influential institutions of art and design history: the Bauhaus. Josef Albers, a famous designer and artist, lecturer at the Bauhaus of Weimar successfully introduced folding techniques in one of his courses in Weimar. The experiment usually started by providing a brief, such as producing an object for interiors using only the materials given and simply leaving the room to give the students space for ideation. A clear example he quotes in his book refers to one of his students, who merely folded the paper through an easy pleat, creating a sort of self-standing room divider (Albers 1935). This example is rather fundamental for the understanding of the whole paper, where mountain and valley folds were used to give a bidimensional sheet with 3D properties, including stability, structure, and not least form. The brilliance is that the student did not cut, glue, or tape the sheet, he only used the characteristics of the material, adapting it to the purpose. Albers was not the only one who associated the concept of folding with teaching and design. In fact, Paul Jackson (professional artist), based on Albers' foundations, defines folding as a primary design tool, a key factor in design education and practice (Jackson 2011, p. 09). Jackson has been one of the first to identify a difference between teaching students how to make origami and teaching them how to fold (Jackson 2011). Folding can be used with many materials and for infinite design applications (Jackson 2011), breaking down obstacles related to the complexity of design and production. Albers and Jackson have been pioneers of folding techniques applied to design teaching and learning, merging arts, digital modelling, and fabrication to reach the most unexpected outcomes (Figure 2). Thinking about the well-known Bauhaus manifesto "form follows function" ('When Form Follows Function' 2019) it assumes an even wider meaning if paired with Albers' (1935) concept "from sheet to form". The whole statement can be seen as a sheet creates a form (through folds) and form satisfies the needs and aims of a defined function, giving us access to a completely new guideline: flat surfaces, if folded and given structure, create form and therefore answer the needs of different products and concepts.

Aim and objectives

This project aims to integrate folding assets in the design of a room divider for the interior, relating design manufacturing to critical thinking and learning. The objectives are to raise the prototyping accuracy and scale, help the students to use origami-based properties (structure, folding, dimensionality of models) as an advantage, and integrate them into the design ideation. Additionally, part of the objectives is to teach the students how digital manufacturing is strictly related to 3D modelling and a thorough understanding of machine properties.

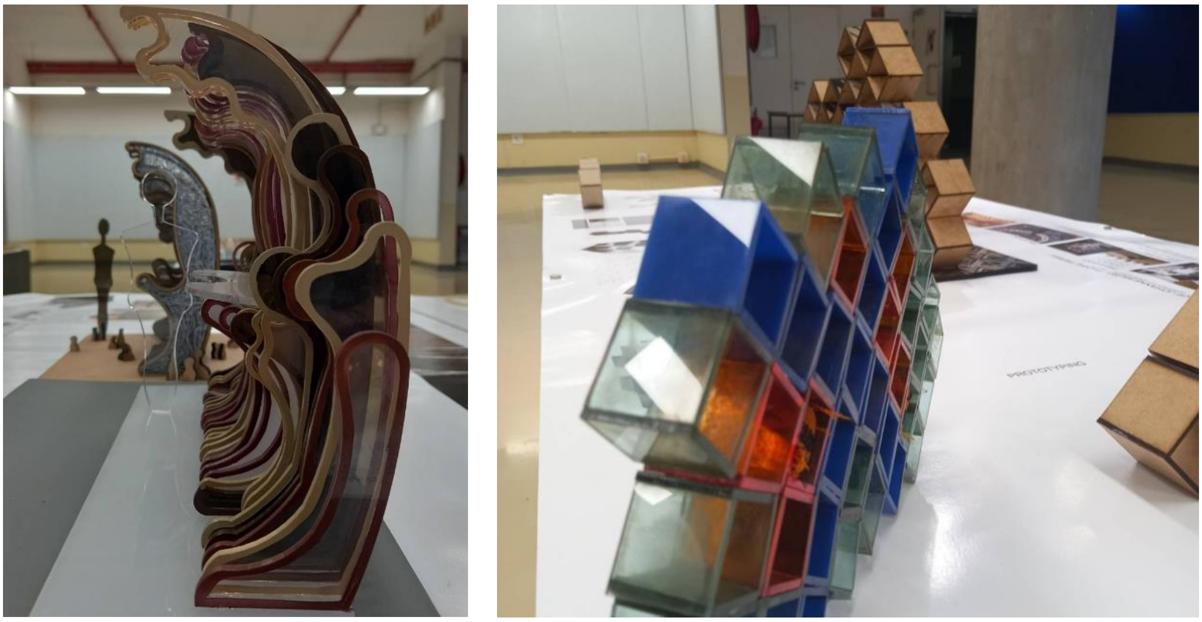

Figure 2, Author (Photographer), examples of the outcomes reached 2022

Methodology

We decided to approach this project from a learning-through-making perspective. As the students receive many frontal classes throughout the year, we developed this module prioritising design ideation, prototyping, and making. The methodology chosen could be paired with Action Design Research. ADR focuses on four fundamental steps: problem formulation, prototyping, observation, and reflection (Sein et al. 2011), with an integrated aim of supporting the development of the design (Cronholm & Göbel 2022, p. 21). Once the problem has been identified, the participants can start with prototyping, followed by observation and reflection for further implementation. This cycle repeats until the best possible outcome is reached (Sein et al. 2011). The ADR methodology is based on practice, therefore to implement the findings of the experimentations, we integrated additional feedback and considerations within the participant's group, through brainstorming sessions and sharing of knowledge. For the duration of the two months, the project took place in the laboratory, allowing students to be inspired by the surroundings and join the conversation with their peers between production phases.

As mentioned above, ADR is a practice-led discipline that works consistently with the research-through-design (RtD) methodology. As Faste and Faste (2012) evaluate in fact, RtD is a Design practice that creates research, where the findings coincide with the thinking process and physical outcomes of the design (Faste & Faste 2012, p. 6). ADR and RtD work together in the generation of knowledge, where an appropriate critical thinking approach, integrated by the peer feedback sessions, guides the discovery of findings and their application in the next iteration. This project has the additional function of pilot for a master's thesis, identifying possible implementation in design thinking and production. As a starting point, the research, therefore, focuses on the formulation of problems and tackles those through folding and digital fabrication, allowing ADR and RtD to work together in the creation of findings and feedback before the next production cycle starts.

Development

Starting from the idea of a flat surface that, when folded, helps the design to meet requirements, we developed an origami-based project through digital fabrication for interiors. The students were required to create a room divider for a chosen context in Johannesburg, whether it was a shop, festival space, or car showroom. The divider is supposed to have two main purposes: separating space and an additional feature at their discretion, some choose to include benches and different sitting solutions, and others add lights, hangers, or shelves. As mentioned above, the most important part is that any requirements would be met by taking advantage of origami characteristics and using folding techniques as a strength in the design choices. Lingering on the brief of the module introduces the document on the other fundamental part of the research, alongside origami: digital fabrication. Thanks to this feature, students were able to pursue outstanding results in the two-month timeframe of the project. In fact, through the open access at the Fab Lab and experts' supervision, students had full entry into every digital and analogue production process, such as 3D printers, laser cutters, and Computerised Numerical Controls (CNCs). Additionally, the manufacturing has been integrated with base wood machinery, carpentry techniques, resins, and silicon modelling (Figure 3). Digital fabrication is, therefore, a key aspect of the project, which allows students to produce many prototypes of high resolution to then have a working finalised outcome, otherwise complicated, imprecise, and time-consuming. While the students already had ideated concepts of the room divider's final design, the implementation of those could only be pursued with access to digital fabrication techniques. Students were required to create digital files, adapted to be fabricated on an A3 size, to then study the prototypes, create conversations, and develop considerations. This project has a big focus on initialising cues and discussions, projecting digital manufacturing into critical thinking, going back and forward until reaching the most implemented finalised outcome (ADR). The reason why digital fabrication enables the production of many objects is due to the computational work of machines, where, thanks to the correct preparation of digital files, the production is fast and precise and does not require the handwork and timeframe that could be needed in analogic manufacture.

Figure 3: Author (Photographer), resins and silicon modelling prototypes, 2022

As mentioned before, origami played a fundamental part in the learning, aside from being the tool used to design the concepts, it needed to be the main feature of production, making folding techniques the centre of ideation and implementation. The students were required to use the folding pattern as a way of answering the brief and incorporating the required features of the divider. A previous study explains how much origami is enabling the creation of new coding processes based on math and physics, repeating the same mechanism (in this case folding) multiple times and therefore implementing the way our brain learns and memorises (Siu 2022). There is something almost meditative about repeating similar actions following guidelines to reach the desired outcome, which is extremely important to implement the thinking activity and passive listening. This very same concept has laid the foundation of the learning process in this project, where the students were not asked to attend frontal classes, but rather learning through making. The strong aspect of the layout is the link between computational origami and digital fabrication, the ability to reverse paper-folding techniques into computational 3D modelling, using folds not as a restriction, but as strength. Computational origami, mentioned above, is a term indicating the projection of folding paper into computer programmes, such as Rhino and Grasshopper, enabling a thorough study of shape and material strength. Additionally, the ability to build origami in 3D modelling programmes creates the possibility of producing complicated shapes and studying how they react through folding patterns. This concept helps the students to realise that with the right tools, there is no limit to what can be done at any level of their educational programme. The key aspect of the project is therefore to create room dividers using origami techniques to implement and innovate a rather simple design. As mentioned previously in fact, origami must not be seen only as an artistic aspect of the ideation but needs to be understood and used to create structures that are strong, compact, and adaptable to various needs. Combining teaching and learning with manufacturing and digital fabrication requires the involvement of experts and an arrangement between different fields, such as interior and industrial design. Not only this relation is fundamental for the development of the project but gives students the possibility of approaching prototyping and small-scale production from an industrial design perspective, acquiring knowledge about file preparation, software use, exportation, and machine work. In addition, the combination of folding techniques and ideation made it possible for students to reach final results that were outstanding, precise, and beautiful (Figure 4).

Findings

As with many of the projects, this experiment gave the chance to improve collaboration and knowledge from a teaching perspective as well. One of the main problems encountered was how to facilitate the students in the preparation of files to avoid having any problems during production, wasting materials and time. While simple exportation, whether for 3D printing (STL files), laser cutting (dxf files), or CNCing (dwg files), could seem to be correct and therefore working in production, there are tools to predict possible errors, which many times come from the exportation itself. Using different programmes, usually due to the metric systems of exportation, is part of the problem, where the student must be careful of scale, mesh-rebuilding errors, and curves overlapping, which could end up in fabrication as unrecognised 3D files, double cutting and engraving (wasting time and resources) or extremely out of scale files. All of these problems are difficult to keep in mind for students, whose focus is usually on the usability and exterior look of the product, leaving manufacturing issues behind. This is the reason why at the very beginning of the project we provided a guided tour of the facilities, including Fab Lab, industrial design workshop, and a thorough explanation of various origami and robotics-related objects, providing examples for inspiration and understanding. From the manufacturing point of view, therefore, the main challenge was to accurately explain the relation between the final produced outcome and computational modelling because it is only through a careful understanding of machines and digital fabrication that it is possible to use those skills in favour of ideation and implementation. During this time of training and trials, it was fundamental, from the expert point of view, that the students attended the preparation and production, assisting in material choosing, machine preparation, and post-production cleaning (3D printed extraction of support for example). Choosing to have the students experience firsthand the most common issues of digital fabrication, including but not limited to the time wasted on fixing files, was fundamental for understanding how digital manufacturing can be efficient only if carefully followed step by step. The students found this last issue particularly frustrating as, if the object is not correctly prepared for manufacturing, the time optimised through digital fabrication gets lost in the adjusting of the file. Nevertheless, from a teaching perspective, having the participants find and correct their own mistakes, alongside digital fabrication experts, helped them to create better files and therefore final products.

Once the students were able to correctly approach the creation and exportation of 3D models, they could start properly utilising digital manufacturing and critical thinking, choosing different strategies and angles. A particular case is the evidence of students wanting to 3D print instead of laser cut, as in the first scenario, the project is done and ready, while in the second there usually is an assembly post-processing of the product. Throughout the learning of origami and folding techniques, almost every participant decided to ultimate the outcome through CNC or laser cutter, demonstrating a proper understanding of the concept "from sheet to form", where the final 3D product is built from a bi-dimensional sheet of cardboard, MDF or paper. This was the ultimate goal from a digital fabrication and computational origami perspective: the use of ancient techniques to study form, structure, flat packaging, and material saving. The learning that the participants were able to absorb during the two

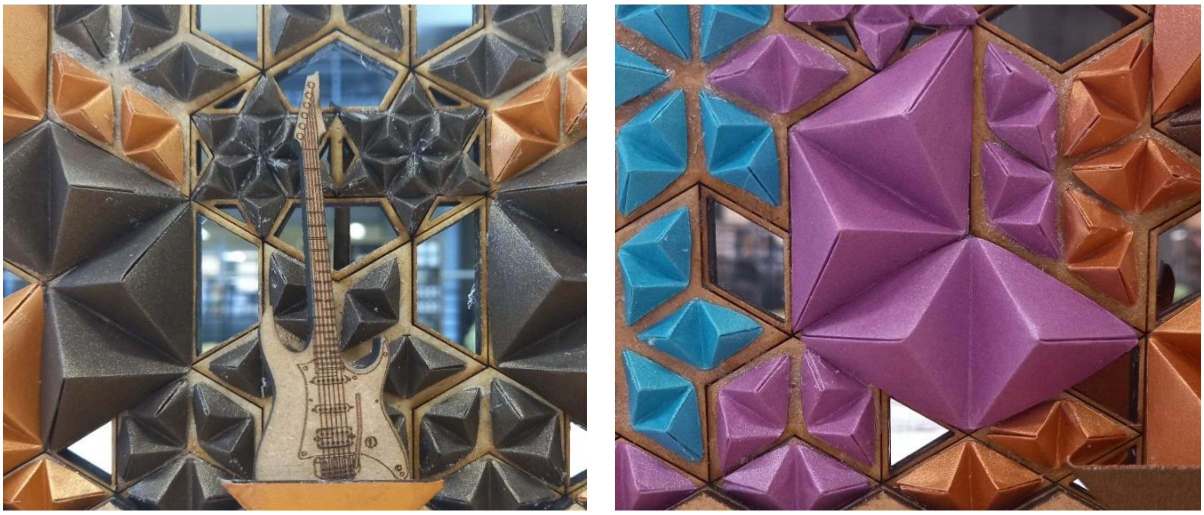

Figure 4: Author (Photographer), outstanding examples of final outcomes, 2022

months of the project has been extremely broad, including the changing of perspective seen in the tackling of ideation and implementation.

Conclusion

Origami and digital fabrication can radically improve the quality of projects, from both a learning and making point of view. Thanks to continuous folding and a thorough study of design requirements, the students were able to optimise folding techniques for the ideation and implementation of prototypes. As often happens in university projects, as good as the concept can be, its realisation is either left behind or minimised due to a lack of resources and time. In this project, the participants were able to manufacture and give life to their ideas on an A3 scale, which is a fundamental aspect of learning through making, alongside the satisfaction of visually appealing products. Origami, computation, and digital fabrication combined were able to answer project needs, design requirements, action research, and technical knowledge, creating a unique learning experience. Students consistently augmented their skills during the module, together with the ability to use critical thinking, providing excellent feedback to one another. This project exceeded lecturers' and experts' expectations, raising possible future applications in different design fields. From the expert point of view, the students allowed us to open new possibilities for learning and making, using origami as a resourceful art and irreplaceable design tool, which we can only keep improving from this point on.

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This was a digital fabrication project within the Department of Interior Design at the UJ Faculty of Art Design and Architecture. It was undertaken with the third-year Interior Design Practice Module, under the lectureship of Sadiyah Geyer, Kimberley Kloes and Eugene Hon. My role within the project was of expert digital fabricator, with the finalisation of the designs and suiting them to be manufactured in the FADA FabLab with the various available Digital Fabrication technologies. The names of the specific students are not included in the document in alignment with conference feedback requested sensitivity around the POPIA Act.

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