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The digital design process of lattice structures in footwear products

Bachelor's thesis

Smart and Sustainable Design

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Smart and Sustainable Design — Abstract
Author Samuli Ranta — Year 2024
Subject The digital design process of lattice structures in footwear products
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This thesis explores the digital design process of lattice structures in footwear products. Digital product design has gained popularity in recent years, and employers of designers have taken an interest in this area of the design process. Many of them have started to support programs that educate students about the use of digital design tools. The digital process of designing footwear products has made it possible to implement lattice structures in footwear products.

The thesis presents the results of research on the digital design process of lattice structures in footwear products. The object of the thesis is to display a fully digitally designed product and show alternative ways to design footwear products. The subject matter follows lattice structures, which are next to impossible to implement using traditional footwear design methods.

Applied research methods mainly consist of academic papers and online resources on the design process, digital fashion, lattice structures, trends, styles, footwear design, and digital design.

To build relevant completion into the subject, a practice-based case study must be completed. The practical part of the thesis is applying the literature information to build a case study on the subject matters. The case study reveals digital tools applications for the digital design process of the footwear product. The goal of the practical part is to analyse the viability of the digital design process and display the capabilities of the process in the form of a lattice structured footwear product.

Keywords Design process, footwear design, digital design, lattice structures
Pages 35 pages and appendix 1 page

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Älykäs ja kestävä muotoilu Tiivistelmä
Tekijä Samuli Ranta Vuosi 2024
Työn nimi Ristikkosolutukirakenteisen jalkineen digitaalinen muotoiluprosessi
Ohjaaja Helena Leppänen, Ville Siipola

Tässä opinnäytetyössä tutkitaan ristikkosolutukirakenteisten jalkineiden digitaalista muotoiluprosessia. Digitaalinen tuotekehitys on kasvattanut suosiota viime vuosina ja erityisesti muotoilijoiden työnantajat ovat kiinnostuneita näiden prosessien tuomista mahdollisuuksista. Monet työnantajat ovatkin alkaneet tukemaan koulutusohjelmia, jotka opettavat digitaalisen muotoilun työkaluja opiskelijoille. Digitaalinen muotoiluprosessi onkin mahdollistanut ristikkosolutukiranteiden käytön jalkineissa.

Opinnäytetyö esittää tutkimuksia, joissa on käsitelty ristikkosolutukirakenteisten jalkineiden digitaalisesta tuotekehityksestä. Opinnäytetyön tavoitteena on näyttää digitaalisia muotoiluprosesseja käyttäen suunniteltu tuote sekä vaihtoehtoisia jalkinemuotoilun menetelmiä. Aiheen käsittelyllä avataan ristikkosolutukirakenteiden suunnittelua ja mahdollisia käyttötapoja, koska tällaisten tukirakenteiden muotoilu ja valmistus on lähes mahdotonta perinteisillä jalkinemuotoilun menetelmillä.

Aiheen taustatutkimusmateriaali koostuu akateemista artikkeleista ja muista julkaisusta, joissa käsitellään muotoiluprosessia, digitaalista muotia, ristikkosolutukirakenteita, trendejä, tyylejä, jalkinemuotoilua ja digitaalista muotoilua. Opinnäytetyön toiminnallinen osuus sisältää aiheeseen liittyvän tapaustutkimuksen.

Relevantin tapaustutkimuksen rakentamisessa hyödynnetään teoreettista taustatutkimusmateriaalia. Tapaustutkimuksella tuodaan esiin jalkineen muotoiluprosessissa käytettävien digitaalisten työkalujen mahdollisuuksia. Toiminnallisessa osuudessa analysoidaan digitaalisen muotoiluprosessin toimivuutta ja luotettavuutta sekä tuodaan esille niitä teknologisia mahdollisuuksia, joita voidaan hyödyntää ristikkosolurakenteisen jalkineen muodossa.

Avainsanat Muotoiluprosessi, jalkinemuotoilu, digitaalinen muotoilu, tukirakenteet
Sivut 35 sivua ja liitteitä 1 sivu

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1 Introduction

Design processes have changed thought the time, and nothing stays the same in this world. The massive digitalization of the world has already started the digital revolution, and the design industry is not an exception. Everything has to evolve or be forgotten.

Technological advancements always create uncertainty in humankind and even fear. But history has taught us that humans are adaptable beings and will always evolve when needed. In the past thirty years, technology has reach significant milestones, evolving extremely fast. Nobody would have ever thought that 3D modeling would have a significant role in our everyday lives. Currently, everyone can see the 3D artists' works in the cinema and entertainment business. Even other industries have started to implement 3D modeling tools to develop better products. A perfect example being the footwear industry, which has always developed with new technologies. Certainly, when the 3D modeling technology started to gain popularity, the logical choice was to implement it in the design processes but where to take it over there? The answer is a very similar technology the additive manufacturing (3D printing). With the combination of these two technologies, the footwear industry gained new structural possibilities, and the lattice structure was the most anticipated possibility because without the additive manufacturing (3D printing) technology the manufacturing of the lattice structures in footwear products is next to impossible. Digital design is giving the designer's new opportunities to evolve with new technological advancements and be part of the non-material design processes.

The research portion of the thesis follows various subject matters that are directly linked to the digital design processes in some formal way. At the end of each main subject matters a practice-based case studies are done to provide validation for the research. Research questions help to construct the overall structure of the thesis. Giving the thesis the opportunity to answer topical questions about the digital design processes and lattice structures.

• What are the possibilities of lattice structured shoes in the footwear industry in the future?

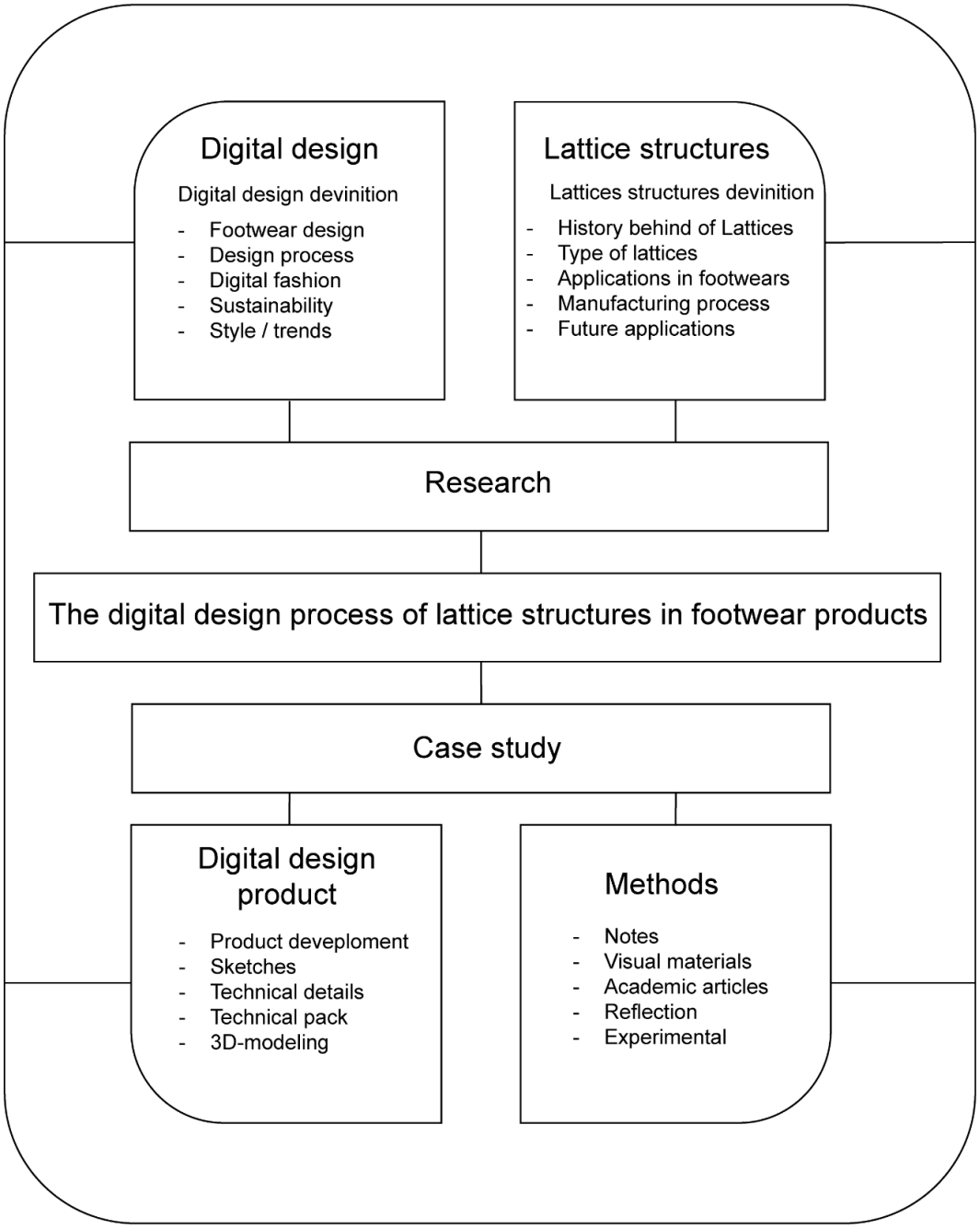
• Are lattice structures just a passing trend in the footwear industry?

• Is the digital design process a viable choice for designing footwear?

• What kind of manufacturing challenges will the digital design process face?

The theoretical framework displays thesis content, research structure, and how the subtopics are connected to each other's (figure 1).

Figure 1. Theoretical framework of the thesis



2 Design processes

The basis of the design process has not changed much in the design industry. The process still follows similar steps, from research to post-processing. Certainly, there have been different iterations in the design processes, but the base of the process is still the same. However, the methods and tools to execute these steps have developed significantly over the years. In recent years, digital design has started to impact the design industry and how designers design products.

The Hasso Plattner Institute of Design at Stanford University's design thinking process is maybe the most well-known design process, this process follows five steps empathize, define, ideate, prototype, and test (The Hasso Plattner Institute of Design, n.d.). These steps, after all, are constructing the most useful design process structure in the design industry.

The design process is part of the design journey, every journey must start with something and end somewhere. Usually, the design process gets stated on identifying the user, mapping the needs of the product or service, along with finding the perfect combination of functionality and user friendliness. Then creating the prototypes and finally testing the prototypes.

One significant change that has happened in the design process over time has been a more user-centered approach. There are multiple different methods to complete the design process. One example would be "User Journey Mapping" this method is based on well accomplish "Story Mapping" method, the "User Journey Mapping" method identifies user triggers, activities, characteristics, behaviors, and known requirements of the product (Endmann & Keßner, 2016, pp.105-107).

2.1 Definition of the digital design process

Defining the digital design process is not hard. It is basically a design process that utilizes different digital design tools and methods to design products. Product design visualization usually starts from the sketching process. Term sketching usually implies old practice to sketch pictures, but currently there are multiple different digital illustration software's to visualize the product in digital format. Software's like Sketchbook, Adobe Fresco, and Procreate being more commonly used in creating digital art and digital sketching. The benefits of the digital sketching certainly introduce options to use various brushes, textures, and colors.

In the 3D-modeling front, Solidwork and Rhino3D are the two most commonly used 3D modelling software's in the industrial design field, these software's have changed designers' approach to design products, offering them more flexibility and freedom to execute designs that have complex geometric patterns (Fathy et al., 2023, pp. 113–114). Blender, on the contrary, is free, open source, all-in-one 3D modeling software, that opens opportunities to learn every aspect of 3D modeling, from sculpting to creating visual cinema scenes (Blender, n.d.). The development of 3D modeling, augmented reality, and virtual reality software's has certainly given designers new ways to express their design and creative skillsets (Fathy et al., 2023, p. 112). Gravity Sketch is being one of the more popular software programs that combines all these new technologies in the industrial design field (Gravity Sketch, n.d.). This software focuses on virtual reality 3D modeling (Figure 2). Making the product design experience more immersive for the designer.

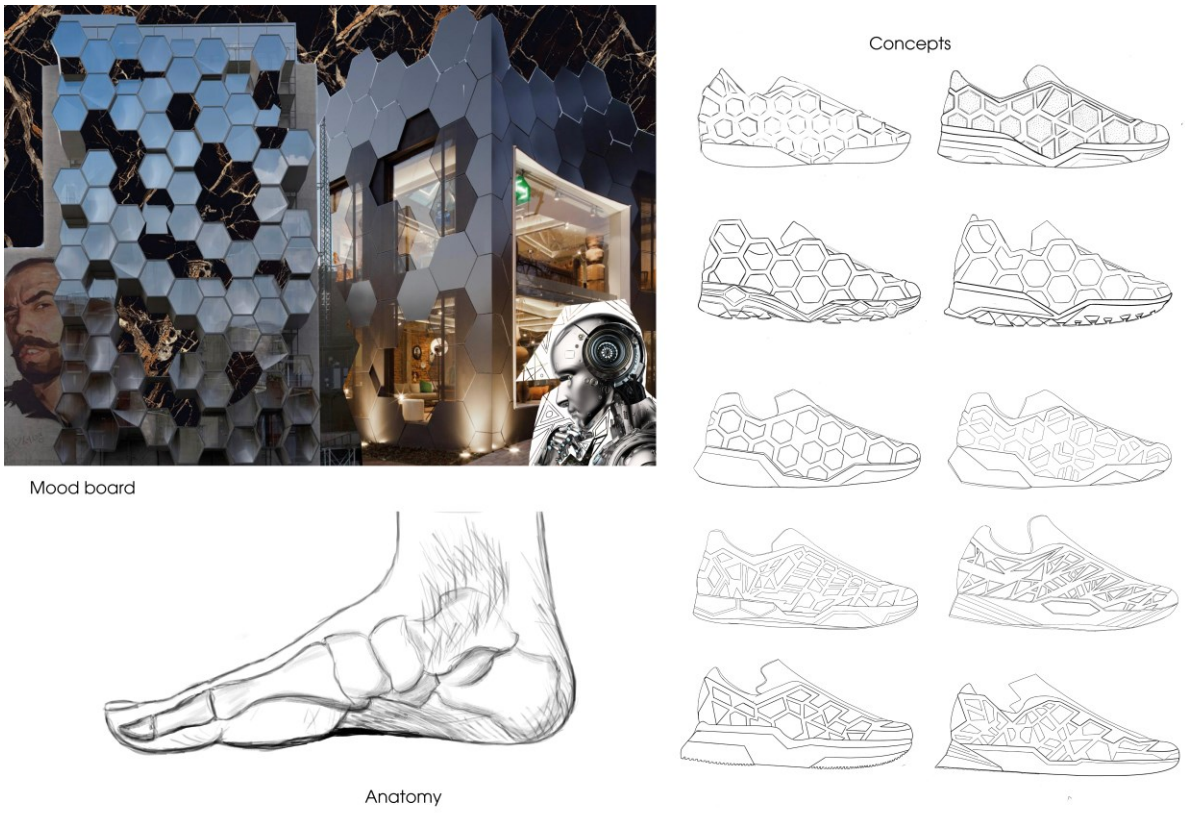
Although these mentioned software's are the most popular ones in the design field, it really does not matter which 3D software designer utilizes, because there are various 3D modeling and visualization software's out there in the design field. The only thing that matters is designers' ability to express their creativity and overall vision for the product.

Figure 2. Gravity Sketch virtual reality experience (Gravity Sketch, n.d.).

2.2 Footwear design

Footwear design is a truly interesting design category. It is basically a combination of industrial and fashion design. This creates unique challenges from an educational standpoint in the industry. Identification of the needed skillsets that the companies need is challenging, and another challenge that the footwear industry faces is a lack of literature materials (Terroso et al., 2019, pp. 347–348).

Figure 3. Samuli Ranta Hx collection project 04.03.2023: Mood board, sketches, and concept visualization.

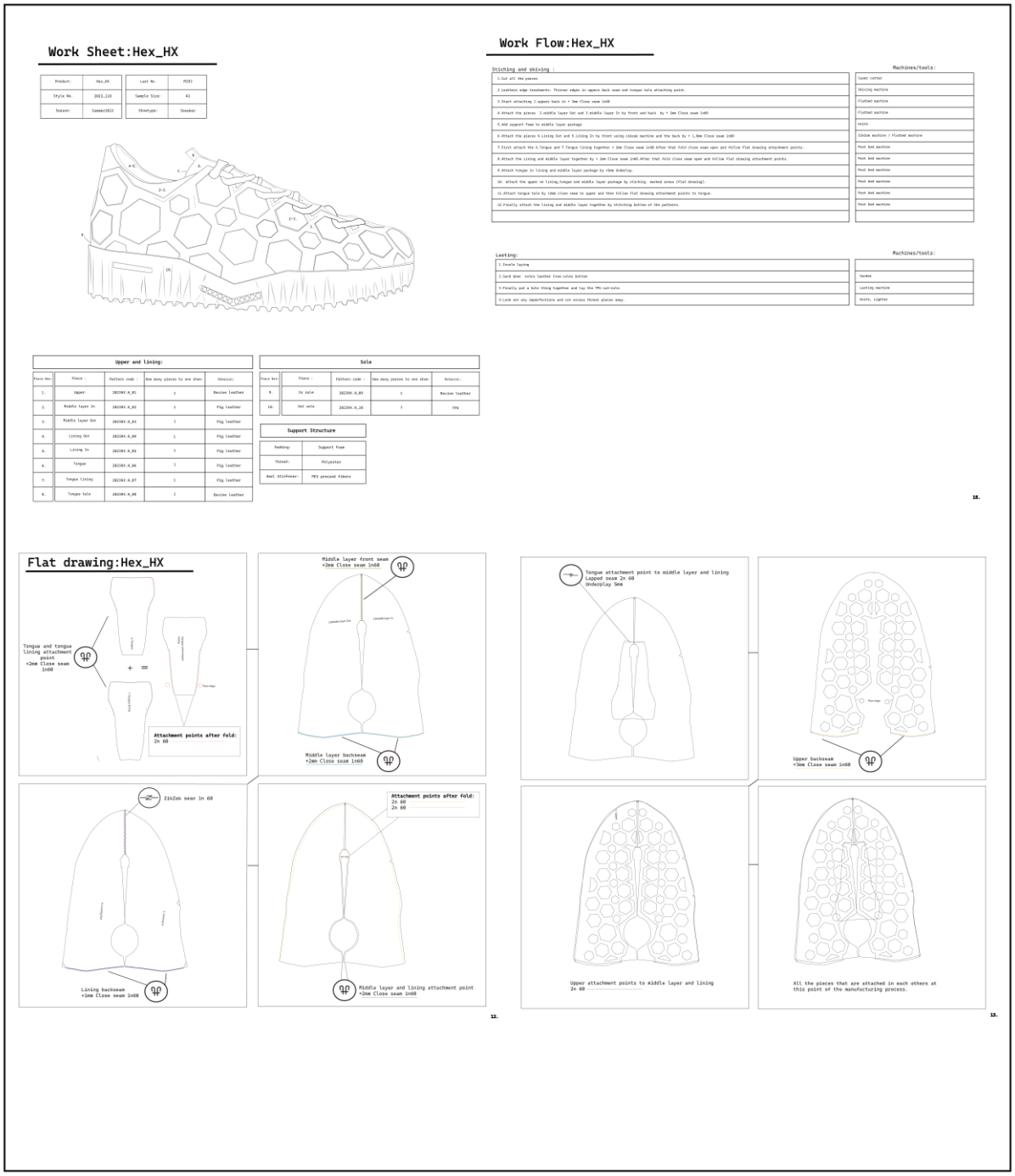


A) The footwear design process starts like any other design process, determining the overall goal, the target audience, and researching the inspiration. When the first phase of the design process is completed, the design process moves on from concept development, which usually involves creating concept sketches, mood board and other visualization of the concept (figure3). The idea becomes more clearer at this point in the footwear design process.

Figure 4. Samuli Ranta Hx collection project 04.03.2023: Mock-up of the upper parts of the footwear.

B) The next phase of the design process is prototyping. This phase consists of making the last copy and primary mock-up patterns to test the functionality of the upper and lining parts of the shoe. A mock-up is a physical prototype that is usually made of lower-quality materials (figure4.) In some cases, the prototyping phase also includes the sole design and mold-making processes, depending on the designer's responsibility areas. The sole design process has been one of the first footwear design areas that has already used the 3D modeling software's for many years.

Figure 5. Samuli Ranta Hx collection project 04.03.2023: Technical Package of the Footwear.



C) After the prototyping phase, footwear design moves onto production, this design stage evolves around the technical package of the footwear (figure 5). This includes vital information for the manufacturer about the technical details of the parts, materials, and workflow of the footwear.

Figure 6. Samuli Ranta Project Derp 22.03.2022: Product photoshoot.

D) The final phase of the design process is postproduction, which focuses on the visual representation of the final footwear concept and the product (figure6). The visual representation of the footwear´s overall style and theme helps later to create more targeted marketing materials.

There are surely different styles of education programs for the footwear design professionals, but the definition of the footwear designer profession is not specifically defined. Is the footwear designer only responsible for just one design area of the footwear? Some of the research materials indicate that the footwear design profession is more about creative work, making mood boards, collecting inspiration, creating graphic elements, concept sketches, handmade monsters (visual prototypes), and technical packages. (Terroso et al., 2019, pp. 348–351).

After that, the design process moves onto specialized technical support, who are making the sample footwear and focusing on the technical properties of the footwear (Terroso et al., 2019, pp. 348–351). After the sample footwear has been manufactured, the footwear designer will continue to promotion part of the product design process, because the industry has shown interest in the communication skills of the designer (Terroso et al., 2019, pp. 350–351). Every education program has its own focus and has different goals for the students, but learning the overall footwear design process would be beneficial for the industry, making the footwear designer more well-rounded in every footwear design area.

2.3 Digital fashion

A description of digital fashion is clothing items that are made using digital tools and software's. Around the 1990s, digital fashion started to emerge, and one reason for that was the accessibility of the internet along with other digital tools (Biliakovych et al., 2024, pp. 5–6). During that time the video game industry started to evolve significantly, graphics did take a huge step forward, and storytelling aspects became a more prominent part of the games. There is no denying that the video game industry had a significant impact on the early development of digital fashion. Even an argument could be made that the video game industry was a precursor for the digital fashion.

Digital fashion has gained popularity in recent years, and now that technology has finally caught up to the point that rendered 3D models are realistic enough, making implementation in mainstream fashion circles possible, the fashion industry has started to notice these emerging technological possibilities. Another variable is that consumer habits have already started to evolve around non-material substitutes, and climate change has become a more critical consumer focus (Schauman et al., 2023, p. 744).

Digital fashion is strongly linked to the digital design process, as mentioned in the previous chapters, 3D-modeling and other visual software tools are big parts of this process. The interest in applying the digital design tools is certainly there, many of the biggest names in the fashion industry have started to design some product lines by utilizing digital design tools, and Tommy Hilfiger announced that the company will be switching to a fully digital design processes in year 2022 (Biliakovych et al., 2024, p. 9). The bigger companies see the future potential of the digital fashion, giving brands opportunities to market, promote, and sell virtual

counterparts of their actual products in videogames or metaverses (Biliakovych et al., 2024, p. 9). Brands like Louis Vuitton, Gucci, and Balenciaga have already presented virtual products in videogames (Biliakovych et al., 2024, pp. 9–10).

Non-fungible tokens (NFT) are the base of the digital fashion. The NFT tokens help consumers claim exclusive ownership of the digital products, but the digital products can also be copied and shared from online. (Schauman et al., 2023, p. 744). This created an interesting dilemma in the consumer market. Do consumers really care about the authenticity of their digital products? The answer is not maybe the simplest, but NFTs need more development, and consumer culture maybe has to change for the direction where digital products see more as physical consumer products. The future role of the NFTs is very uncertain, and various industries are still looking for its direction in the digital art and fashion spaces. (Schauman et al., 2023, pp. 744–745)

The videogame and virtual word industry is valued at over 180 billion dollars in 2021 and is estimated to grow to over 390 billion dollars in 2025. (ARK Invest, 2021, p. 21). That certainly makes a compelling point about why the fashion industry should consider entering in the virtual product space and start selling digital counterparts of their actual products in popular videogames.

2.4 Sustainability of the digital design

The sustainability aspect has surely been one of the reasons why the digital design has been gathering popularity in the design industry. Nonmaterial methods to design products are certainly better for the environment for multiple reasons. It does not create any extra waste, does not require any extra materials from the sketching phase to prototyping, and the life cycle of today's computational devices are relatively long.

Consumer culture is directly linked to sustainable practices and changes that are now happening in consumer behaviour are indicating a major shift. 76.9% of consumers in develop countries are supporting sustainable practices, and 93.5% of consumers are willing to pay more for sustainable products (Schauman et al., 2023, p. 746).

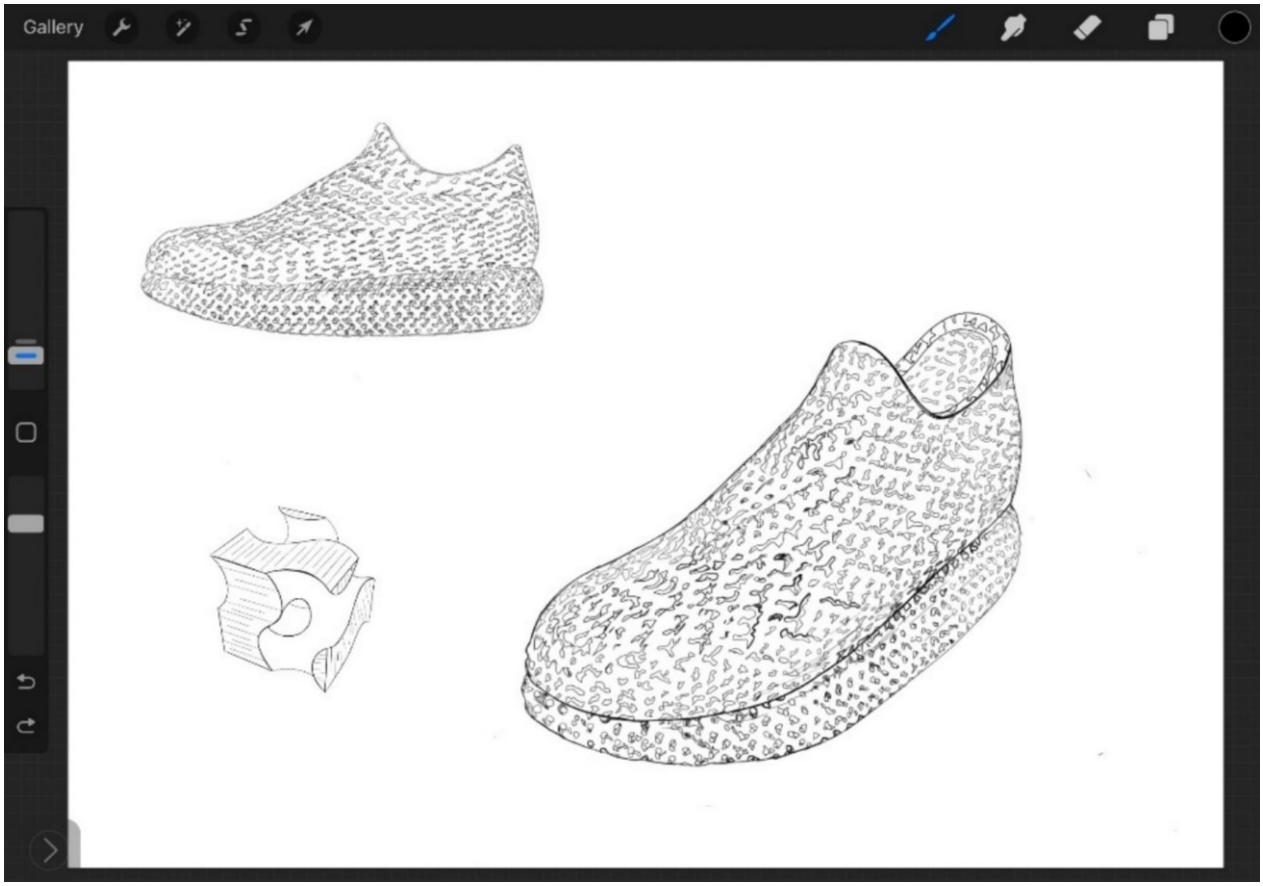
Overall, sustainability has become an important point in many industries in recent years, affecting radically the design processes, product life cycles, and waste reduction, the focus has shifted toward minimizing the environmental impact (Fathy et al., 2023, pp. 114–117).

The fashion industry has been criticist in the environmental impact it produces on the world, but there is potential that the digital design in the metaverse and videogame industry may be the salvation that the fashion industry is looking for (Biliakovych et al., 2024, p. 12). In the future, the fast fashion business model may take on a new form in the digital design area, producing similar amounts of revenue for the fashion industry without having a negative environmental impact on the world.

2.5 Case study: Digital visualization of the footwear

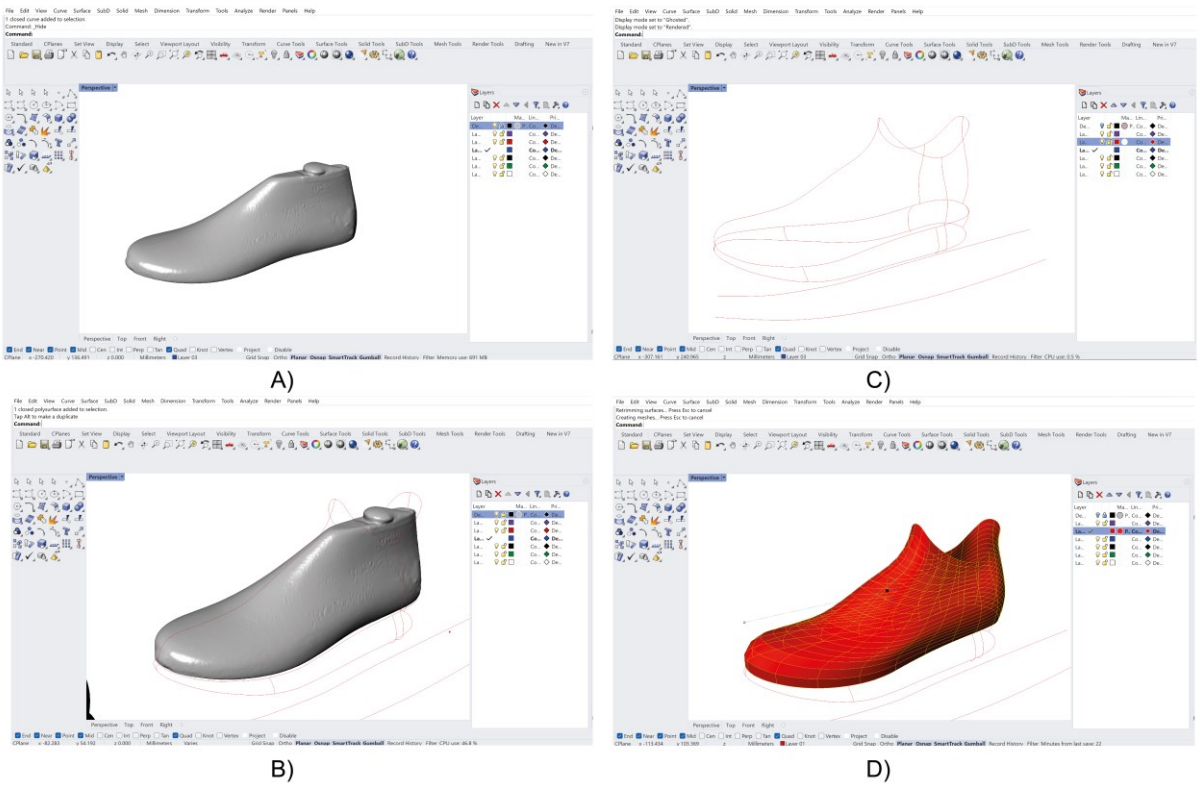
After the background research is done and the source of inspiration have been discovered, the actual footwear visualization process can start with the sketching process. In this phase, footwear usually finds its visual direction (figure 7).

Figure 7. Procreate interface: Sketching process of the footwear.



When the visual direction of the footwear has been decided, the 3D modeling part can be applied. The 3D modelling consists of various phases and is the building block of the actual footwear in the digital design (figure 8).

Figure 8. Rhino3D interface: 3D modeling process of the footwear



A) Imported last in Rhino3D software is the starting point of the footwear modelling process and works as a base for the footwear.

B) Tracing the shape of the last with the curve lines gives the designer the perfect last copy, which creates a starting point for the overall footwear and sole structure.

C) A designer can make new direction lines to last copy or modify existing curve lines for the desired shape.

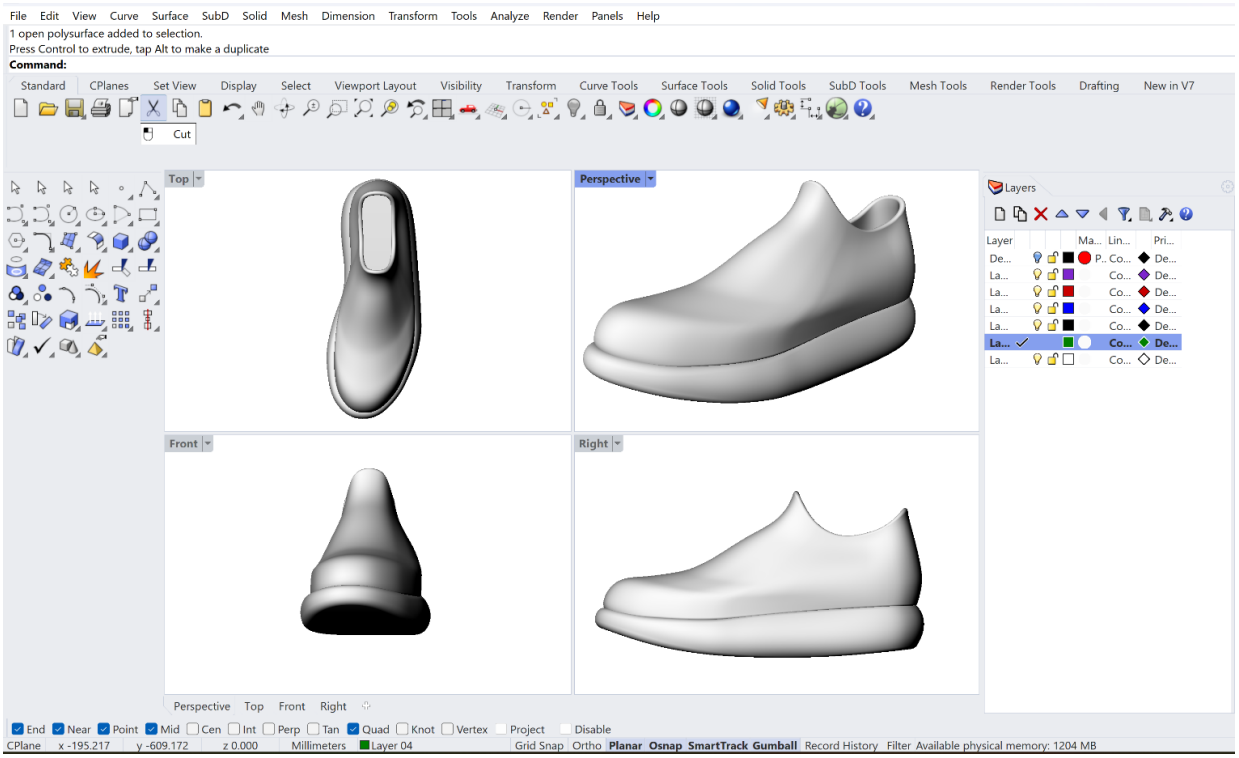
D) The curve line network works as a basis for a surface buildup.

These four phases offer a solid basis for a 3D model of the footwear (figure 8). After the solid understanding has been accomplished, it is just repeating all over these phases for a different part of the footwear. Furthermore, these phases and design methods can also be applied to different 3D-softwares (figure 8).

After repeating all the phases on the sole part of the footwear (figure 8). The modelling process continues with refining the shape of the footwear by trimming, rounding, and rebuilding the surfaces, ultimately forming the final shape of the footwear (figure 9). At this point in the digital design process, the visual direction looks to be on track, if compared to the

concept sketch (figure 7). This footwear model works as a base for lattice cells at a later point in the thesis.

Figure 9. Rhino3D interface: Final 3D model of the footwear



2.6 Summary

Design processes certainly have changed over time, along with various digital design methods and tools, but there is still a place in the design field for more traditional design methods. Traditional design methods offer designers valuable knowledge from past centuries, this especially applies in the footwear design area. When designing footwear products, there is a remarkable amount of technical information that has to be taken into consideration. Learning the traditional design methods will ultimately help designers understand the overall design process better, and this information can be applied to the digital design processes.

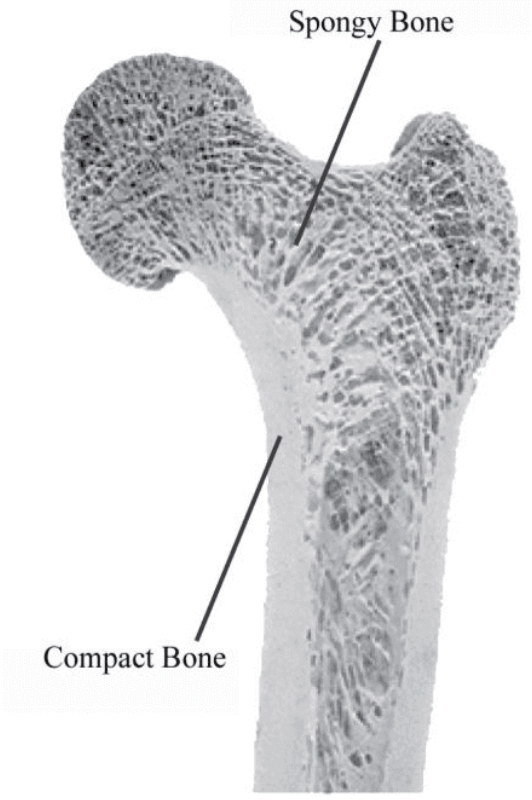
One of the beneficial aspects of the digital design process is the expansion possibilities for other industries, like videogames and metaverse without any extra work or complications. Fundamentally making one product design into two products digital and physical. Of course, there are still unanswered questions about NFTs and the copyrights of the digital designs.

From a viability standpoint, the digital design process does not face any problems if the designer has a basic knowledge of the design processes and the intended product. From a visual viewpoint, the 3D modeling of the product presents a more accurate and vivid representation of the concept product.

3 Lattice structures

A lattice structures those hollow cellular structures that can be seen naturally in bones, mushrooms, and honeycombs. Lattice structures have been named in bones as “Spongy Bone Structure” (figure10). Also, at the cellular level lattice structures can be seen in various materials, the perfect example being EVA foam.

Figure 10. Spongy Bone structure (Rahim & Adibah, 2018, p.2)

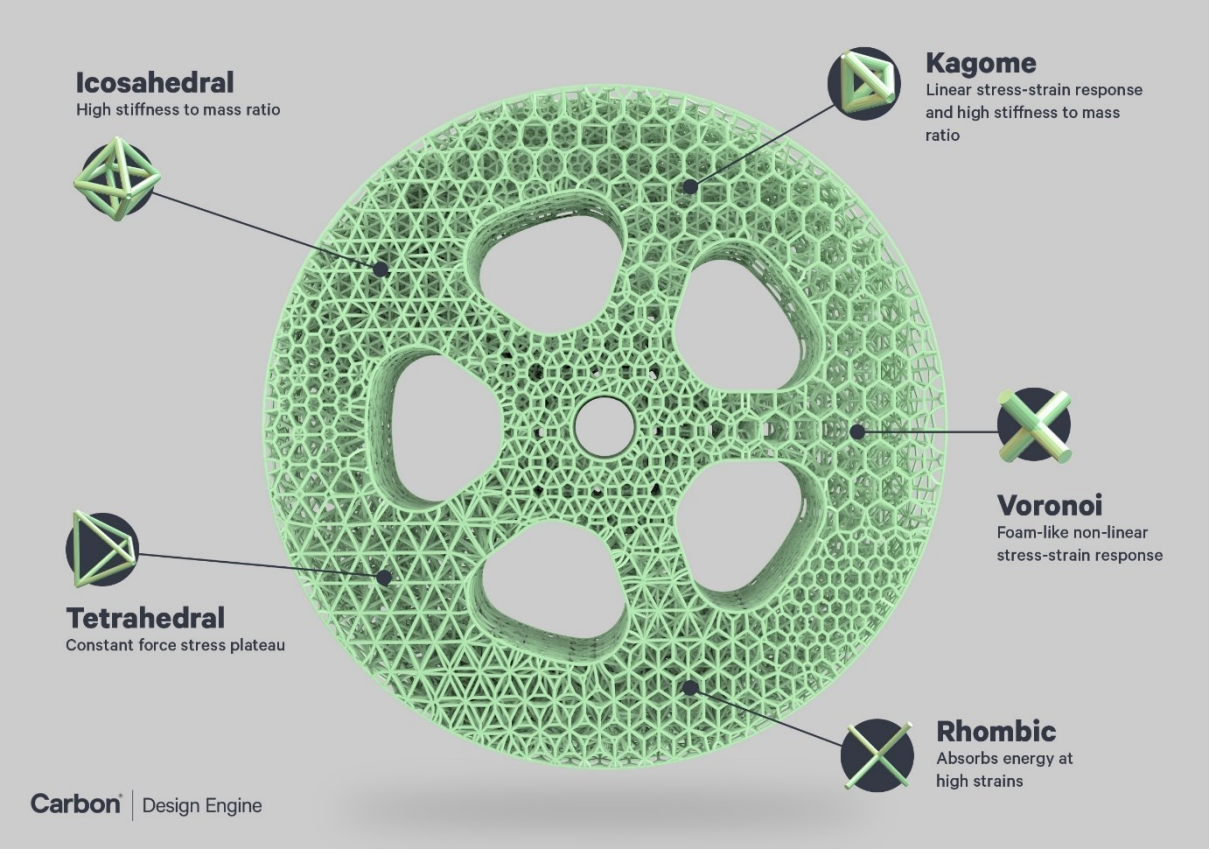


The technology has evolved to the point that people can now design their own lattice cells to match the needed properties of the product, thanks to advancements in additive manufacturing technology and 3D modeling software’s. The visual direction of human-made lattice structures has mainly been a bigger version of the cellular structures and focus on the symmetrical cell designs, but perfect cell symmetry can only be achieved if the applied object of the lattice cells is symmetrical.

The lattice structures can be symmetrical geometrical patterns, but lattice structures can also be unsymmetrical patterns or a combination of the different lattice cell types (figure 11). There is not truly one defining definition to describe these structures.

Automotive, biomechanical, and aerospace industries have already started to implement lattice structures for the different parts of their products (Seharing et al., 2020, p. 6).

Figure 11. Different cell types (Carbon Inc, 2022, p.3).



3.1 History

The beginning of lattice structures was just a mathematical theory, but over the years, this theory has reshaped multiple industries. This theory was named for lattice theory, and it was the result of multiple areas of mathematics, according to lattice theory, the lattices can be divided by lattice properties into different types, distribution, modular, and complemented (Bilová, 2001, pp.251–252).

The biggest contribution to putting lattice theory on the map belongs to Garrett Birkhoff, who is often considered the father of the lattice theory, he did not only introduce the English term "lattice" he also introduced distinct applications for the theory (Bilová, 2001, pp. 253–254).

At the end of the 1930's, lattice theory started to appear also in mathematical circles, the Garret Brinkhoff's well-known "Lattice Theory" started to get some attention, which fuelled further development of the lattice theory, later theory became recognisable part of modern algebra (Bilová, 2001, pp. 254–255). There is no denying that the work of mathematicians like George Boole, Richard Dedekind, and Karl Menger had an extensive impact on the early mathematical logics, algebra, and geometrics, which ultimately helped to birth the lattice theory (Bilová, 2001, pp. 252–255). Newer iterations of these theories still lives on the computational design area and have an extensive impact on the topologies of the lattice cells.

3.2 Types of lattices

Topologies in the lattices are the base of the cellular structure (figure12). The cells are linked to other cells, creating a network of cells, which is more commonly known as a lattice structure. There are various pre-existing topologies, but a lot of research has also been done for custom cell topologies. The main goal of the research is usually to create cell topologies for a specific need.

Different cell topologies offer various properties for stiffness, strength, weight, and flexibility. (Dong et al., 2019, pp. 722–723). Optimizing the topology of lattice structures can be beneficial for many reasons, for an example, in the footwear industry the right type of lattice structure can help absorb energy better and improve the overall user experience (Ghimouz et al., 2023, pp. 15–16).

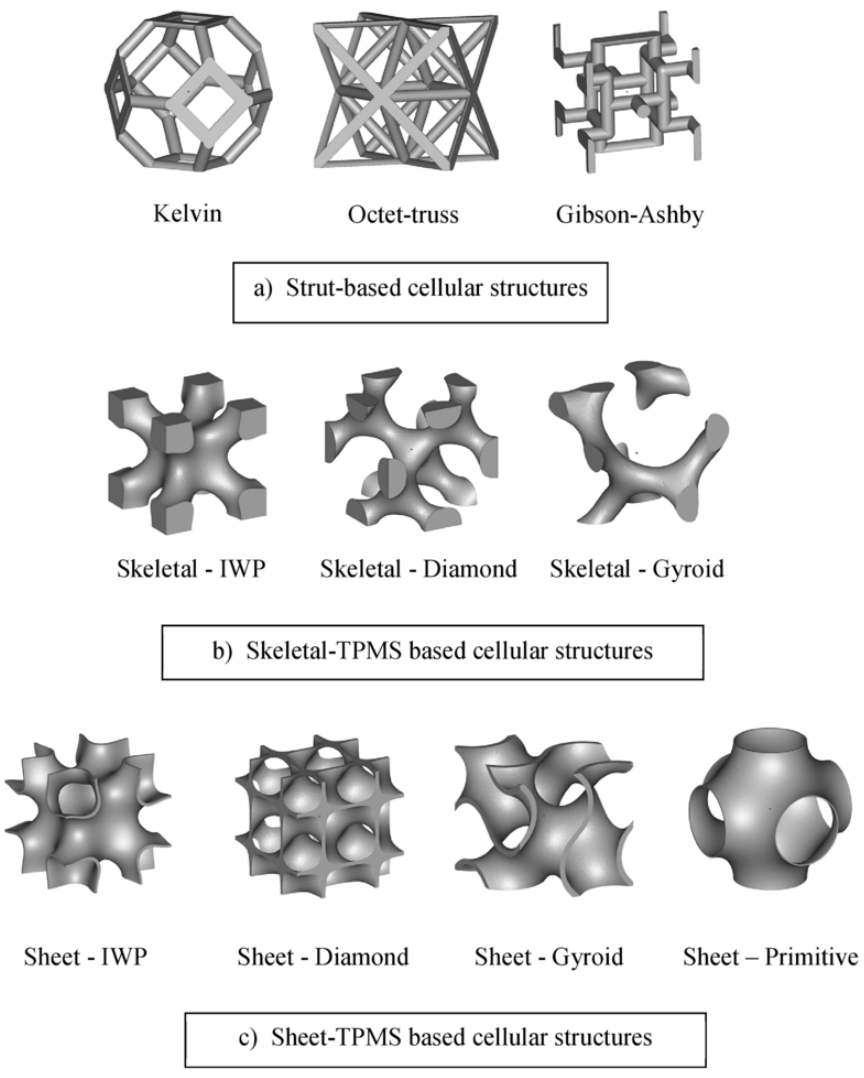
All lattice structures start with cell topologies, the lattice cells can be put into three different categories strut-based lattices, skeletal-TPMS based lattices, and sheet-TPMS based lattices (Benedetti et al., 2021, pp. 4–7).

The strut-based lattice cells are built around vertices and edges, forming a cell unit, a couple of cells can be put together in a regular and undistorted way to form patterns and connections for the other cells by struts or more commonly named beams (Benedetti et al., 2021, pp. 4–7).

The Sheet TPMS lattice cells are based on triply periodic minimal surfaces (TPMS), these cells have continuously curved geometries and are based on mathematical formulas, the structure has been put together in a 3D patterns, the sheet TPMS cells are created more solid along with a thicker structure (Benedetti et al., 2021, pp. 4–7).

The Skeletal-TPMS lattice cells are like the Sheet TPMS lattice cells these cells are also based on triply periodic minimal surfaces (TPMS), Skeletal-TPMS cells are less dense oriented cells, creating a more separated cellular structure (Benedetti et al., 2021, pp. 4–7).

Figure 12. Different cellular structures (Al-Ketana et al., 2018, p. 168).



3.3 Footwear applications of the lattice structures

The style of the lattices is truly unique, and that can be the future trend starter in the fashion industry. In the footwear industry, commercial lattice structures are just starting to appear. Big brands like Adidas already have commercially manufactured lattice structured footwear products in the footwear market (figure13). Also, another German brand, Puma is following in Adidas's footsteps into the commercial lattice structured footwear area at their Porsche Design 3D MTRX footwear in 2023 (Puma CATch up, 2023).

When two big brands enter the same design area, that certainly indicates demand for lattice structured footwear products because these big brands put a lot of money into customer research. The lattice structure footwear application has mainly consisted of the sole part of the footwear, but there are endless implementation possibilities in other parts of the footwear as well.

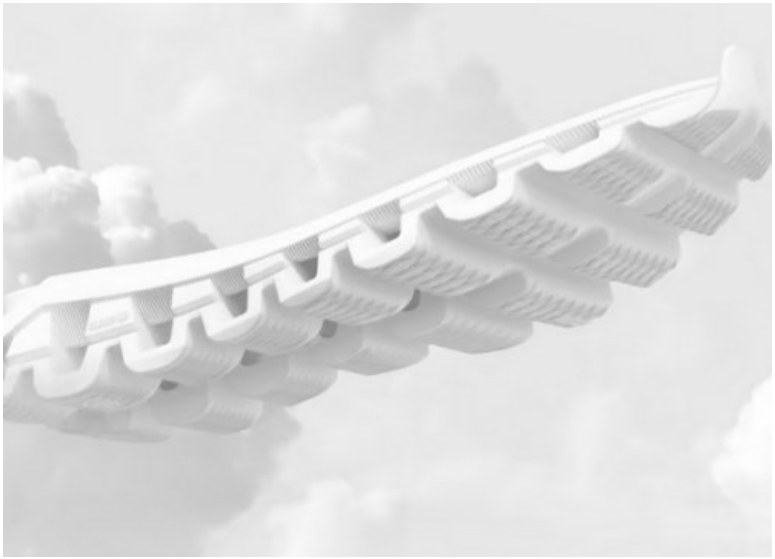
Figure 13. Lattice structured footwear: Adidas 4D Futurecraft (News Adidas, 2017).

The lattice structures in footwear are part of the hollow sole structure’s subgroup, not all the hollow structures are lattice structures, but other hollow structures offer similar properties for the footwear products.

On Running popularise the hollow structures in a footwear sole by introducing their CloudTec technology (On, n.d.). Proving data at the same time, that the hollow structures in footwear

products can work style- and performance wise (figure14). This also significantly boosted the development process of the lattice structured footwear products. In 2017, Adidas launched 4D Futurecraft footwear, this being the first commercially produced lattice structured footwear product in the footwear industry (Gregurić, 2022). Both innovations kicked off a new era in the footwear industry by innovating whole new structures in the footwear soles.

Figure 14. On CloudTec sole structure (On, n.d.).



The lattice structures are becoming a more valid structural choice in footwear products. Offering better energy absorption, structural durability, weight distribution, and natural frequency of the foot compared to other multicellular structures (Wang et al., 2021, p. 1–3).

Orthopaedic and foot health benefits are not usually listed as perks of lattice structures, but there is a lot of actual data supporting this. The lattice structures can reduce pressure on the ligaments and the heel points of the foot, the diamond lattice structure seems to be an optimal choice for shock absorption and reducing stress on the metatarsal bones (Liu et al., 2020, p. 6–10).

3.4 Lattice structures manufacturing

There are various additive manufacturing (3D printing) options for the manufacturing of the lattice structures. Selective Laser Sintering (SLS), Laser Powder Bed Fusion (LPBF), Stereolithography (SLA), Digital Light Processing (DLP), and Multi Jet Fusion (MJF) are just a few additive manufacturing choices from the 20 subtypes (Schwaar, 2024).

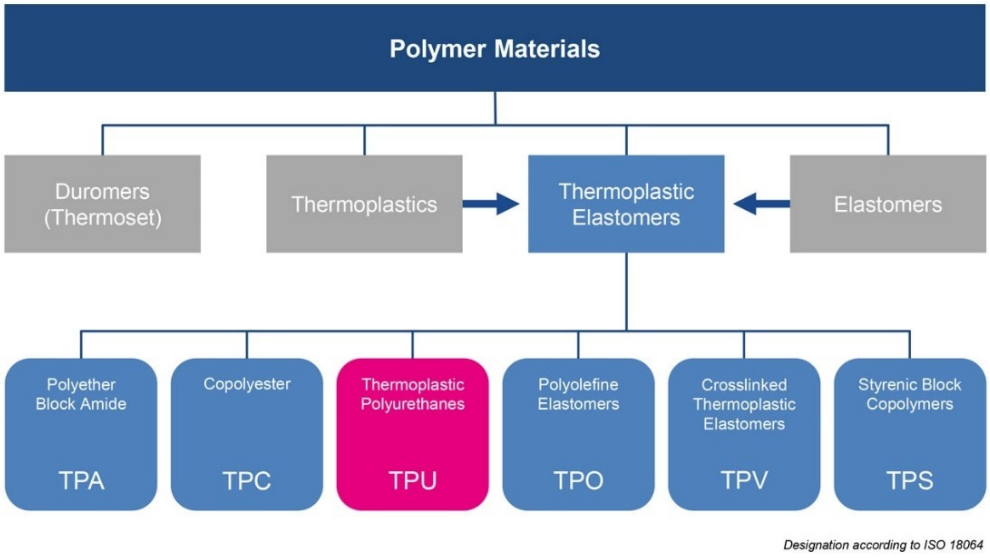
These additive manufacturing (3D printing) methods have made possible to manufacture complex geometrical patterns, before additive manufacturing three-dimensional cellular lattice structures were next to impossible to manufacture (Dong et al., 2019, p. 720–721). Additive manufacturing debuted first in the 1980s and has not yet reached its full potential (Ghimouz et al., 2023, p. 5). This makes 3D printing technologies over 40 years old. In the technology industry, that is a significant milestone, but in the manufacturing industry, the technology is still relatively fresh. At the commercial manufacturing level of the lattice structures, the most popular manufacturing method is being different digital light processes, based on the already launched Adidas 4D Futurecraft (figure15). This method uses projected digital light to build a 3D model by flashing an image on each layer, this process is repeated layer by layer (Schwaar, 2024).

Figure 15. Adidas 4D Futurecraft sole (News Adidas, 2017).

The additive manufacturing (3D-printing) offers various material choices from hard to soft. Often, 3D printing is linked to hard materials such as PLA and ABS (Vicknair & Renganathan, 2023). But chemists and material scientists have developed materials that can mimic rubber-like properties, making flexible 3D prints possible (Vicknair & Renganathan, 2023). Materials such as TPU, TPA, and TPC are part of the thermoplastic elastomer's subgroup of the polymers (figure 16). These are typically softer and more flexible 3D printing materials (Vicknair & Renganathan, 2023). These were the materials that truly started the 3D

printing revolution in the footwear industry, providing a viable substitute for traditional materials such as rubber and EVA.

Figure 16. Polymer Materials: Thermoplastic Elastomers (KRAIBURG TPE, n.d.).

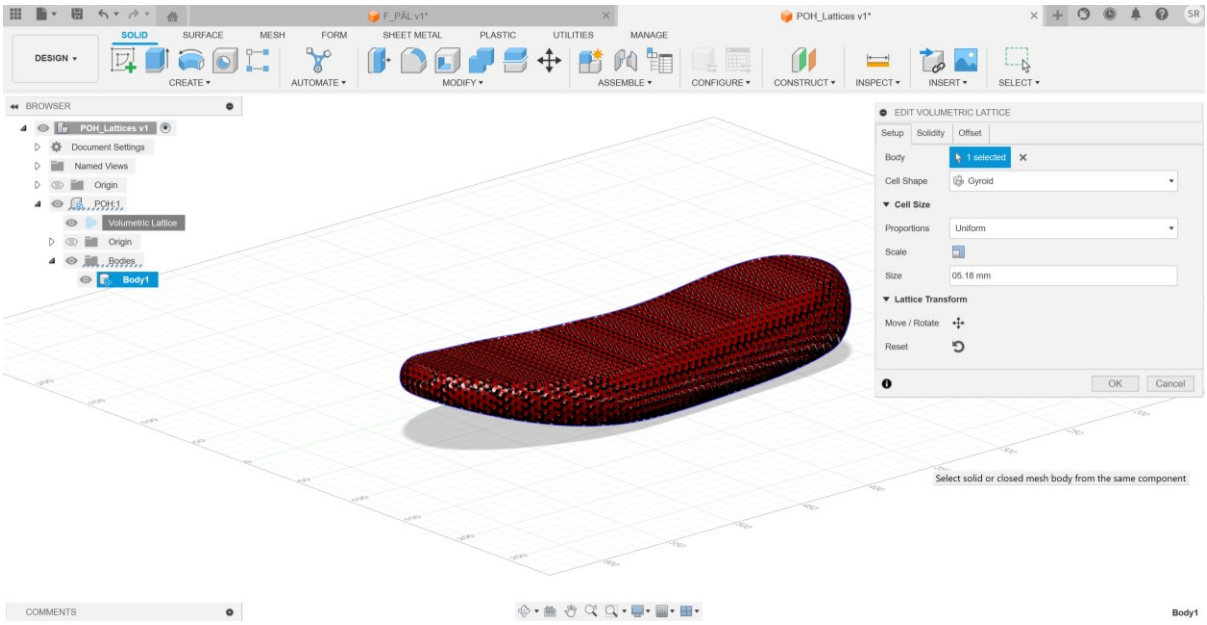


Ultimately, the footwear industry did choose resin as their main additive manufacturing (3D printing) material due to the manufacturing method of Digital Light Processing (DLP). This method offers opportunities for larger and faster manufacturing volumes along with relatively affordable 3D-printing machines if compared to a similar additive manufacturing method, Stereolithography (SLA) (Schwaar, 2024).

3.5 Case study: Implications of the lattice structures in the 3D model

Applying the lattice structures starts with importing or making the base for the lattices. In this case, the first piece is the sole part of the footwear (figure 17). After the desired cell structure has been found, the similar process can be repeated on the upper part of the footwear (figure 18). A lot of variations can be made from one cell type. This case study uses different variants of the sheet TPMS lattice cells to build the structures in footwear soles and upper pieces (figure 18). Certainly, a visual difference can be seen between these structures, but the reason for that is the specific gyroid cell variants also, position, ancle, and size of the cell affect the lattice structure aesthetics.

Figure 17. Fusion360 interface: Imported sole part of the footwear.



Later, the volumetric lattice structures can be converted into meshes and then combined with each other's (figure 18).

Figure 18. Fusion360 interface: Sole and upper parts of the lattice structured footwear.

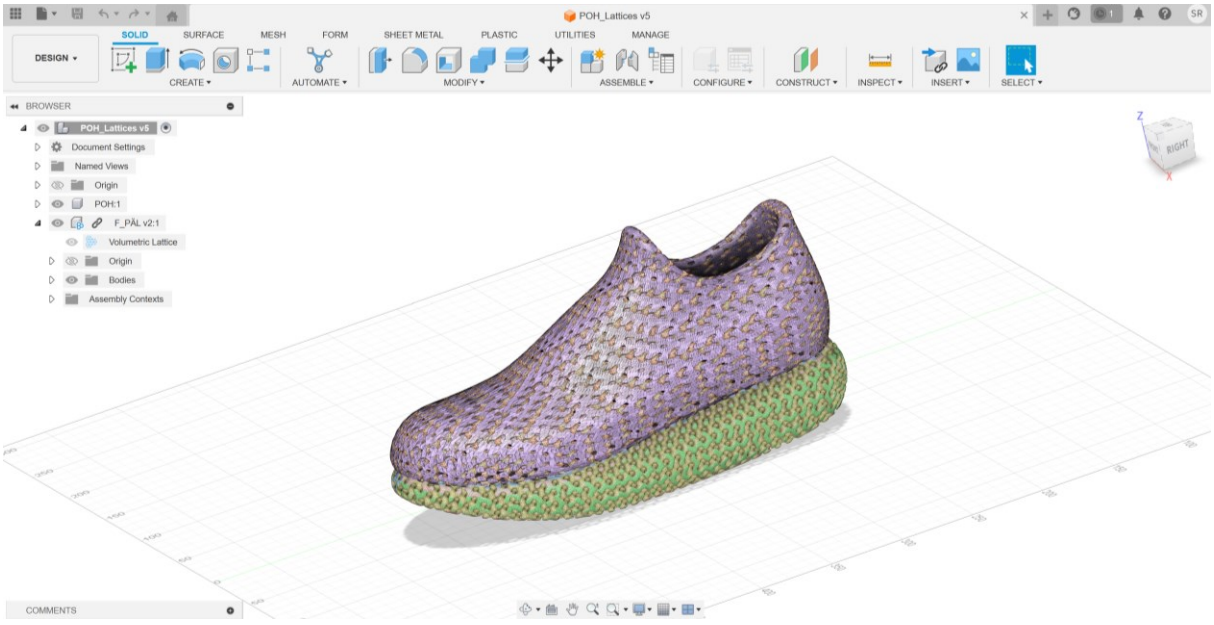
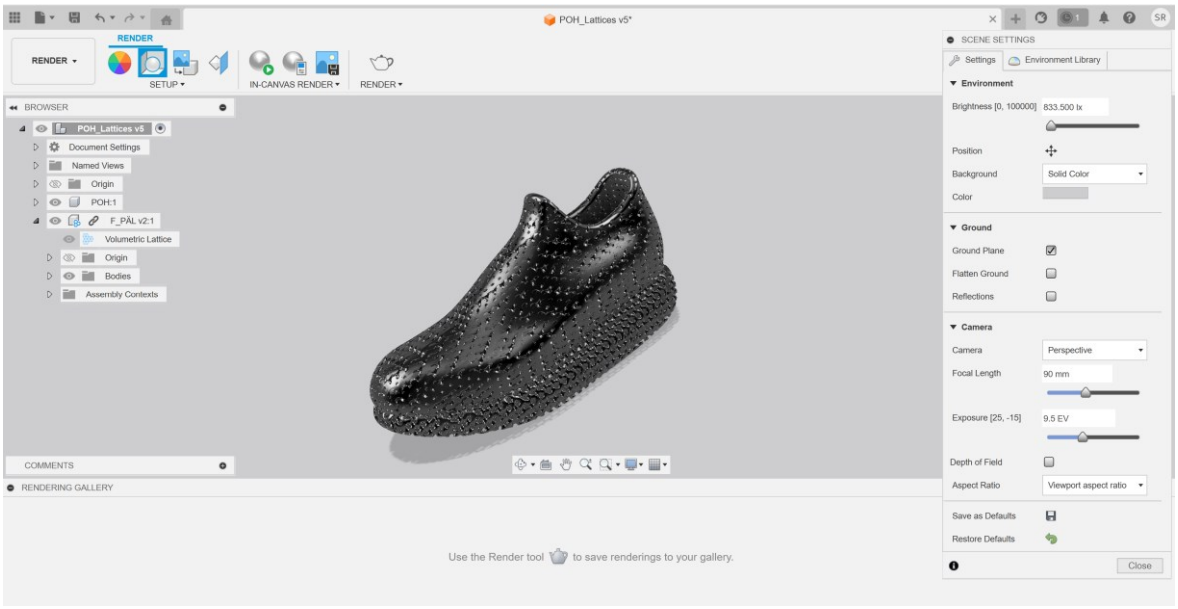


Figure 19. Fusion360 interface: Rendering the footwear.



The final phase of the design process always consists of a perfect visual representation of the product (figure 19). The product rendering consists of material, texture, and scene selection. The designer can alter the light source to give the product a more highlighted look in the scene selection, and the environment of the product can also be changed there. At the appearance selection, the designer can select the materials of the product and alter textures, from roughness to surface reflectance. Rendering products in 3D modeling software's makes the digital product stand out a bit more and appear more realistic.

Figure 20. Fusion360 interface: Final render of the lattice structured footwear.

The final render displays the glossy resin surface, capturing all the structural detail of the lattice structured footwear (figure 20). Furthermore, the case study shows the future possibilities of lattice structured footwear, demonstrating the multiple ways to use lattice cells.

3.6 Summary

The lattice structures definitely have unique features and technical advancements, at this point it is surely hard to imagine that the lattice structures got their start from a mathematical theory. Additive manufacturing (3D printing) has made the manufacturing of cellular lattice structures possible, but the only manufacturing challenge that the digital design faces is time. It is still uncertain which additive manufacturing (3D printing) method will be most reliable in the future because there is no long-term data available yet on the quality of commercially 3D printed products.

Just a few additive manufacturing (3D printing) methods have been deemed to be suitable for larger scales of manufacturing, and Digital Light Processing (DLP) is one of them. But the development of the different additive manufacturing (3D printing) materials has made significant impact on the footwear industry, making the footwear manufacturing process possible by using the additive manufacturing (3D printing) method. The technology still needs more development time and development breakthroughs to start the next industrial revolution. The future possibilities of this technology still looks more than promising, if the various industries interest in the technology is any indication.

The footwear industry has surely linked its own future vision to lattice structure footwear products. Giving us indication that the lattice structures in footwear products are here to stay and are already trending in the fashion industry.

4 Conclusion

Digitalization in a modern society is not anymore groundbreaking ideal, basically everyone has some sort of computation device with them all the time. Indefinitely, digitalization will be implemented in any design process in some capacity. Making the digital design processes part of the designer’s everyday life. The digital design process has opened new opportunities

for the design industry to expand in the videogame and metaverse areas. By using 3D modeling tools in a product design process, the actual 3D model of the product can be easily exported to any digital platform without making any changes to the actual product design process. At this point, even serious sceptics have to recognize the beneficial parts of the digital design methods and the viability of the process. Surely traditional design process methods will work as education material as well as direction for young designers. Giving them knowledge that can be applied to digital design processes as well. Digitalization in the design field is not just changing the design processes but has also opened up new structural possibilities, giving designers more freedom to express the wildest shapes and patterns in the product design. With the digitalization of the design processes and additive manufacturing (3D printing) technology, even the wildest design can be accomplished. The lattice structure being the perfect example of a complex and innovative structural choice.

In the footwear industry the lattice structures have become an industry phenomenon, speeding up the research work on additive manufacturing technology and making the implications of digital design processes part of the industry's product design process.

These practice-based parts of the thesis provided valuable information about the digital design processes and the implications of the lattice structures in the footwear products. The case study’s 3D file of the footwear can be sent to any additive manufacturing facility to be printed on functional footwear product as well as imported into videogame or metaverse worlds. This certainly leads to the conclusion that the lattice structures have become more than just a passing trend in the footwear industry, and the development process of the perfect lattice structured footwear will admittedly continue in the future.

The objective of the thesis was accomplished. The thesis provided deep research into the digital design area of the design industry along with practice-based case studies that introduced the implications of the lattice structures in the footwear products and at the same time confirmed the viability of the digital design process.

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Appendix 1. Data management plan

Research data includes photographs, observations, and images.

During the thesis process, data has been handled in Microsoft Word software and stored on a private storage device. Only the author has access to the data and other information. The thesis does not include any personal data or sensitive information.

The thesis is made without any employer. Making its data, findings, and ownership belong to the author. After the work has been completed, the author does not want to make research data available for the further use. The author of the thesis will store the data in a secure manner for a period of one year from the date of approval of the thesis, in this way the results of the thesis can be verified and dispose in a secure manner, if required.