FACULDADE DE ARQUITETURA

Analogue vs digital. Specificities and complementarities from personal experiences

Marco André da Silva Rosa

U.PORTO

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Orientator: Professor Dr. José Pedro Sousa.

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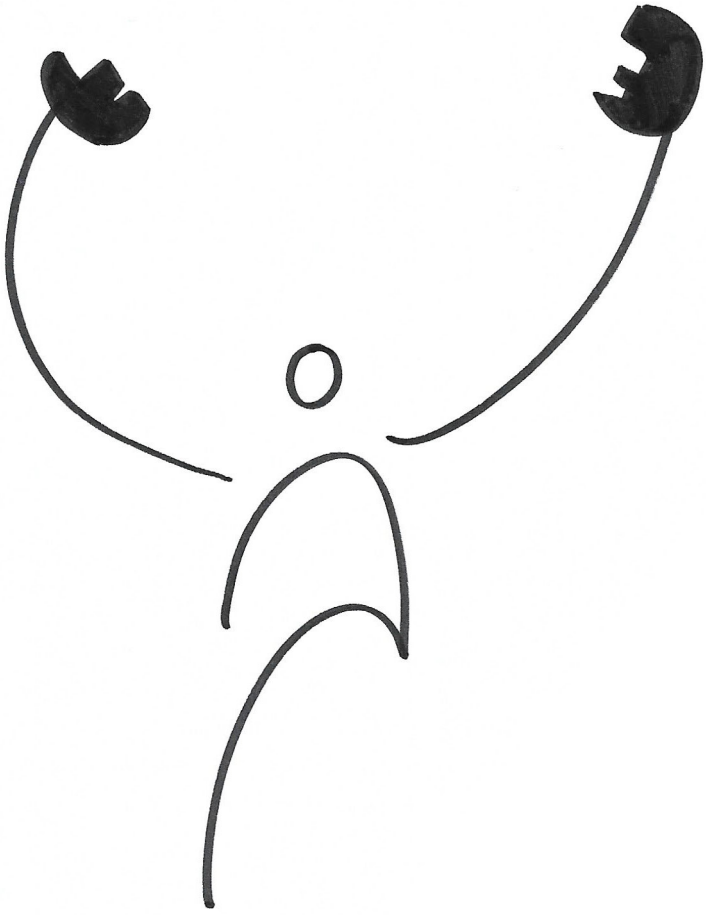


“The New European Bauhaus is the soul of the European Green Deal. And, we want to bring it to life in an attractive, innovative and human-centred way. That is why, we are aiming for three kinds of transformations.

…

Second, transformation needs to happen in the enabling environment for innovation, for instance by intelligently combining new and traditional technics, and local crafts and knowledge” (Gabriel, 2021).

Maryia Gabriel

EU Commissioner for Innovation, Research, Culture, Education and Youth

Figure 1. Concept sketch for the thesis. Fusing analogue and digital

Abstract

The author has been provided previously with the opportunity of experiencing an analogue dominant and digital dominant methodology both within his education and practice of architecture. These experiences occurred in Portugal and the United Kingdom, two countries with starkly different approaches to architecture. This thesis intends to analyse these two different experiences within design and construction to therefore propose how each can complement one another.

To analyse such work, interviews with lead architects associated with the respective experiences will offer a professional and mature perspective to the work. This will be supported with primary sourced interviews with architects from the architecture talk series *Café com Esquissos*, along with conversations with individuals from the architectural and art community. These primary sourced references will be supported with literature to provide depth and ensure a well-rounded thesis.

The study offered an accurate insight into why and how the tools assisted both the author and respective architects in completing each of the design and construction phases of both methodologies. The study proposed each methodology could complement one another. However, this interaction relied upon two circumstances, design difficulty and the skillset of the workforce both within the design and construction phases. Future studies into the actual application of this hybrid methodology would test these proposed theories.

Keywords.

Methodology, Analog, Digital, Hybrid, Personal, Experience, Design, Construction, CAD, CAM, Craftsman, Portugal, United Kingdom, New European Bauhaus

Resumo

O autor teve a oportunidade de experimentar uma metodologia analógica dominante e uma metodologia digital dominante tanto na sua educação como na sua prática de arquitectura. Estas experiências ocorreram em Portugal e no Reino Unido, dois países com abordagens fortemente diferentes da arquitectura. Esta tese pretende analisar estas duas experiências diferentes no âmbito do design e da construção para, por conseguinte, propor como cada uma pode complementar-se mutuamente.

Para analisar este trabalho, entrevistas com arquitectos principais associados às respectivas experiências oferecerão uma perspectiva profissional e madura do trabalho. Isto será apoiado com entrevistas de fonte primária com arquitectos da série de palestras de arquitectura *Café com Esquissos*, juntamente com conversas com indivíduos da comunidade arquitectónica e artística. Estas referências de fontes primárias serão apoiadas com literatura para fornecer e assegurar uma tese bem fundamentada.

A análise ofereceu uma visão precisa do porquê e como as ferramentas ajudaram o autor e os arquitectos a completar cada uma das fases de concepção e construção de ambas as metodologias. O estudo propôs como cada fase poderia ver cada metodologia complementar-se mutuamente. No entanto, esta interacção baseou-se em duas circunstâncias, dificuldade de projecto e conjunto de competências da equipa de trabalho tanto no projecto como na construção. Estudos futuros sobre a aplicação efectiva desta metodologia híbrida testariam estas teorias propostas.

Palavras-chave.

Metodologia, Analógico, Digital, Híbrida, Pessoal, Experiência, Design, Construção, CAD, CAM, Artesão, Portugal, Reino Unido, New European Bauhaus

Contents

Acronyms

AR Augmented Reality

AH Adam Holloway

AHA Adam Holloway Architects

CAD Computer-Aided Design

CAM Computer-Aided Manufacturing

EGD European Green Deal

FAUP Faculdade de Arquitetura

IR Industrial Revolution

JPL João Paulo Loureiro

ML Machine Learning

NEB New European Bauhaus

OBSA Oxfrod Brookes School of Architecture

PJ Pedro Jervell

VR Virtual Reality

WEF World Economic Forum

1.Introduction

1.1 Motivation

The thesis is written during the fourth industrial revolution, an era characterised by drastic change. It is shaped by disruptive technologies that continuously reformulate all aspects of life. Since the third industrial revolution, society has had a varied approach toward technology and in turn, has created a variety of technological communities. The most extreme of these communities are the technophobes who reject technology in its entirety and the technophiles who enthusiastically embrace all technological innovations.

The architectural profession and the construction industry have also experienced change under the fourth IR. However, it has been in smaller increments in comparison to other industries. The principal reason for the slow development within the architectural profession can be best understood within the design process, which has been based on a design paradigm established during the renaissance. Regarding the construction industry, the principal reason for resisting change can be sourced to liability, after all, new materials and techniques reduce predictability and consequently increase risk which is not a sustainable business model. As has been in society, both industries have fragmented into various technological communities in face of the previous and current IR, forming in their extremities the technophobes and technophiles.

With respect to architecture, I have had the opportunity of working with analogue and digital methodologies both in academia and in practice. These experiences have taught me, that these methodologies are essential to creating successful architecture. Therefore, using the opportunity of writing a master's thesis, I will reflect upon my previous experiences, with the intention that the study will give me an in-depth understanding of the application of analogue and digital techniques within architecture. To therefore propose ways of combining such methodologies. The aspiration is that this will contribute to the New European Bauhaus, which is researching and implementing methods of combining digital and analogue techniques within design to therefore contribute towards a reduction in the carbon emissions of the European Union. Along with contributing to the European community, this study intends to guide me on my professional architecture career.

1.2 Objective

To reflect on the specificity and the chances of complementarity between analogue and digital methodologies, both in the process of designing architecture and in relation to materiality and construction. The thesis intends to explore the tensions that exist between the analogue and the digital in specific moments when designing and making. The case studies under analysis will be of my own previous experiences in architecture until now. The intention of this study is to comprehend the advantages and disadvantages of each technique and how to therefore combine the various tools when projecting and constructing architecture. The result of this study does not aim to offer a finalized answer; however, intends to begin a dialogue between the two methodologies and myself.

1.3 Methodology

- Literature Review

  Secondary references in the form of books, journals, documentaries, and lectures; shall offer a variety of expert opinions on a variety of ideas that will accompany the interviews and the experiences had.

- Experiences

  As previously mentioned, the content under analysis will be comprised of my personal experiences within architecture. Along with primary sourced interviews and secondary sourced references, my own opinion will assist in deconstructing the steps involved in these experiences.

- Direct Sources

  The experiences under analysis involve different projects led by four architects all with varied skills and perspectives on architecture. To therefore comprehend each experience, it is necessary to interview them.

- Discussion

  Discussions held with Professor Dr. José Pedro Sousa offered an opportunity to discuss ideas which were instrumental to the development and execution of the thesis. Conversations on an individual basis with Kenneth Frampton and Ricardo Flores from *Flores & Prats* also assisted with the development of the thesis. Co-hosting the podcast *Café com Esquissos*, offered an invaluable opportunity to discuss ideas relevant to the study.

- Analysis of work

  To conduct the analysis of the various topics in question, it will be necessary to gather content from various case studies. These will offer direct insight into the techniques applied and how they were utilized. This shall prove most instrumental for the analysis.

1.4 Structure

This thesis is divided into five chapters, including this introduction chapter.

Chapter 1. Introduction

The introduction will introduce the motivations behind such study, the methodology, and the goals.

Chapter 2. Fourth Industrial Revolution

Will be divided into three subchapters: Context, Society and Architecture. Context will offer an insight into the Fourth Industrial Revolution: understanding its predecessors, when it came to be and its characteristics. The following two chapters will observe the implications it has had upon society and architecture.

Chapter 3. Two countries, Two experiences

This chapter will be divided into two subchapters: the Portugal and United Kingdom. Portgual will be composed of three subchapters: Technology, *Faculdade de Arquitectura da Universidade do Porto*, and *Skrei*. The sub topic United Kingdom, will imitate this structure and will be configured as follows: Technology, *Oxford Brookes School of Architecture* and *Adam Holloway Architects*. In both technology sub-chapters, the intention will be to offer insight into each of the nation's relationship with technology, which will offer some insight into why architecture is taught and practiced in a certain manner. This will be followed by an introduction into each of the institutions and practices.

Chapter 4. Project

Project will be divided into four sub-chapters: understanding, concept, experimentation, and construction. Within each of these sub-chapters, experiences from Portugal and of the United Kingdom will be analysed side by side, offering the reader the opportunity to understand the differences in approach and therefore permit a basis of analysis. Understanding will focus on the experiences that took place within academia. The following subchapters concept, experimentation and construction will be from practice. This is will then be followed by a proposal of how to combine the methodologies.

Chapter 5. Conclusion

The conclusion will evaluate the content of the thesis and raise questions on the future of architecture.

1.5 Contribute

The aspiration is that this will contribute to the New European Bauhaus, which is researching and implementing methods of combining analogue and digital techniques within design to therefore reduce Europe's carbon footprint.

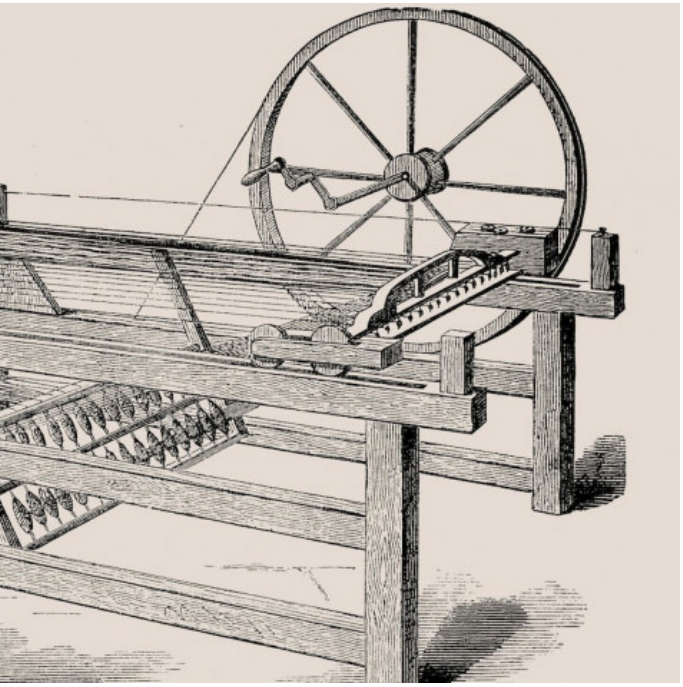
On a more personal note, the thesis will help me understand the application of these methodologies and propose how to combine them. Thus, allowing me to create my own architectural language and assisting me in my future in architecture. By displaying my personal experience and showing how I approached this topic, it will hopefully inspire readers to ask themselves why they are using certain tools to design and build.

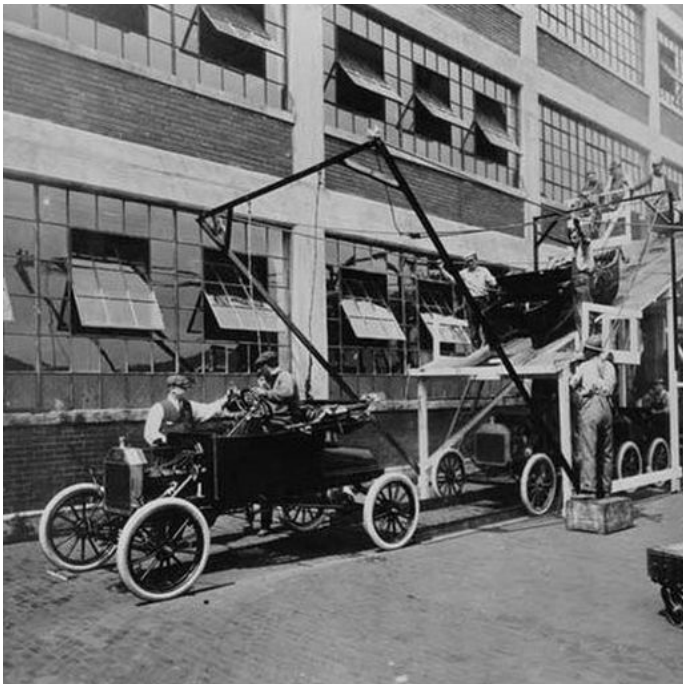
Chapter 2. 4th Industrial Revolution

"... building on a shared understanding, we need to develop positive, common and comprehensive narratives about how we can shape the fourth industrial revolution for current and future generations. Although we may not know the precise content of these narratives, we do know critical features that they must contain. For example, they must make explicit the values and ethical principles that our future systems must embody" (Schwab, 2017).

Fourth Industrial Revolution is altering humankind's paradigm, to better comprehend how this is taking place the sub chapter will be divided into three parts, context, society and architecture. Context will delve into the industrial revolutions that have taken place till the year 2022, it will go onto explain when they took place, what were there characteristics and will give an example of a disruptive technology of that era. The topic of the fourth IR will also offer insight into how the founder of the *World Economic Forum*, Klaus Schwab identified the taking place of the current revolution. Society will analyse two core aspects of day-to-day life: identity and socialising. Architecture will analyse the evolution of two aspects of the profession, designing and making. The intention of each of these sub chapters will be to guide the reader into understanding how the several revolutions have reshaped each of these categories.

Figure 2. Metaverse






AERODYNAMIC HEATING

2.1 Context

Humanity has been marked by technological innovations, being to no surprise that human history has been categorised by them. Previous examples have been the Stone Age, Iron Age, and Information Age. Within the various ages there coexists Industrial Revolutions, which are triggered by the introduction of disruptive technologies. According to Stearns, these eras have the capacity of altering humankind's paradigm (2013). This is evident at various levels of society, from "economic systems and social structures" (Schwab, 2017, p.1). Till this day humanity has seen the passing of three industrial revolutions and is currently living through its fourth.

The founder and executive chairman of the WEF, defines the four industrial revolutions (2017). The first IR took place between 1760 and 1840, an era characterised by the shift of "human and animal labour technology" (Mohajan, 2019, p.377) towards "systematic production" (Mitchell and McCullough, 1994, p.1). This was achieved with the invention of a variety of machines such as the spinning jenny (figure 3) being invented by James Hargreaves in the 1760's. This period also saw the harnessing of energy in the form of steam power.

Mokyr establishes that the second IR, commenced in 1870 and ended in 1914 (1998). This IR was characterised by mass production achieved by the creation of the assembly line (Schwab, 2017, p.13) which can be sourced to a variety of companies such as Ford Motors to whom used that exact system to create the iconic Ford Model T ('The Model T', n.d.) (figure 4). The second IR also saw the coming of age of electricity, which slowly propagated itself throughout a variety of areas as it became more economical to use.

In the 1960's the third IR took place, also known as the "Computer Revolution" (Mitchell and McCullough, 1994, p.3). Mitchell and McCullough classify this era as the shift of human brain power to "information-processing machines" (1994) (figure 5). This was made possible with the introduction of a variety of disruptive technologies, such as the silicon chip and transistor integrated circuit. Silicon chips were conceived by Jack Kilby and Robert Noyce.

According to Klaus Schwab, the fourth IR directly builds off the third IR and can be sourced to the beginning of the 21st century (2017). The fourth IR is characterised by the "fusion of technologies being notable for blurring the lines between the physical, digital, and biological spheres" (Schwab, 2016) (figure 6). This was made possible with the introduction of various disruptive technologies such as "artificial intelligence and machine learning" (Schwab, 2016). Artificial intelligence has seen its use in a variety of sectors, one such example being medicine with the application of artificial neural networks.

Top left. Figure 3. Spinning Jenny

Top right. Figure 4. Ford T Type assembly line

Bottom left. Figure 5. Computer

Bottom right. Figure 6. Metaverse

Klaus Schwab's argument, for the current revolution, is founded upon reliable precedence and accurate analysis of the current global market. In 2011 the internationally acclaimed event *Hannover Messe*, saw Professor Wolfgang Wahlster, director and CEO of the *German Research Center for Artificial Intelligence* (Lydon, 2014) introduces the term "Industry 4.0" (Lydon, 2014). Later in 2014, Professors Erik Brynjolfsson and Andrew McAfee from MIT, referred to the current period as the "second machine age" (Brynjolfsson and Mcafee, 2014). These observations from internationally acclaimed individuals all point toward the fourth IR, taking place right now. Regarding analysis, Schwab (2017) identifies three characteristics of the current global market which leads him to deduce that humanity is currently living through the fourth IR. These categories are "velocity […] breadth and depth [...] systems impact" (Schwab, 2017, p.9,10). The velocity in which the 4th IR is propagating itself is not similar to any of its predecessors, it is doing so at a much more rapid rate. Secondly, the breadth and depth of the current IR is altering humankind's "framework of existence" (Stearns, 2013, p.6). Finally, systems impact is altering "countries, companies, industries and society" (Schwab, 2017, p.10).

After gaining insight into how humankind has evolved with the passing of IR's, the study will now focus on how society and architecture have changed.

2.2 Society

The fourth IR is changing humankind's "framework of existence" (Stearns, 2013, p.6). It is therefore, important to understand what are the actual changes that are taking place within society, after all, society influences the direction of architecture. To do so, the study will analyse two core aspects of society, socialising and identity. Within each of these categories, three eras will be analysed: pre third IR, third IR, and fourth IR. The intention of doing so, is to facilitate the understanding of how society has changed since the introduction of the digital realm.

Socialising is an integral part of society, as it contributes to "individual development and personal influences" (Pescaru and Prof, 2019, p.18). This key activity in society, has led to architects of various eras designing spaces for it, take the Ancient Greeks, who constructed the emblematic agora, an "open space designed for gathering and exchange" (Evangelidis, 2014, p.351). As humanity progressed and as other cultures emerged various interpretations of a social space were made. For example, British culture is accustomed to socialising in pubs and within Portuguese culture, it is accustomed to socialise in cafes. These spaces are only frequented at specific times of day, and they require their users to travel to them. However, these parameters imposed by reality began to be questioned during the third IR, with the

Figure 7. Horizon

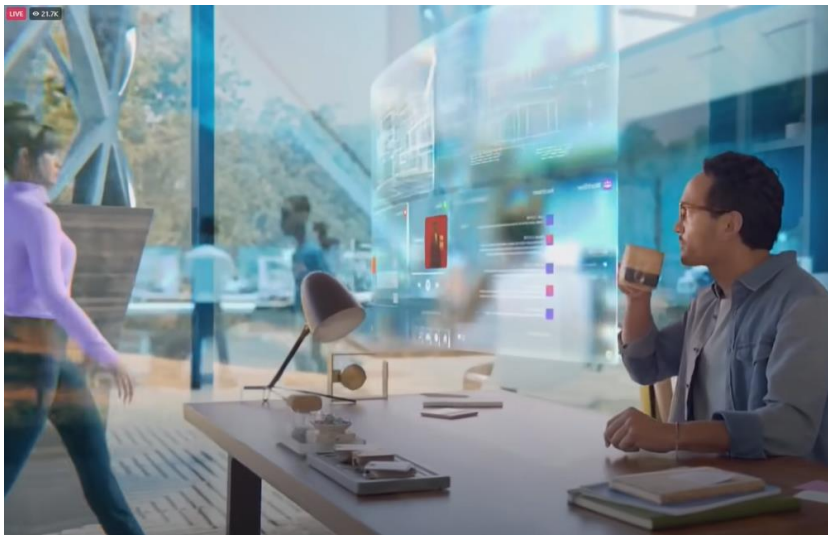
introduction of the digital realm, which William Mitchell refers to as, the “City of bits”(1997). This city envisioned the digitalisation of many activities thus replacing their physical counterparts. An example of this can be seen with the digitisation of post (physical letter) to electronic mail. However, the inhabitants of the “City of bits” (Mitchell, 1997, p.24) desired for a more humane form of interaction, which saw the creation of social media networks. Various social media networks were introduced in the late 20th century, however, the most iconic and most successful was *MSN Messenger* which was introduced in 1999 (‘MSN Messenger to end after 15 years’, 2014). *MSN Messenger* permitted its users to socialise whenever they wanted, reducing the need to travel to socialise. Its users merely needed to have access to a computer and the internet. This method of socialising was still very limited to sending content from one user to another, this could either have been through written text or via emojis. Now in the early 21st century, social media networks are dominating how we socialise. Its current global penetration is recorded at 54 % (‘Daily social media usage worldwide | Statista’, n.d.).

Social media in the fourth IR has continued from where the third IR left off. It has done so by redefining how we socialise by fusing the physical, digital, and biological realms (Schwab, 2017). Social media networks within the fourth IR, permit its users to “create profiles, sharing different kinds of information, with a subset of users” (Sebastian, 2018). Consequently, this has created a digitally networked based society. It can bring people together from all over the world. Social media networks, like *Instagram* and *Facebook* have integrated AR technologies into its software’s, altering the way we communicate with one another. However as is common in the fourth IR, change is taking place at a rapid rate and now with the introduction of virtual reality, or more specifically the *Metaverse*, experts such as Christophe Ginisty, founder of *Internet Sans Frontières* are speculating that this will make *Facebook* obsolete (2021). According to the founder Mark Zuckerberg, this technology allows for “an embodied internet where you’re in the experience, not just looking at it” (2021). Within the *Metaverse* individuals will be able to socialise within a variety of virtual realities, which can be generated by the individual or it can be bought. This can be done in a variety of software’s such as *Horizon Homes* (figure 7) or *AltspaceVR*. As mentioned in the previous chapter, there has been a desire since the third IR, for communication software’s to be as similar to the actual performance of talking face to face. Within the VR software, this becomes concretized (Figure 7), as the headset and controls track and mimic facial expressions, eye contact, hand gestures, and body movement onto

the digital avatar (Zuckerberg, 2021b). Blurring the physical, digital and biological.

Originally businesses were contained within four walls and a roof, with publicity being predominately done by word of mouth along with via other mediums such as television, radio and newspapers. Also, employees had to travel to their workplace and customers were predominately dealt with in person. The third IR however, introduced new business paradigms in the late 20th century. Businesses could now have a digital platform, where they had instantaneous access to global markets therefore increasing revenue and profit margins. Employees had the opportunity of teleworking and customers no longer needed to travel to a physical shop, they could now get into contact via email. However, these digital potentialities were not fully explored for a variety of reasons: digital technologies were expensive, a majority of the global population were not educated in their potentialities, and some were technophobes. However, the passing of the Covid-19 pandemic saw society as a whole explore these digital potentialities, and this was no more evident than within business. Businesses "increasingly 'went digital', providing and purchasing more goods and services online, raising e-commerce's share of global retail trade from 14% in 2019 to about 17% in 2020" ('How COVID-19 triggered the digital and e-commerce turning point ', 2021). Teleworking also gained traction, this was evident in the USA where it grew from 17% to 44 %. Now in 2022, the globe is attempting to return to normality, however, businesses are now opting to integrate this method of working into the long-term. Data scientists from *Ladders*, are expecting 25 % of the workforce in North America to be teleworking by the end of 2022 and this is set to further increase in 2023 (Robinson, 2022).

The fourth IR is completely altering the way in which businesses operate, an exemplification of this can be seen with the *Metaverse*. As previously mentioned, teleworking has gained momentum and is being seen as a method of working to stay. Whilst studies show that productivity increases (Bailey and Kurland, 2002) with this method of working it does also contain a major flaw being social isolation. Businesses have attempted to respond to this, with the use of social media platforms and video chatting apps such as *Zoom*. However, its advantages are extremely limited. *Metaverse* with its immersive capabilities intend to resolve this, by permitting individuals to work wherever in the physical world and yet be within a VR office space (figure 8), where it is possible to interact with colleagues and bosses directly (Zuckerberg, 2021b). Businesses such as *Amazon* are also integrating disruptive technologies. Author Blake Mogan writes that the company has reorganised itself



around AI and ML (2018). It has adopted a flywheel methodology, which, "means that innovation around machine learning in one area of the company fuels the efforts of other teams. Those teams use the technology to drive their products, which impacts innovation throughout the entire organization" (Morgan, 2018). Allowing for the company to operate more efficiently and therefore grow. AI is also used on their e-commerce site, creating a more personalised service (Cohen, 2020). Products presented can be either influenced by current global shopping trends and or can be influenced by the subscriber's pervious activity on the site.

2.3 Architecture

Following the critical changes commented before, it is important to understand how architecture has been impacted by the IR's. To do so, the study will analyse two key aspects of architecture, drawing and making. Within each of these categories, three eras will be analysed pre third IR, third IR and fourth IR. Offering a clearer reading upon how architecture has changed since the introduction of the digital realm.

Branko Kolarevic, in his book *Architecture in the Digital Age: Design and Manufacturing* (2009) breaks down how the process of designing has developed over human history. He firstly, makes the observation that architects from the period of Ancient Greece till the Middle Ages were constantly associated to the construction site. This was due to the fact that architects of these eras relied very little on drawing as a means of communication and instead relied heavily upon verbal communication with the craftsman. Subsequently, the architect had to be constantly present on site, to direct the construction of the project. This would all change in the late renaissance, with the architects becoming dissociated from the construction site and would see them produce "perspective representation and orthographic drawings as medium of communicating the information about buildings" (Kolarevic, 2009, p.57). This approach to architecture would predominately continue through the third IR, the only difference would be the digitalisation of these techniques. The introduction of cybernetics would permit the creation of CAD, Computer-aided Design (Menges and Ahlquist, 2011, p.68), which originally began as a two-dimensional drawing tool. As time progressed, the user could begin to explore projects three dimensionally (Allen and Kouppas, 2012, p.1). This revolution would also evolve the definition of drawing to a language more relatable to the digital realm, coding. Code is used within computational design. Computational design is based upon "mathematical thinking" (Yalınay-Çinici et al., 2008, p.3) and as such requires a different manner of thinking when projecting. Here the individual needs to use "well-defined steps, algorithms and parameters, which necessitates a design strategy to be developed at the initial phase of design process" (Yalınay-Çinici et al., 2008, p.3). According to Patrik Schumacher these digital capabilities have permitted the exploration of

Figure 8. Metaverse Teleworking

a new architectural style, named “Parametricism” (Schumacher, 2009).

The fourth IR introduces a wide variety of disruptive technologies, which are altering the way architecture is designed. Take for example, the parametric design software *Finch*, it “automates repetitive tasks and helps to make more informed decisions using simulations and AI” (‘Finch’,2022) consequently providing a more efficient manner of working. VR is another disruptive technology which is being integrated within the design process. At *Leonard Design Architects*, they are using *Tilt Brush* to draw three dimensionally (Leonard, 2016), subsequently, redefining the notion of sketching and sculpting. VR is also being used as a means of communication within the project. Perhaps the most interesting of these explorations, is at *Foster & Partners*, where architects and clients carry a VR backpack to site and experience the project at the scale of one to one. In doing so, VR permitted a “multi-sensory experience of walking around the plaza, seeing the very powerful virtual visuals, but feeling the real beneath your feet and hearing the sounds of the city around you” (Aish and Basra, 2021) (figure 9). Which contributed to a better understanding of the project, of its spaces and how it would be integrated within site. This may encourage architects and society to move away from a visual dominant architecture to a more experiential one. The technology also permits that all parties within the VR can interact with another. Contributing to a better understanding of the project and a higher level resolution. Also, those who are not within the VR, can look onto the project on the “screens on the rear of the backpacks” (Aish and Basra, 2021), which make for a more inclusive design process.

Humankinds first experiments with construction saw the creation of the nomadic tent (Tobolczyk, 2020, p.20) which was followed by a variety of experiments in various materials and tools. As civilization progressed, the definition of craftsman emerged, who David Pye refers to as an individual who specialises in a certain method of construction (2008). The need for human labour for construction would be questioned in the third IR, with the experimentation of robotics. The epicentre of this research can be sourced to Japan, a country that at time was experiencing strong economic growth and an increase in construction. However, the nation’s construction industry could not respond to the sheer quantity of projects. The reasoning for this, was that the construction industry was already depleted, due to an aging labour force and a lack of adherence from the younger

generations (Cousineau and Miura, 1998, p.11). This led to five Japanese firms, to combine and explore the potential of robotics (Cousineau and Miura, 1998, p.8). Various models were made such as *Boardman-100* which mounted boards. The conclusion of these prototypes saw them be deemed as impractical, as they had to transported to site, the system could not recognise imperfections and could not respond to them in real time (Cousineau and Miura, 1998, p.91). This led to the fall of robotics within the construction industry. Interest in robotics within the construction industry would later return in the early 21st century, with the likes of Gramazio & Kohler Architects, who worked on bespoke projects with the robotic arm.

Since then, the early 21st century has been plagued by a global labour shortage in the construction industry, which has been further aggravated with the passing of the Covid-19 pandemic. Various incentives to attract a younger generation of builders has been unsuccessful. Experts, such as Marie Olivares, senior industry strategy and business manager, building products and manufacturing from Autodesk believes that "the future of construction will be highly robotised"(2021). There are currently several robots operating within construction, with the use of disruptive technologies from the 4th IR. Take for example the firm *Built* it "retrofits construction equipment with self driving technology" ('How Autonomous Robots Are Changing Construction', 2020), and *Canvas* which has "created an antonymous machine to finish dry wall" ('How Autonomous Robots Are Changing Construction', 2020). According to Grace Ellis, editor in chief of *Digital Builder*, an Autodesk Construction Cloud blog, AR has also shown huge potential in altering the construction paradigms (2022). AR is able to educate builders on how to use a variety of equipment, contributing to a more efficient work force. It has also shown it's potential in assisting builders during the construction phase, as was evident with Gramazio Kohler Research project in Kitrus, Greece (figure 10). Where augmented bricklaying was used to construct a complicated façade. The project saw the combined "advantages of computational design with the dexterity of humans, supporting an entirely new way of fabrication" ('Augmented Bricklaying', 2019).

Following a global understanding into how the world has been shaped by IR's and how they have altered society and architecture, the following chapter will begin to understand how two differing countries in Europe have two different relationships with technology and the implications that this has upon economy, education and the practice of architecture.

Left. Figure 9.
Foster +Partners

Right. Figure 10.
Augmented bricklaying

Chapter 3. Two countries, Two experiences

History, economy, culture and politics all have implications upon architecture. However, for the purposes of this thesis, the chapter will merely focus on the relationship between technology and economy. After all technology directly influences the economy as acknowledged by economists Sachs and McArthur, “The harder we think about it, the more we realize that technological innovation is almost certainly the key driver of long-term economic growth” (Sachs and McArthur, 2002, p.157). By understanding the history of technology within the countries in question, it will offer some insight into why architecture is educated and practiced in the manner that it is. Following this study, the chapter will introduce the schools of architecture and the practices.

“‘What is good architecture?’ Is it a house by Mies, Palladio’s Villa Rotonda, or a stone shelter in a remote mountain landscape? If students ask the same question, the answer may depend on whether they are inquiring from the Escola do Porto in Portugal or the Architectural Association in London. Both answers may be correct, even if they are diametrically opposed” (Tschumi, 2012, p.748).

Countries	**Experiences**	**Timeline**
Portugal	FAUP	2019-2022
	Skrei	2017-2019
UK	OBSA	2013-2017
	AHA	2017

Left. Figure 11. Siza Vieira Former professor at the Porto School of Architecture

Right. Figure 12. Zaha Hadid Former student and professor at the Architectural Association

Right. Table 1. Countries, Experiences and Timeline

AFRICA
INDIA
Mar Indico
Mar Pacifico

3.1 Portugal – Analogue

3.1.1 Technology & Economy

Portugal's relationship with technology can be traced back to the Age of Discoveries, which began in the 15th century and ended in the 16th century. During this period, various maritime technologies were invented, and existing ones were improved upon to aid seafaring, such as the caravela, needle compasses, nautical charts and more ('Portuguese Technology', n.d.). These technologies contributed to Portugal becoming one of the wealthiest European nations. However, a combination of wars such as the Napoleonic Wars, the loss of its colonies, a divided bourgeoisie, and a lack of investment led to its economic decline (Reis, 1987, p.208). As a result, Portugal fell behind other European countries, especially in terms of industrialization, which came later (Reis, 1987, p.208). The effects of the past meant that the country had to rely on imported technologies to develop, as the country lacked the capital and manpower to pursue technological ventures (Caraça and Gonçalves, 1987). It was only after the revolution in 1974, and the countries integration into the European Union, which took place in 1985 ('the accession of Portugal and Spain to the European Union - Consilium', n.d.), that the country began to develop more impactful digital technologies. The Portugal of today, has contributed to the technology industry in various ways, such as the creation of the Multibanco network, which was considered one of the more sophisticated banking networks in the world according to the Portuguese government ('Tech/innovation | Portugal IN'), and the development of "Pre-Paid Mobile Phones, that quickly became the foundation for the mobile revolution we live today" ('Tech/innovation | Portugal IN', n.d.). This somewhat distant relationship with technology, could be one of the reasons into why CAD and CAM techniques have been integrated in such limiting fashion.

Left. Figure 13. Map of the Portuguese discoveries, XV and XVI century

3.1.2 Faculdade de Arquitectura da Universidade do Porto

"Faculdade de Arquitectura da Universidade do Porto, was founded in 1979" ('U.Porto - Faculty of Architecture', n.d.) and its education draws inspiration from the Faculty of Belas Artes , where it was originally taught ('U.Porto - Faculty of Architecture', n.d.). Drawing is considered an integral part of the education; it is seen as a tool of thought and representation. In the first two years, students are engaged in hours of drawing, where they practice on how to observe and accurately express what they see. These skills assist with the design modules, helping students express, discuss, and investigate their own ideas.

The integrated masters course is organized as such.

Year 1	Design 1 General Theory and Organisation of Space Drawing 1 Geometry and Architecture History of Architecture (Old and Medieval)
Year 2	Design 2 Theory 1 Construction 1 Drawing 1 History of Modern Architecture Optional course
Year 3	Design 3 Theory 1 Construction 1 Drawing 1 History of Modern Architecture Optional course
Year 4	Design 4 History of Portuguese Architecture Theory 3 Structural Systems Construction 3 Urbanism 2 Optional course
Year 5	Design 5 Dissertation Optional course

Left. Figure 14. FAUP

Right. Figure 15. *Douro [Dwr] 3 solos entre céu e terra*

Table 2. FAUP Integrated masters course

The course focuses primarily on the following disciplines: Project, History, Theory, and Drawing.

Regarding the fourth-year design project, students were given two tasks, firstly resolve the surrounding context and secondly propose a building. The predominant method of designing is by drawing and modelling by hand which is a technique that is ingrained into the educational system.

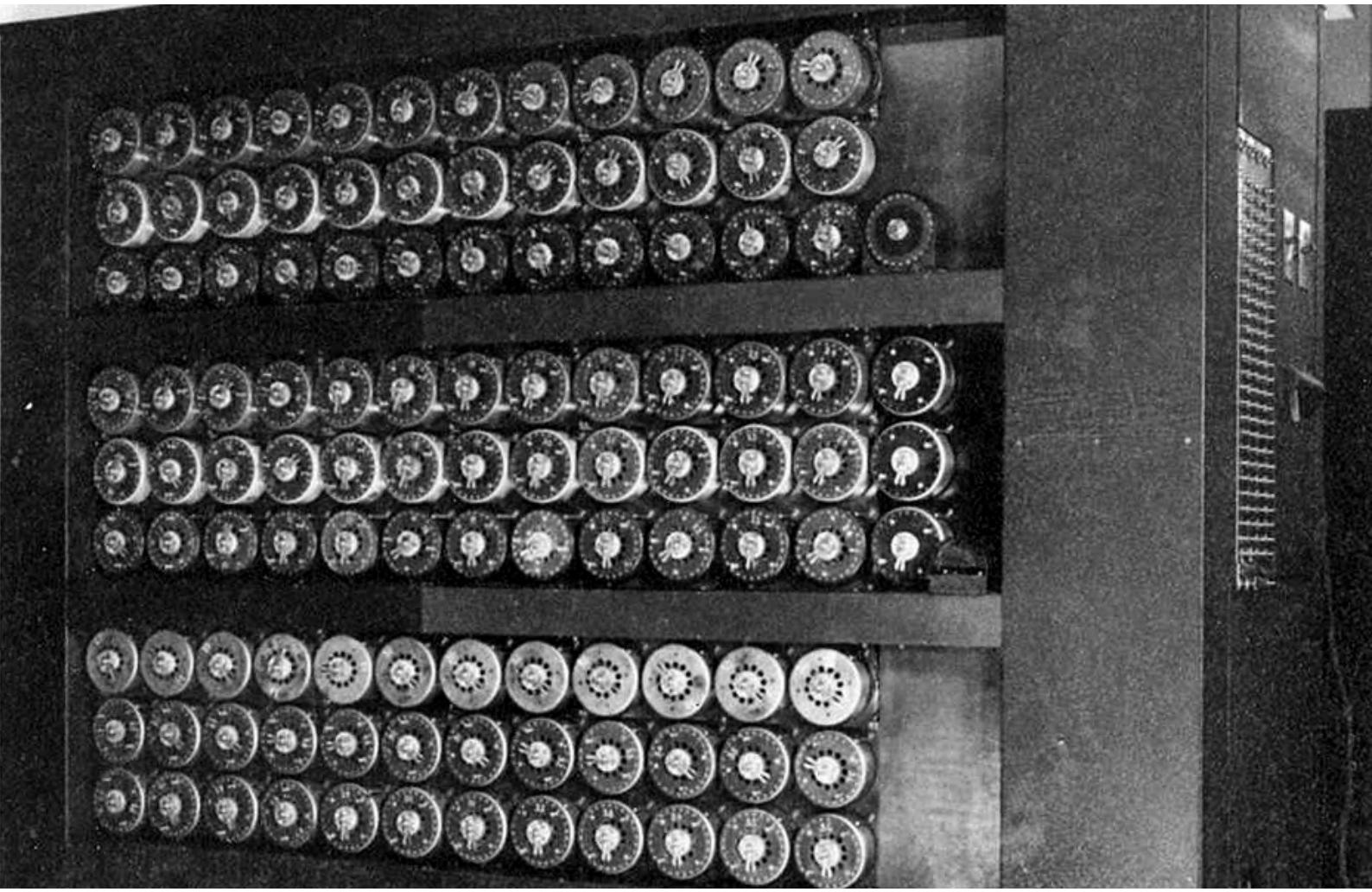
The work under analysis will be my fourth-year project which was led by project tutor Professor João Paulo Loureiro, construction tutor Professor Clara Pimenta Do Vale, and structures tutor Professor Rui Póvoas. The program consisted of designing a student residence that included public programs that served the local and student population.

The fourth-year project was located in Travessa das Eirinhas, Porto, Portugal. The location itself was extremely complicated to read and build upon, there were various reasons for this. Firstly, the topography was extremely inclined. Secondly, the urban context was composed of a variety of typologies: residential houses, block of flats, school, and a hospital.

3.1.3 Skrei

Skrei was a Porto based atelier, that was recognised for its architecture projects and material investigation laboratory. It was founded in 2010 ('SKREI: About | LinkedIn', n.d.) by architects Francisco Adão da Fonseca and Pedro Jervell.

During the internship I had the opportunity of working on the exhibition Douro [Dwr] 3 solos entre céu e terra for the municipality of Porto. The exhibition portrayed the entire Douro region through images, objects, sounds and smells. The focus fell on the land, its history, the different types of soil that give life to the vines, and their impact on the quality of the grapes. To conceive such an ambitious project, analogue techniques were utilised such as drawing by hand and the use of hand craft techniques. *Autocad* assisted with the resolution and communication of the project. The Skrei team was composed of lead architect Pedro Jervell, architect Andrea Roveda, model maker João Pacheco, blacksmith Augusto Silva, his assistant Odayr Lopes Delgado and interns Lilli Scheucher, Nilaus Müller and Marco Rosa.



3.2 United Kingdom - Digital

3.2.1 Technology & Economy

The UK's close relationship with technology can be traced back to the Industrial Revolution, of which it was the epicentre of in 1750-1760 (Clark, 2006, p.2). The Industrial Revolution was influential to the extent that it made Britain into a superpower, as stated by Paul Kennedy. It provided the foundation for the country's continuing and increasing growth, making it into a new sort of state – the only real-world power at the time. Industrialization not only furthered British supremacy in commerce, finance and shipping, it also underpinned its own naval supremacy with a previously unheard-of economic potential (Kennedy, 1983, p.150,151). The industrial revolution provided the foundations for the empire, and enabled the UK to continue to have a close relationship with technological advancements, that would go onto change the world. There are many examples that could be mentioned, however for the purpose of this dissertation, the most relevant were Turing-Welchman Bombe and the World Wide Web. Turing-Welchman Bombe was designed by Alan Turing and improved by Gordon Welchman in 1940 ('The Turing-Welchman Bombe — The National Museum of Computing', n.d.), it was used to decrypt the Enigma. World Wide Web was proposed by Sir Tim Berners- Lee in 1989 ('A short history of the Web | CERN', n.d.) and still is used till this day when accessing the internet. This close relationship with technology contributes for a smoother integration of CAD and CAM techniques within design and construction.

Left. Figure 16. Bletchley Park Bombe

3.2.2 Oxford Brookes School of Architecture

The *Oxford Brookes School of Architecture* was founded in 1927 ('Reginald Cave in memoriam - Oxford Brookes University', n.d.). When I was accepted into the school, its intention was to "give you the opportunity to challenge, explore and develop not only you as individual but also your portfolio" ('The School of Architecture – Undergraduate courses - Oxford Brookes University', n.d.). This was achieved by the faculty providing students with a variety of tools, such as digital cameras, plotters, computers, software's along with a workshop equipped with analogue and digital tools. The undergraduate degree is organized as such.

Above. Figure 17. OBSA

The undergraduate degree is organized as such.

Year 1	Introduciton of Architectural Design 1 Introduction of Architectural Design 2 Architecture and Society Architectural Representation Introductory Tehcnology Introduction to Architectural Hisotry and Theory
Year 2	Architectral Technology 1 Architecctural Desgin 1 Architectural Design 2 Digital Culture Cities, Culture and Society Introduction to Architectural Design 2
Year 3	Architectural Design 3 Architectural Technology 1 Architectural Design 4 Management Practice and Law Dissertation

Above Table 3. OBSA Undergraduate course 2013-2017

Design, is the most dominant course of the undergraduate degree, as can be seen from the structure of the course. Students have two design projects in an academic year, the first of which starts in the first semester and the second lasts for two semesters. The implications of this, is that students must work efficiently and quickly to produce well resolved projects and present them in a professional manner. This directly affects the tools used to design and communicate such projects.

The work under analysis is of the authors final year project, which was guided by professors David Shanks, Frederick Petersen, and Aditya Aachi. The author's program was to design a weaving studio that incorporated public spaces.

The site was located in the north-western area of Oxford, along the Castle Mill Stream. It consisted of a railway line, two waterways that were divided by a path, and a residential area. There were only two communities living on the site, the nomadic canal community and a homeless community. To resolve and communicate such a project CAD and CAM techniques were utilised. It is important to note that analogue methods assisted the digital process.

3.2.3 Adam Holloway Architects

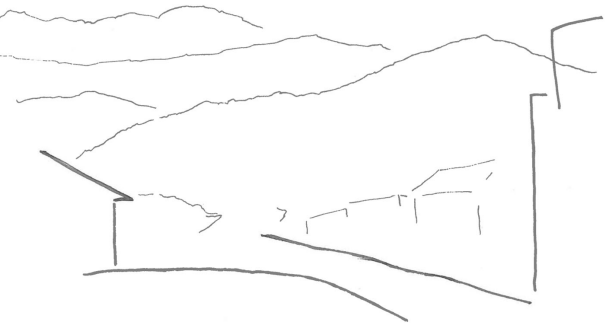
Adam Holloway Architects is a London-based practice known for its ecological architecture, computational design and strategic thinking ('Profile - Architecture & Computational Design | Adam Holloway', n.d.). It was founded in 2011 by architect Adam Holloway.

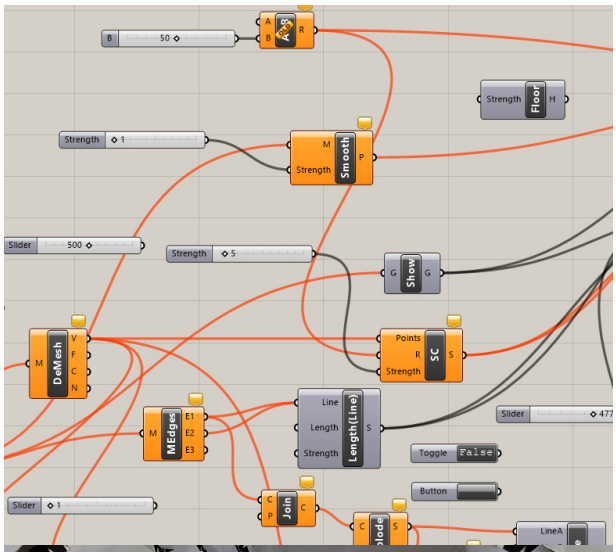
The project under investigation is the *Apeiron Flow*, a paper sculpture designed for the UK City of Culture. The brief was to use paper from G.F. Smith Papers and show different imaginative ways in which it can be used. The office therefore designed and constructed a paper sculpture inspired by nature. To conceive such an ambitious and unique project, it was necessary to employ digital techniques such as computational design, CAD and CAM. It is important to note that analogue techniques assisted the digital process.

The team consisted of lead architect Adam Holloway, Part 2 architects Parth Jivrajani, Aled Evans and Anna Gnecco, and Part 1 architects Jack Young and Marco Rosa. Stephanie Holloway also participated in the project.

The following chapter will explore how each project was approached and to do so the chapter will be divided into four sub chapters: understanding, designing, experimentation and construction. Offering the reader a comprehensible understanding of what tools were used and why they were used.

Above. Figure 18.
Adam Holloway




B
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R
Strength
SC
S
M
MEdges
E1
E2
E3
Line
Length
Strength
Length(Line)
S
Slider
Toggle
False
Button
Slider
1
C
P
Join
C
C
S
LineA

Chapter 4. Project

“Above all else, tools take practice. You must learn how to bring skills and intentions together. You must learn how each tool works, how one tool works with another, and how all are maintained. You must know what tools are for” (McCullough, 1998, p.61).

A project is composed of various phases, they can be summed up in four categories: understanding, concept, experimentation, and construction. Each of these phases require specific tools to successfully complete them. In the case of the Portuguese experiences, analogue tools were predominately used and in the case of the UK experiences digital tools were predominately used. To conduct this study, each of the phases will see the tool used in Portugal and in the UK analysed side by side. To understand how such tools were used within each of the phases, they will be analysed under the following topics: context and use. Context will explain the task set, the individuals who participated and what tool or tools were selected for this task. Finally, ‘use’ will analyse two specific advantages of working with this specific methodology.

Left. Figure 19.FAUP
Right. Figure 20. OBSA

The study will be constituted of academic and professional experiences, the table below shows how this will be organised.

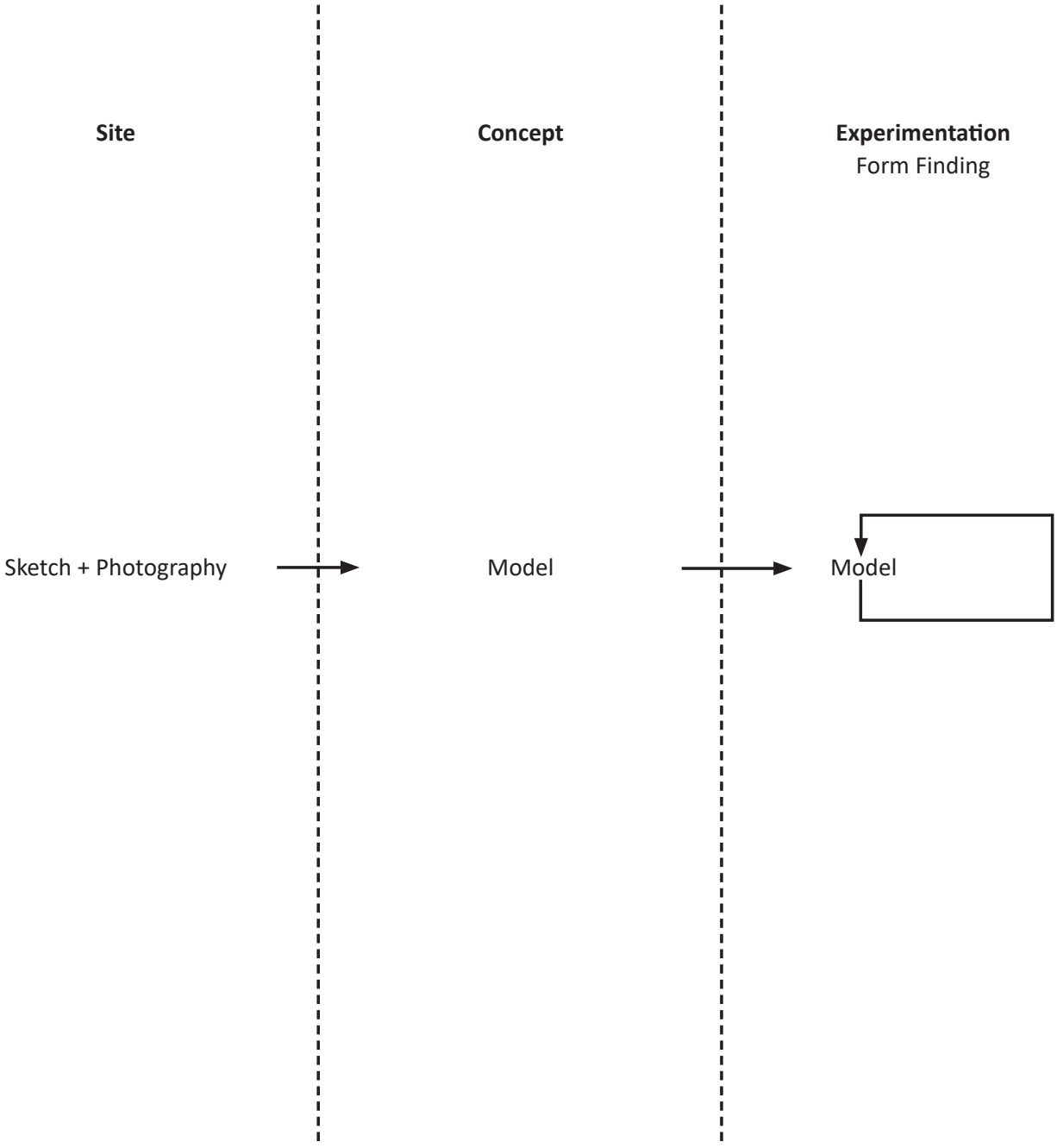
Left. Figure 21.Skrei
Right. Figure 22. AHA

Phases	**Portugal -Analogue**	**UK -Digital**
Understand	FAUP	OBSA
Concept	Skrei	AHA
Experimentation	Skrei	AHA
Construction	Skrei	AHA

Left. Figure 23.Skrei
Right. Figure 24. AHA

Left. Figure 25.Skrei
Right. Figure 26. AHA

Right. Table 4. Case Study Composition


Site
Concept
Experimentation
Form Finding
Sketch + Photography
Model
Model

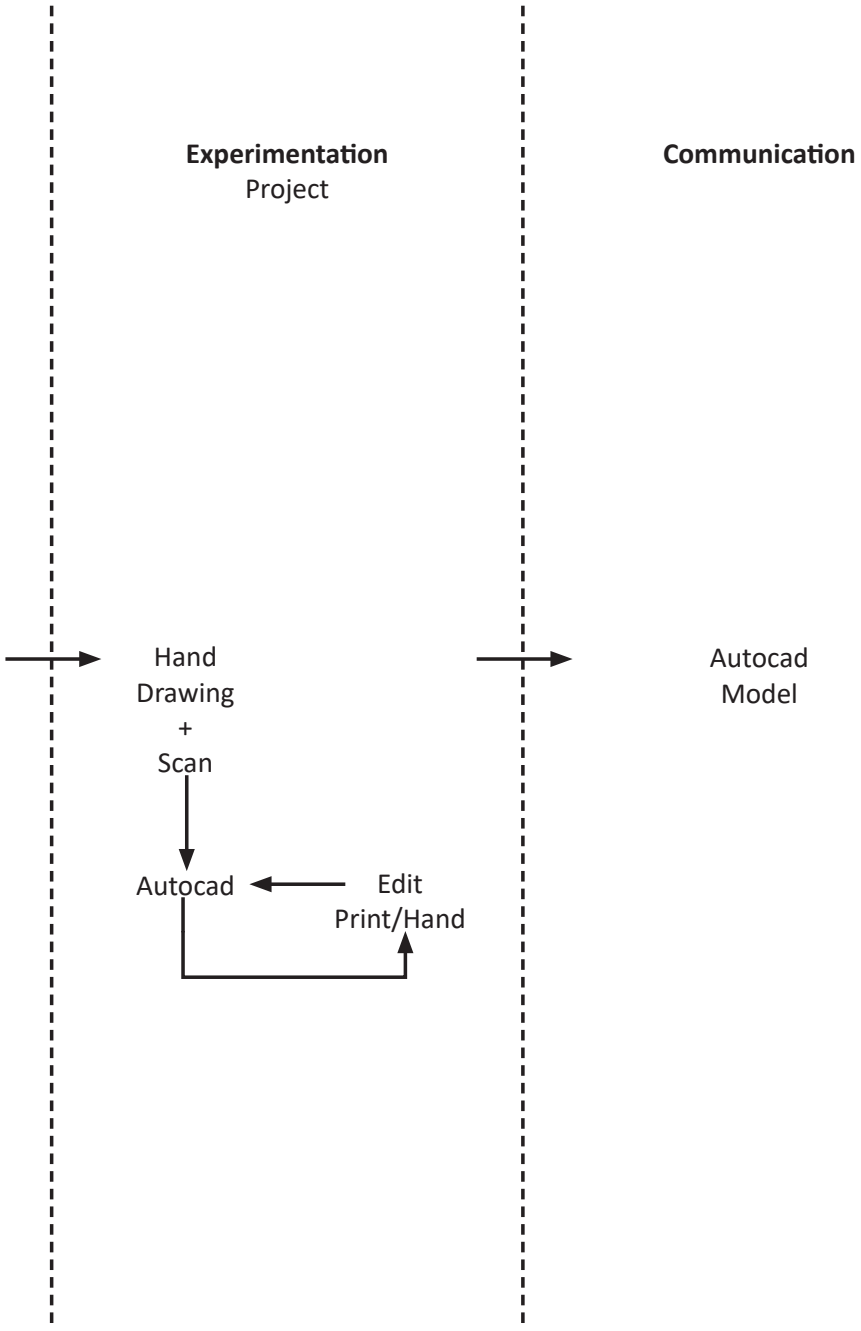
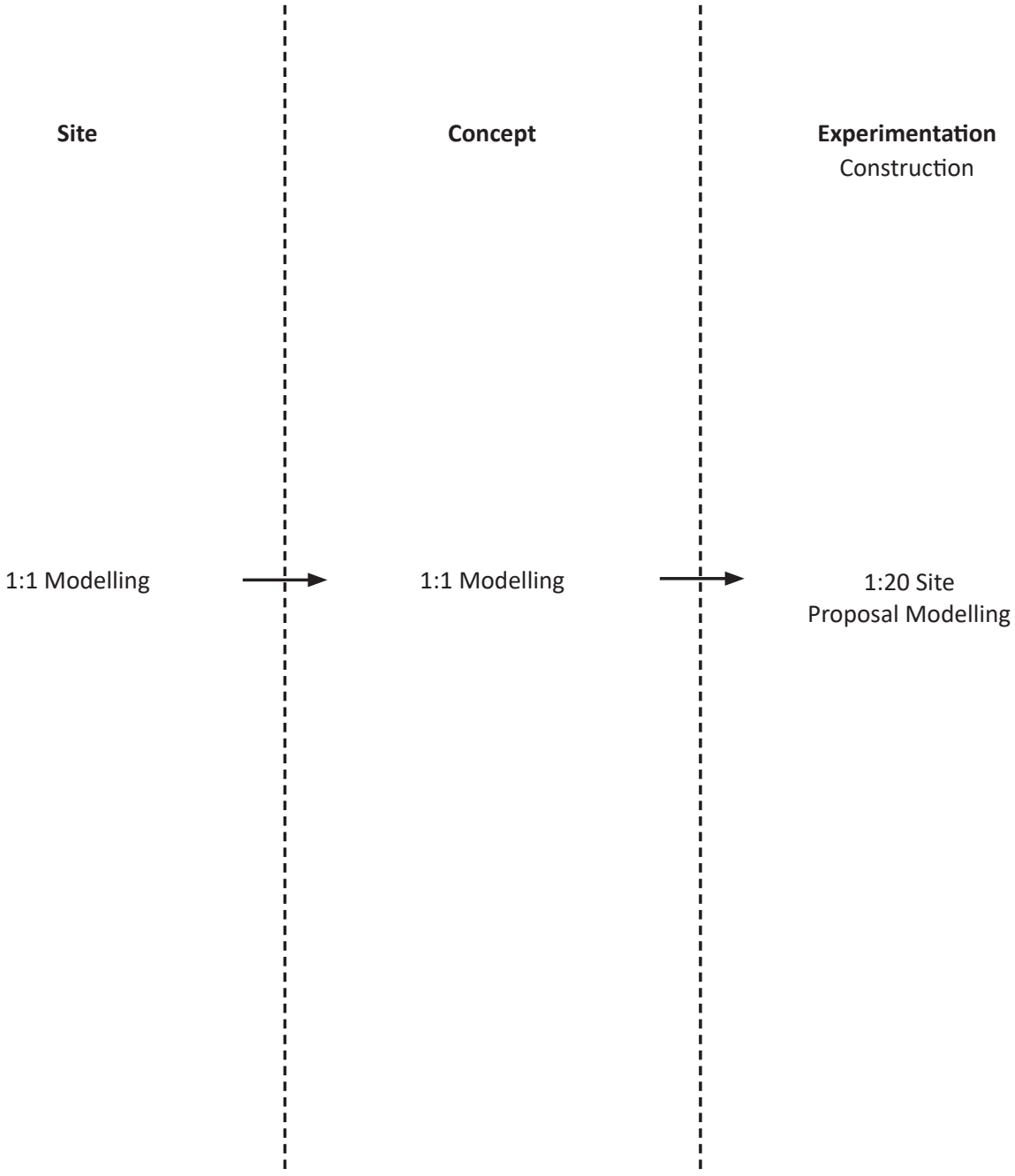


Table 5. FAUP. Design process


Site
Concept
Experimentation
Construction
1:1 Modelling
1:1 Modelling
1:20 Site
Proposal Modelling

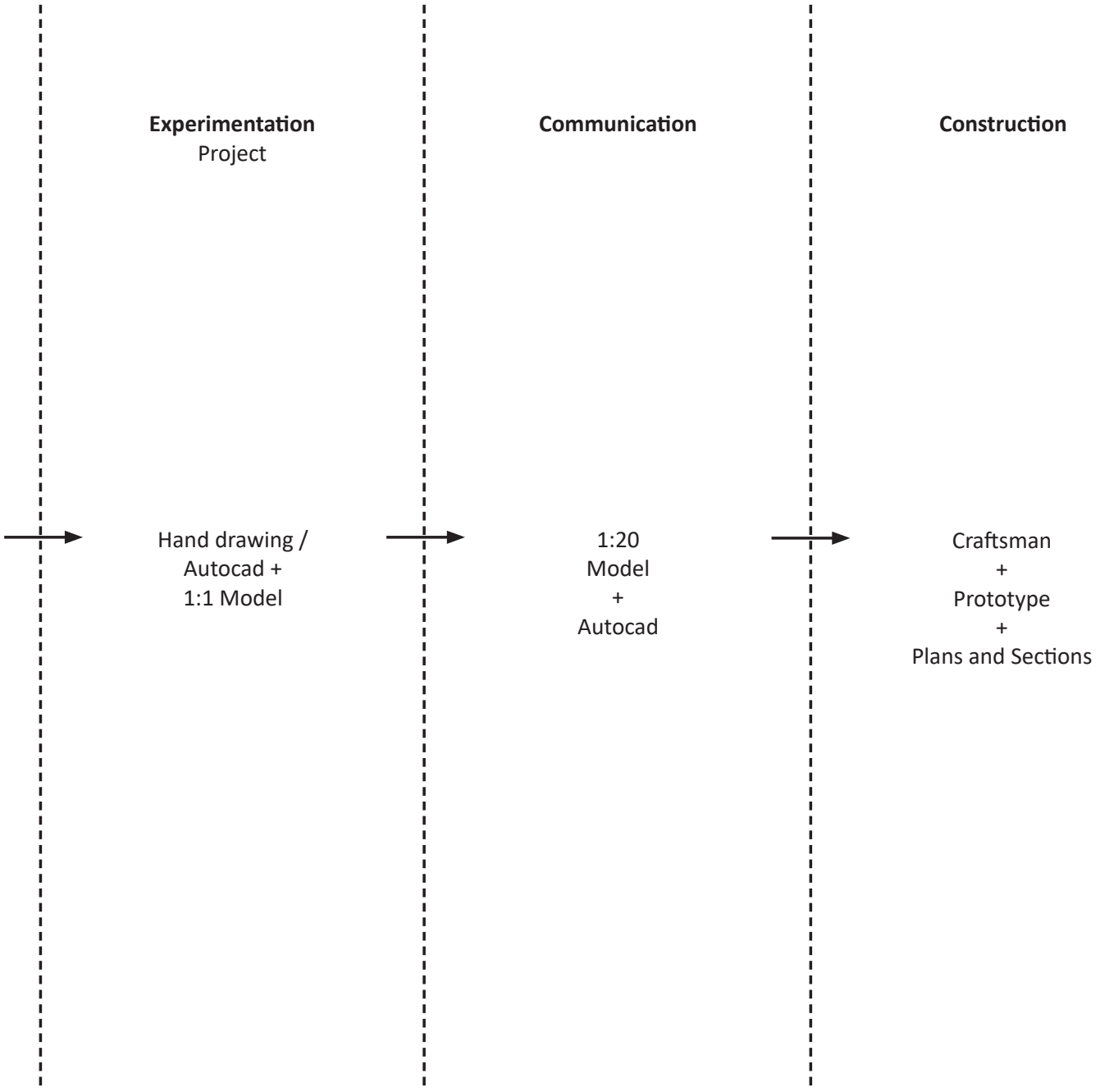
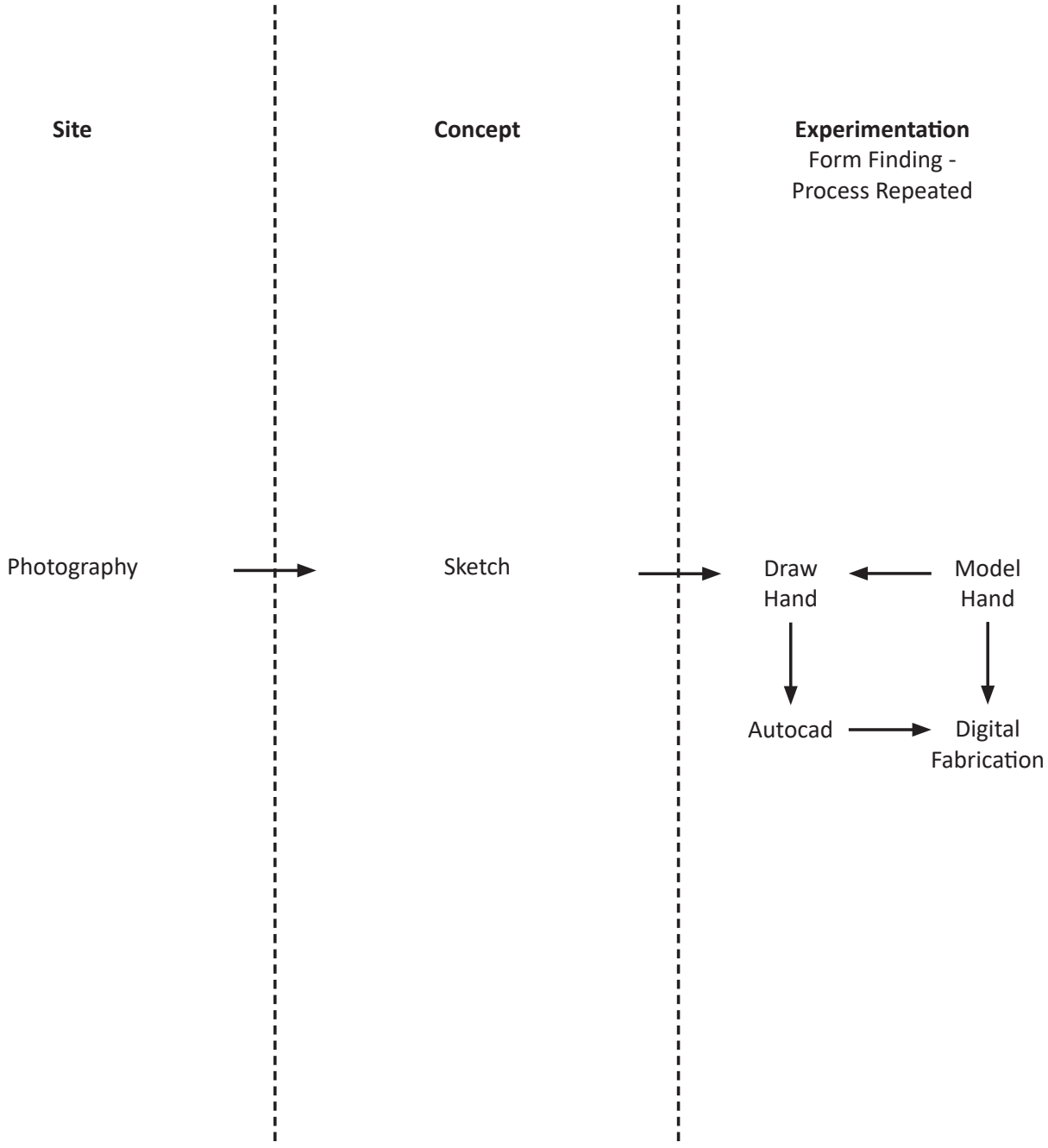


Table 6. Skrei. Design process


Site
Concept
Experimentation
Form Finding -
Process Repeated
Photography
Sketch
Draw
Hand
Model
Hand
Autocad
Digital
Fabrication

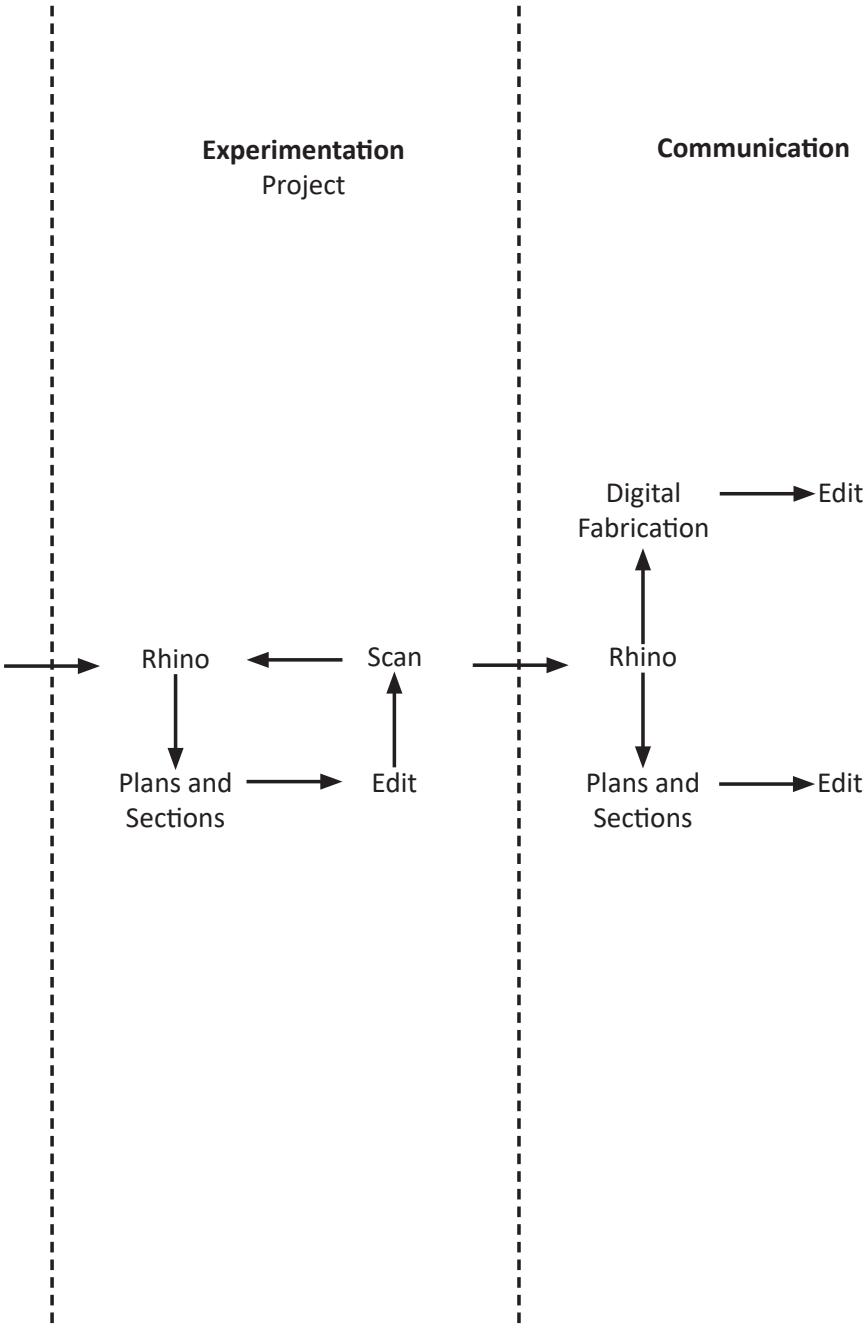
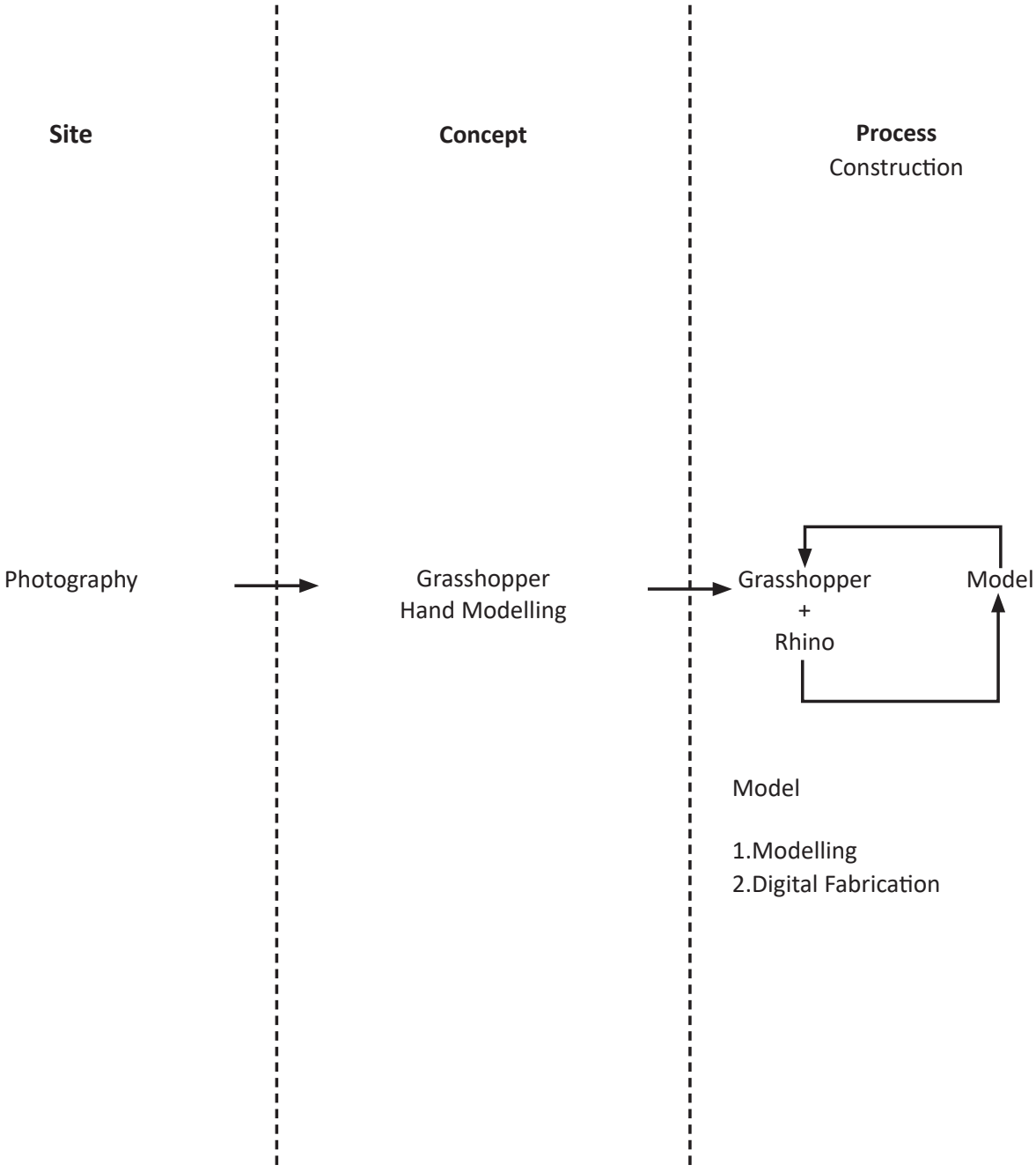


Table 7. OBSA.
Design process


Site
Concept
Process
Construction
Photography
Grasshopper
Hand Modelling
Grasshopper
+
Rhino
Model
Model
1.Modelling
2.Digital Fabrication

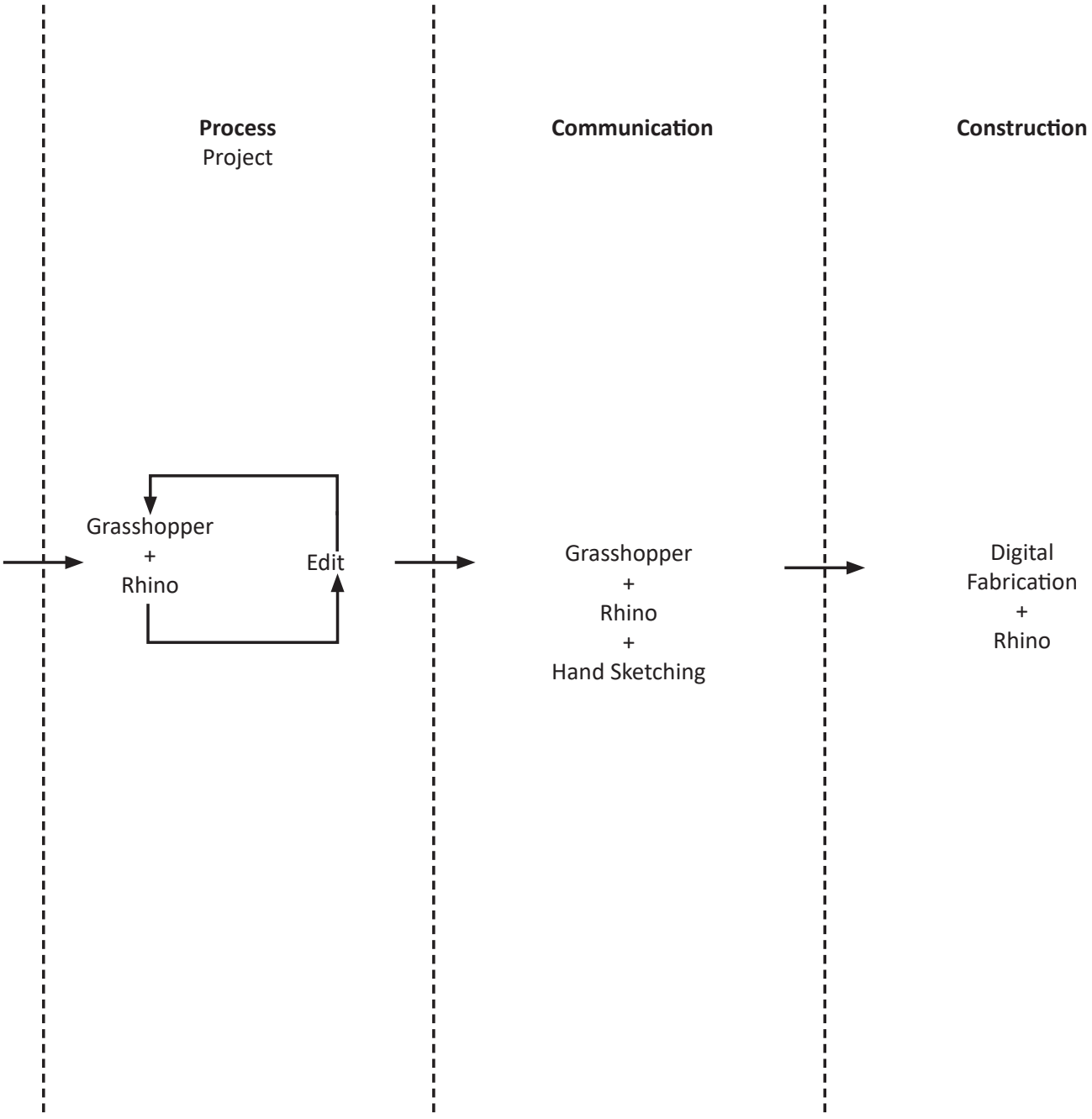
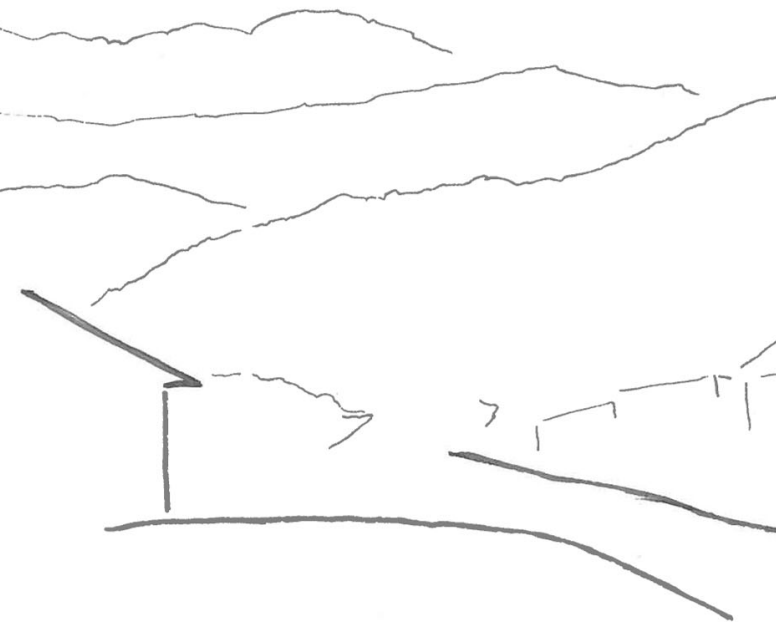


Table 8. AHA. Design process



4.1 Understanding

“The site itself expresses opportunities and constraints […] (Reid, 1993, p.IX) The designer needs to discover and define this spirit to find out what the site wants to be, sensitively to interpret it into proposed uses and design form…” (Reid, 1993, p.1).

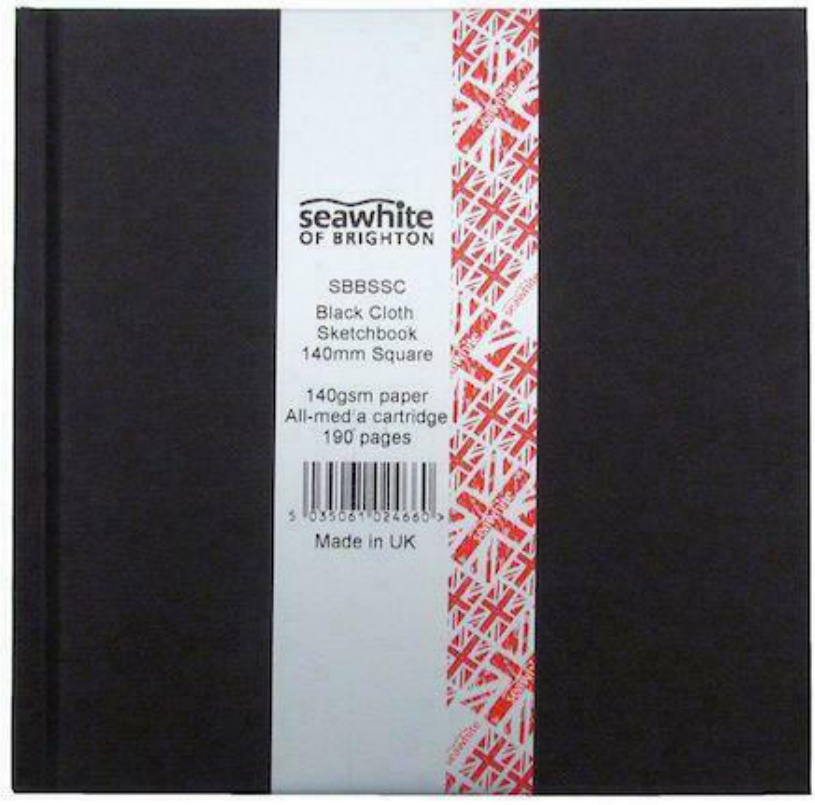
Left. Figure 27. FAUP. Sketch
Right. Figure 28. OBSA. Photography

Right. Figure 29. Sketch-book

Far right. Figure 30. Pens

Context

Students were given the task of designing a student residence within a pre-established area of site, that accounted to 11 km^2. Students were also given a further 4 km^2 for urban planning. The site itself was extremely complicated, with the terrain experiencing a change in height of 30m, the topologies on site also extremely varied with their being a hospital, an abandoned school, houses, and a block of flats. The first impressions of site were one of fragmentation. Following the success of using photography at Oxford Brookes University, which will be further expanded upon in the following subchapter, the same tool was initially used. However, it had little effect in comprehending sites identity as the images contained too much noise. This led to the experimentation of sketching on site, a technique which permitted the removal of noise that in turn allowed for the essence of site to be captured.



Use

After days of visiting site, it became apparent that sketching would be the solution in understanding it. However, the mind set in which site would be approached would have to be different to that of the previous times. It would have to be approached with a minimalist mind set. A minimalist, is a way of being that removes excess noise and in turn identifies what is essential (VanEenoo, 2011, p.1). This method of being was translated to the arts by a variety of artists, such as Frank Stella ('Minimalism | Tate', n.d.). This method of representation is also used within cinematography when communicating the actions within a scene, perhaps the most renowned architect who uses this exact technique to understand and design is Rem Koolhaas. To implement this technique on site, the mind's eye (McCullough, 1998, p.53) had to filter out colour, sun light, shadows, materiality and people. After this filtering of information, it became apparent that the school, apartment block, topography and the view were the essence of the space. The sketch was made using Derwent Line Maker pens varying from 0.1, 0.3, 0.5. The thicker pen, being 0.5 was used for what was in close proximity, 0.3 was used for the intermediate, 0.1 was used for what was situated afar and in doing so created hierachy. A technique inspired by Nadir Afonso's fractal period (figure 31) and Rem Koolhaas's drawing techniques. The choice in black pens also assisted with this minimalist approach, as it further reduced the distractions during the process of sketching and in the reading of it. The outcome is an extremely legible sketch that captures the essence of the space. As the minimalist artist Frank Stella said "What you see is what you see" ('"What You See Is What You See": Donald Judd and Frank Stella on the End of Painting, in 1966 – Page 2 – ARTnews.com', n.d.).

Drawing is a discovery (Jervell and da Silva Rosa, 2021), a process that forces the user to fully comprehend what is exactly is being seen and then represent it. This notion cannot be better explained than by 1906 Nobel Prize winner Santiago Ramón y Cajal ('The Nobel Prize in Physiology or Medicine 1906', n.d.), father of modern neurobiology. He demanded that all of his pupils to take up classes in watercolour painting (Pallasmaa, 2010, p.90), he explained that "the act of depicting something disciplines and strengthens the attention, obliging us to cover the whole of the phenomenon studied and preventing, therefore, details from escaping our attention which are frequently unnoticed in ordinary observation […]" (Hobson, 1989, pp.95–97). It is the process of drawing which permits this understanding to take place. The process is as follows, "VM-VD-VM" (Pelayo, 2009), VM stands for visualization of the model and VD means visualization of the drawing. By fragmenting the entire process of documentation, the user is given the possibility of dissecting site into its mere elements via the "mind's eye" (McCullough, 1998, p.53). Permitting more control and understanding over what is being looked at and therefore the

Top. Figure 31.
Nadir Afonso. A Cidade Incerta 2010

Right. Figure 32. FAUP.
Sketch Part 1

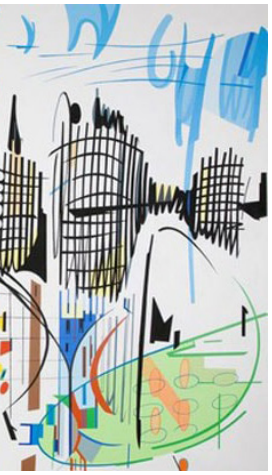
Right. Figure 33. FAUP.
Sketch Part 2

Right. Figure 34. FAUP.
Sketch Part 3

Right. Figure 35. FAUP.
Sketch Part 4

Right. Figure 36. FAUP.
Sketch Part 5

Far right. Figure 37. FAUP.
Sketch



user can clearly communicate it on paper. This is evident in the way that the sketch was constructed. The ground was marked out first (figure 32) as the drawing shows with the land dipping drastically to the right-hand side. The second part (figure 33) of the drawing was the school, which framed the view on the left-hand side. The third part (figure 34) was the view that filled most of the page and travels too far along it that the fourth element (figure 35) being the apartment block is drawn over it. Giving a stronger understanding of how dominant the building was. The drawing is completed with the representation (figure 36) of the pathway which travels from the block of flats down to the other side of the terrain and it is boarded by apartment blocks. The drawing would be later key in guiding the project.

Site presented a substantial amount of complexity, with the terrain experiencing a change in height of 30m and there were a variety of topologies. Photography had offered very little assistance in the reading of the space. Sketching was used instead and was found to be a success when reading, documenting, and communicating site. It assisted in two ways, the filtering of noise and an increase in understanding. The filtering noise was key in identifying the essence of the space. This was made possible by having a minimalist approach to the site both mentally and via the design tools taken. Secondly, an increase in understanding of site was made possible via the process of drawing. As it forced the user to understand what exactly they were looking at. The fragmented process of drawing, VM-VD-VM (Pelayo, 2009) allowed for the mind's eye (McCullough, 1998, p.53) to break down site into more tangible elements permitting a more controlled understanding of each.

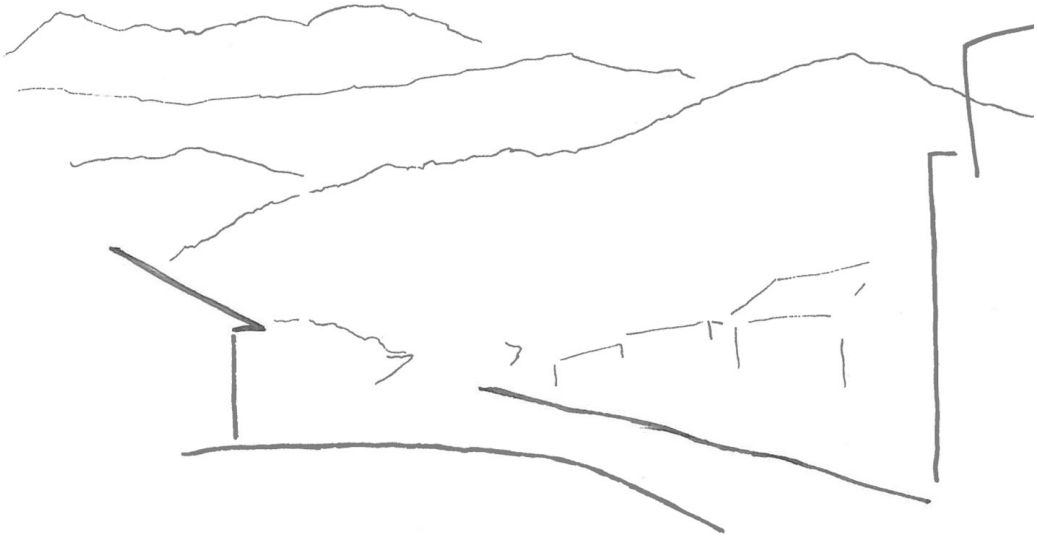


Figure 38. Canon EOS 100D

Context

In Unit B, students were given an area of roughly 300 km^2 to explore and find the location in which their first semester project would be situated. This entire process would take place in a day. The mere scale of site and the time restraints imposed by the unit leaders forced students to use documentation tools that were fast at documenting, easy to use, light to carry, had the potential of recording accurate information, and that assisted in the understanding of site. Therefore, students opted between their personal smartphones or their SLR cameras. Between both photographic tools, the author opted to predominately use the SLR camera as it offered more documentation capabilities, and the images were of higher quality as they were taken in RAW format instead of the typical JPEG, Joint Photographic Experts Group.

Use

The camera has the capacity of assisting the user in reading the site. This is made possible because of the process needed to photograph, I – F – D - C, I identify, F frame, D dialogue and C capture. After identifying the subject of interest, "I" which in this case was the relationship between the passers-by and the canal boat (figure 42), the author opted to move across onto the grass to photograph the subjects. The summoning of the camera, "F" forces the user to look at the site through the limitations of the frame. In the perspective of photographer Lara Jacinto, this mediation of the camera forces her to be more focused, more conscious of what is being seen, as without the camera as mediator she is exposed to a variety of information which distracts her from her subject (2022). The same was applicable here, the lens forces the eye to focus within the limitations of the frame and enclosing the user's world to one eyeball. Anne Spirn refers to this as "acute seeing" (Spirn, 2014, p.49) and which is further enhanced within the dialogue phase. The dialogue firstly begins with the position of the camera towards the subject of interest. Here the user needs to understand what is the best position for the device, in this case it was at hip level and perpendicular to the body. The camera in this position was almost able to produce a section of the current site conditions, showing the distant relationship of the two subjects which were separated by a strip of grass. Following the position of the camera, the dialogue begins with how much information is of actual importance within the frame. This dialogue is mediated with the zooming in and out of the lens, this can be done with the assistance of the camera, meaning that the user does not need to be proficient with this technique. This can also be done manually. In this case, the capturing of the pathway, grass and canal boat was sufficient to communicate the idea. Finally focus, this is what gives hierarchy to the image, this can also be done with the assistance of the camera or can be done manually. By offering hierarchy to the image, it can explicitly communicate the ideas of the photographer. Which in this case can be understood as the subjects in close proximity being of greater importance.

Photographs are a very useful medium for documenting, as in comparison to drawing and painting it is considered as being in closer proximity to reality (Jacinto and Da Silva Rosa, 2022). Susan Sontag goes to the extent of saying that photographs are in "actuality miniatures of reality" (Sontag, 2001, p.2). As such, scientists opt to use such method of documentation (Gaba et al., 2004) and it is also for this reason why it is suitable for documenting site. Images however, are charged with information and embody a way of seeing (Berger, 1990, p.14) specific to that of the photographer. Images however, are still open to a variety of interpretations. There are various reasons for this, however, according to Gombrich this is to do with the viewer. Each viewer has accumulated different experiences and have differing amounts of knowledge and therefore, when presented an image, the image no longer is "a mere representation of "reality" but a symbolic system" (Gombrich, 1972, p.82). These interpretations can be controlled by reducing

Far Right. Figure 39. Site conditions

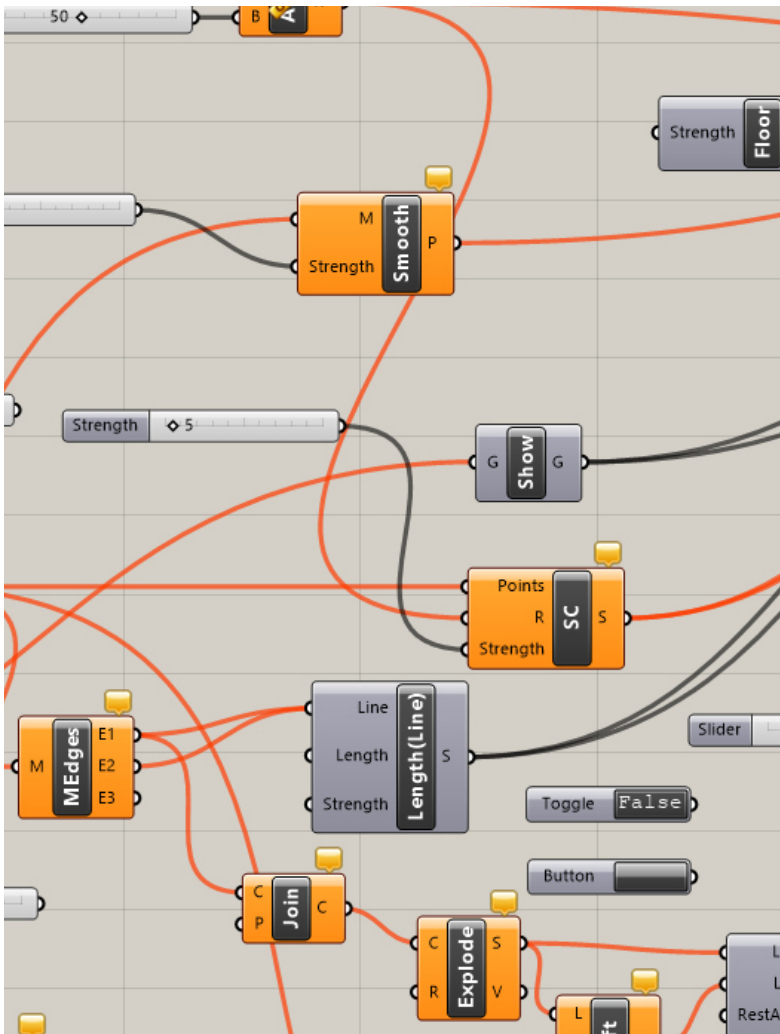
Top Right. Figure 40. 1968 Olympic Games Icons

Center Right. Figure 41. Photograph of site

Bottom Right. Figure 42. Photograph of site in black and white

the amount of information in which the images contain, for instance, take the example of the signs for the 1968 Olympic Games (figure 39), the images are "self-explanatory because the number of possible meanings is restricted" (Gombrich, 1972, p.86). This is made possible by the choice in shapes used and the colour pallet being in black and white; limiting the amount of information being communicated and interpreted. The images of site however, contained too much information (figure 40) and therefore permitted too many interpretations of the images themselves which was unacceptable. What was of interest was communicating the forms and the activity taking place within the space. The decision was made to edit the images into black and white in *Adobe Lightroom* (figure 41). The reason for doing so can be best explained by internationally acclaimed photojournalist Ted Grant, who concludes that when photographing "people in colour, you photograph their clothes. But when you photograph people in Black and white, you photograph their souls" (Fayle, 2014, p.208). By converting the images into black and white, the essence of the space became emphasised. Offering a clearer representation of the site to the viewer.

Under the constraints imposed by the unit, the camera was the most practical tool to use to document site. The tool specifically outshone in two areas, in reading and in representing site. Regarding reading, the process of taking a photo I – F – D - C, permitted the "mind's eye" (McCullough, 1998, p.53) to dissect site and in doing so offered a stronger and in depth understanding of it. Representation was the second advantage of using the camera, it had the capacity of documenting site in a manner that was close in proximity to reality which was extremely beneficial for later readings. Finally, the notions that the images were unclear and subjective to a variety of interpretations led to them being edited into black and white.


50
B
A
Strength
Floor
M
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4.2 Concept

“The making of concepts is the justification for architecture; otherwise, functional buildings with attractive shapes would suffice. Concepts differentiate architecture from mere building. For example, a bicycle shed with a concept is architecture; cathedral without one is just a building […] The concept becomes an overarching idea that will qualify the intent and character of the project from its overall urban presence down to its smallest details” (Tschumi, 2012, p.742).

Left. Figure 43.
Skrei Experimentation

Right. Figure 44. AHA. CAD & Script

Right. Figure 45. Oven

Far Right. Figure 46. Pan

Top Right. Figure 47. Soldering Iron

Skrei

Context

The challenge was to understand the unique properties of the organic matter on site, this being: rock, soil, grape leaves, grapes and beeswax. The intention was that this would later inspire the direction of the exhibition. To do so, the team used a variety of tools to explore the material at a scale of 1:1. This phase of the project was composed of a team of four individuals, lead architect Pedro Jervell, architect Andrea Roveda, model maker João Pacheco and architectural assistant Marco Rosa. All members of the team participated in interacting with the materials. The time given to execute the conceptual phase was two weeks, which PJ considered essential for development of the project.

“if we want it to happen very quickly, it will never be the same. It will never be the same because, because it would accelerate things to happen. So in this time, it’s very important to respect the quality of time…” (Jervell and da Silva Rosa, 2021).

Use

Pedro Jervell believes that all materials are a mystery (Jervell and da Silva Rosa, 2021). Each material is composed of “a load of energy, of knowledge, of intelligence” (Jervell and da Silva Rosa, 2021) which needs to be deciphered to offer an understanding into what takes place within the DNA or the atomic structure (Jervell and da Silva Rosa, 2021). To achieve this one must use their “body, physically and mentally” (Jervell and da Silva Rosa, 2021), to decode the material. It is important to observe that when referring to the body the architect also refers to the tool as explained by Juhani Pallasmaa, “the tool is an extension and specialisation of the hand that alters the hand’s natural powers and capacities” (Pallasmaa, 2010, p.47). This process of interacting and decoding of the material is referred to as tacit knowledge, a term invented by Michael Polanyi (Schrijver, 2021, p.7). It refers to knowledge which is “obtained through experience” (Danaeinia and Hodaei, 2019, p.62). The outcome of this, is that it “helps the discipline of architecture to (re)connect its practices and theories, and contributes to a better understanding of the built environment…” (Schrijver, 2021, p.7). An example of this can be best understood with the knowledge gained with the interaction with beeswax during the phase. When pouring liquified beeswax within a copper frame it does not attach itself to the copper. The reason for this was that the temperature of the copper was not the same as the beeswax preventing them from adhering (figure 48). It was after various experiments that team acknowledged that after collecting a sample of liquified beeswax one should wait until the transparent liquid gains a thin yellow opaque layer on the surface. It is at this point that the liquid should be poured within the frame and over it to ensure that it attaches itself. This knowledge would later be extremely beneficial, as it would contribute to the creation of the centre piece of the exhibition, which was the relief of the human body made of beeswax, retained within a steel frame (figure 50).

Play is an activity most commonly associated with children. Studies have shown its essential role in children’s development (Perkins and Taylor, 1976, p.7), but has a vital role in the development of designs. These ideas are shared by internationally acclaimed architects and academics, such as Alvar Aalto (Pallasmaa, 2010, p.73) and Malcolm McCullough (McCullough, 1998, p.223). To better comprehend the multifaceted manner in which play helps develop designs, the study will first understand the notion of play within the project followed by the benefits of the social interaction. Firstly, McCullough makes the observation that play is “learning through experimentation without risk. Play often lacks any immediately obvious aim, other than the pursuit of stimulation, but functions almost instinctively to serve the process of development” (McCullough, 1998, p.223). Experimentation without risk was fundamental in the conceptual phase, the

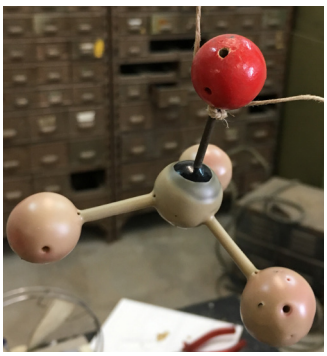
Left. Figure 48. Beeswax and frame

Far right. Figure 49. Beeswax and molecular structure

Right. Figure 50. Relief of human body

team started by coating grapes in beeswax which turned out to be unsuccessful in the long term as they would begin to grow mould. However, this instigated new experiments which were key in developing the project (figure 49). Secondly, play is a social activity and as previously mentioned the team was composed of four individuals who worked together in experimenting with beeswax. The benefits of working in this manner was that “when you can get a group of people to answer a problem more responses are found” (Jervell and da Silva Rosa, 2021). The team would work on individual projects and from time to time would join the other colleagues in playing with the material which would instigate new ideas and responses to problems. This created a rich atmosphere for generating ideas.

Exploration of the material permitted the opportunity of gaining knowledge via the process of play. Tacit knowledge was seen to be integral in the conceptual phase as it was an opportunity for the body to interact with the material, to break it down and to understand it. The accumulation of knowledge assisted the design process and the construction phase. Play was the process in which tacit knowledge was used. The process saw little direction and more instinctual actions take place. This phase lasted two weeks and upon reflection the time was necessary to develop a strong understanding of the materials and the possible directions of the project.



Right. Figure 51.
Rhinoceros 3D

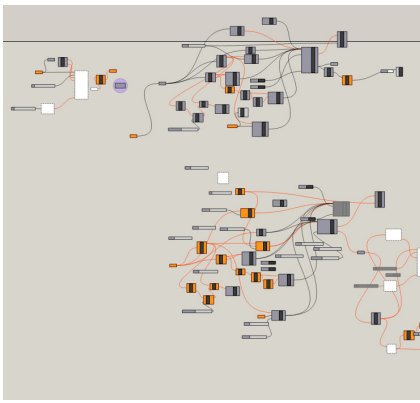
Far right. Figure 52.
Grasshopper

Adam Holloway Architects

Context

Adam's early interests were differential geometry which was inspired by how plants grow, or more specifically how leaves grow. Leaves with ruffled edges are the outcome of some cells growing faster than others "which warp the plane of the leaf" (Holloway and Da Silva Rosa, 2021). He was also inspired by ceramicist Eva Hild, whose work process begins with the adding of clay to the edge of a flat plan and then continues with this additive process until it creates a form. It is at this point where the ceramicist identifies the edges which are in close proximity and joins them, creating a new type of geometry. The geometry was substantially complex to explore and therefore AH, opted to use *Rhinoceros 3D* a CAD software and *Grasshopper* a computational design software. Both are generative software's which he had become well acquainted with in his architectural studies and in practice. The tools offered him more control over the geometry and over the direction of the project. It is important to note that the process assumed by AH during the concept phase, was one that worked in parallel with both digital and analogue techniques. However, the initial action of the architect was taken within the digital process and it will be here which the study will be focused on.

Use

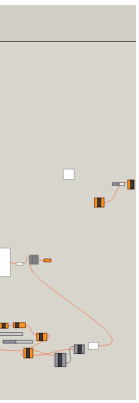


As is evident in the previous paragraph, Adam was intent on creating a geometrically complex artifact that at the very least would be very difficult to achieve with analogue techniques. This immediately became apparent, when the architect attempted to translate his early thoughts of the project into reality. Upon interviewing AH, he made the observation that sketching the complex geometry was not feasible and therefore opted to use “algorithmic testing, geometric testing with 3d model” (Holloway and Da Silva Rosa, 2021). He did this within the generative software’s *Rhinoceros 3D* a CAD software and *Grasshopper* a computational design software. As is common with all the tools analysed within this thesis; they all had the capacity of assisting the user in concluding each phase. In the case of the current study, Adam makes a stark remark that the digital morphogenesis approach, assisted him in generating new ideas, it “enables you to imagine things that you can’t imagine by yourself, so that the designer working with the computer is more than the kind of vision of the designer by himself…” (Holloway and Da Silva Rosa, 2021). Robert Aish comments that the use of computational design software’s also offer an invaluable benefit within design as they offer a higher “number of levels of indirection, that in turn introduced higher levels of expression and control” (Aish, 2005, p.11). This is made possible, as instead of the architect focusing directly in generating the artefact, they focus on indirectly generating it with script. The script in this case operates as an invisible “‘control rig’” (Aish, 2005, p.11) (figure 53) which imposes rules upon the geometry. This is then manifested within the 3-dimensional design software, *Rhinoceros 3D*. As more sets of code are generated, the more control the architect has upon the artefact and consequently allows for them to be more expressive.

Within each of the phases identified within this thesis, each follow the same sequence “input, output and feedback” (Bertalanffy, 2011, p.50). Each of these states equally play a decisive role within the design process. Regarding this case study, the states were represented by the following software’s, *Grasshopper*, *Rhinoceros 3D* and *Grasshopper*. Within *Grasshopper* the architect would write the script which would immediately be transferred to *Rhinoceros 3D* where a 3-dimensional model would be generated on screen (figure 54). The digital model produced was the precise output of the code, offering Adam an accurate reading upon the output of the code. This reading was further enhanced with the possibility of exploring the object three-dimensionally, permitting a complete understanding of the output. After gathering accurate information upon the three-dimensional model, the architect would return to *Grasshopper*, in the feedback state. This state is best explained as follows, “whereby the system is in constant transformation, poses a mechanism by which information is reinvested into the system

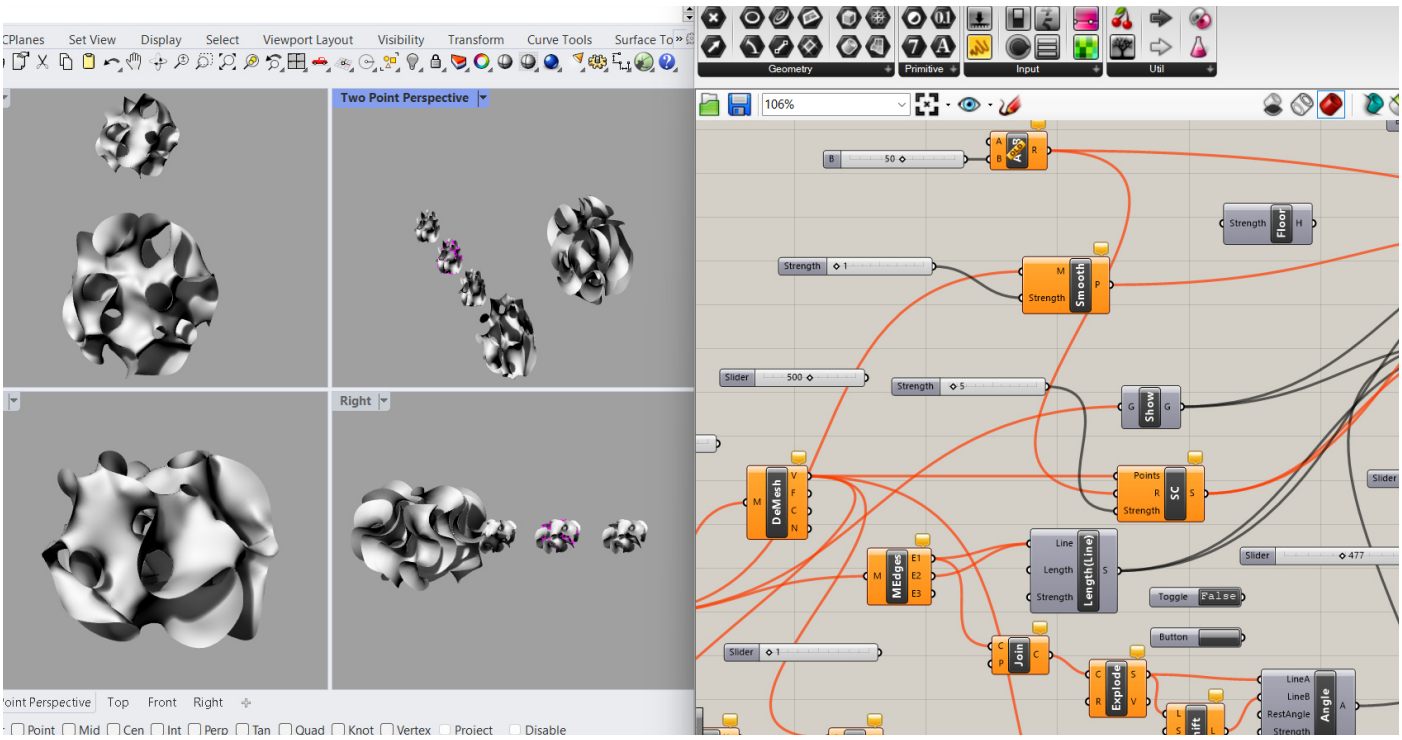
Above. Figure 53. Code

Right. Figure 54.
Rhinoceros 3D and Grasshopper



to provide a constant rebalancing and recalibration of its functioning state" (Bertalanffy, 2011, p.50). This rebalancing and recalibration is in relation to the chosen direction of the project. This is essential, as it provides for a more accurate and directed development of the design. This entire process was extremely efficient, due to direct manipulation. This term refers to the "'combination of three fundamental activities: (1) continuous visibility of the object of interest; (2) rapid, incremental, reversible, physical actions on the object; and (3) immediately visible results'" (McCullough, 1998, p.23). The speed of this depends on the 'weight' of the file and the capacity of the computer's installed RAM. The outcome of this is that architect was exposed to enough information to make design decisions (Young and Da Silva Rosa, 2021) which contributed to a shorter concept phase.

The limitations with analogue techniques led the architect to explore the geometry via digital morphogenesis. The generative software's assisted him during the design process by offering a higher level of expression which would have otherwise been very difficult to do with an analogue tool. Also, control over the complex geometry, was essential in directing the project through the design phase. Furthermore, the digital realm assisted the architect in making quicker design decisions or at the very least provided the architect with an opportunity to be given enough information to then make decisions. This was made possible due to the ability to directly manipulate.



4.3 Experimentation

"The important aspect of the process is its 'circularity', the constant shifting of viewpoints from the idea to the sketch, the model, a full-scale test, and back again. As a consequence of this arduous and complex process, the building exists as a full immaterial mental construction long before the actual construction work begins. In fact, the building has often been built and tested as a mental construction in several alternatives before the final concept is chosen" (Pallasmaa, 2010, p.67,68).

Top. Figure 55. Skrei.
Prototype

Bottom. Figure 56. AHA.
Rapid Prototype

Right. Figure 57. Metal Ruler

Right. Figure 58. Sketchbook

Right. Figure 59. Pens

Right. Figure 60. Metal set square

Far Left. Figure 61. Metal vice

Far Right. Figure 62. Mitre saw

Skrei

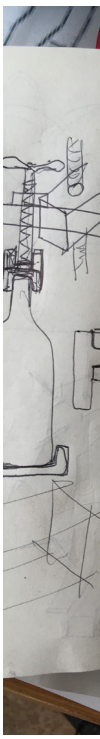
Context

Following the conceptual phase, the project entered the testing phase. The challenge in this phase was documenting ideas and testing them. The approach for these specific challenges was orientated in the traditional design methods, of sketching and modelling by hand which were explored at various scales. The team was composed of lead architect Pedro Jervell, architect Andrea Roveda, model maker and craftsman João Pacheco and architectural assistant Marco Rosa. The team were proficient in both sketching and modelling. With this, the team initially explored the proposal via sketching and then produced a model of the exhibition space at a scale of 1:20 and later produced a prototype of the shelves with the varying mechanisms to hold the exhibition samples. It is important to mention that digital techniques were used in this phase, however, it's impact was minor. For the purposes of this study, the focus will be to merely analyse the analogue techniques used.

Use

Passing the concept phase, the team moved into the experimentation phase to explore the exhibition pieces. The intention was to understand what they were and how they would occupy the space. A 1:20 (figure 64) working model (Burry et al., 2007, p.142) was constructed as it permitted material exploration and facilitated with the interaction with the objects. The materials used represented, or closely represented that of the actual construction, this was evident with the armillary sphere, where the team opted to construct the structure out of brass wire due to its malleability, its capacity to be soldered and it represented the steel tubing which was intended to be used. The scale of the project permitted the use of shale, which was intended to be used as the centre piece to the armillary sphere. The decision of working with the material helped direct the project (Gänshirt, 2020, p.154) as it firstly offered control over the materials which intended to be used, allowing for a material harmony to be created amongst all exhibition pieces. The working with a 1:20 scaled model of site was extremely beneficial when communicating the relationship and location of the exhibition elements to the various entities involved in the project. It permitted everybody to freely interact with it, which contributed to a more resolved layout. The model also had a certain charm which assisted in convincing parties to adhere to the proposal. This is best understood by Mark Morris, who in his book *Models: Architecture and the Miniature* notes that models are semi-independent pieces of art (2006). To a certain extent it had the capacity to seduce "the eye of the beholder" (Gänshirt, 2020, p.153).

When approaching the design of the metal crates which would exhibit leaves, bottles and rock samples, lead architect PJ opted to begin the design process with sketching (figure 63), which is a technique "suited to and supportive of intuitive and generative ("lateral") thinking" (Gänshirt, 2020, p.121). According to the architect, the reason for opting for this technique had to do with the connection between mind and body, "The body is completely attached to the brain, where we can imagine" (Jervell and da Silva Rosa, 2021). It is this natural connection between body-eye-mind which permits the transformation of the immaterial, mental world into reality. Juhani Pallasmaa makes the observation that this mediation is done by the tool (2010), which in this case was a biro pen. The use of scale permitted the architect to control the amount of information that he both dealt with and communicated with. This is evident in figure 66, where the architect drew the metal crates at a scale of 1:20, exploring specifically the appearance of the exhibited pieces. The architect whilst dialoguing with the drawing, begins to question how the samples are fixed within the structure and opts

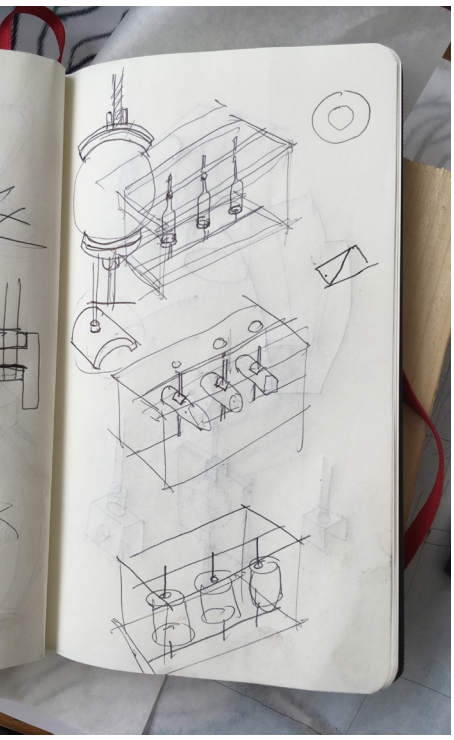


Right. Figure 63. PJ Sketch

Far right. Figure 64. 1:20 Model

to explore this at 1:10. At this scale the architect explores the meeting of materials. This is evident with the drawing, as it is clear that a metal rod with a continuous thread is screwed into a nut which is welded to a plate with a curved surface. The sketch not only acted as a tool for PJ to capture and resolve an idea but also was instrumental in guiding João Pacheco and myself in producing a prototype, as the drawing contained enough information to generate it.

The making of a 1:20 model of both the exhibition space and the proposed exhibition pieces permitted ideas to be tested quickly. The scale permitted ideas to be efficiently communicated to all parties and to an extent the models further persuaded all parties to agree on the proposal. The second part of this process was the ability to sketch and model by hand. Sketching offered an efficient manner for exploring the metallic crates at two different scales. The 1:20 sketches allowed for the architect to understand how the objects would be exhibited within the crates while the 1:10 sketches permitted the exploration of details.



Right. Figure 65.
Rhinoceros 3D

Right. Figure 66.
Grasshopper

Far right. Figure 67.
Laser cutter

Adam Holloway Architects

Context

Following the initial explorations within *Grasshopper* and *Rhinoceros 3D*, the team entered the testing phase. The objective of this phase was to rapidly prototype a variety of ideas within the digital software and to gain feedback on the proposals from engineers. During this phase the group grew to include master students Aled Evans, Parth Jivrajani and undergraduate student Jack Young who all had a limited amount of knowledge in *Rhinoceros 3D* and *Grasshoppe*r excluding that of Jack who was strongly proficient in *Rhinoceros 3D*. With this, the team explored a variety of proposals within *Rhinoceros 3D* with the assistance of the complex script which Adam Holloway had generated and was then later sent to the engineers to be tested. This whole process was assisted with the possibility of rapidly prototyping designs with CAM. Once again analogue techniques were used, however, they were not as influential as the digital.

Use

Efficiency was integral for the success of the project and this was predominately achieved with the use digital software's, as can be seen with the use of *Rhinoceros 3D*. With the complex *Grasshopper* script created by Adam Holloway, a team of three: Aled, Parth and Jack began to explore various proposals within *Rhinoceros 3D*. The team as acknowledged by Jack had limited experience with *Grasshopper*, however that was not an issue as theteam had basic knowledge in *Rhinoceros 3D*. According to Jack, the knowledge needed to model was minimal, "After an hours tutorial you would be probably be able to do it" (Young and Da Silva Rosa, 2021). By working with this specific software with parameters established within grasshoppper, various proposals could be explored effortlessly and quickly (Gänshirt, 2020, p.147). The ability of testing new geometries was further accelerated with the working of low polygon models as it required less processing power (Young and Da Silva Rosa, 2021). Another method in which working within the digital offered efficiency was the ability to transfer digital data to various parties, such as engineers and vice versa (Kolarevic, 2009, p.59). With the *Apeiron Flow*, the engineers would test and edit the digital data that was sent to them which would then be returned to AH (Young and Da Silva Rosa, 2021). Within the document, the team could see "different areas of stress and of deformation" (Young and Da Silva Rosa, 2021). As the file had been edited within *Grasshopper* the team could test new proposals within the parameters established by the engineer, "run it live, to see these are the areas that aren't working and the areas that are" (Young and Da Silva Rosa, 2021). This allowed for the team to continue to experiment with new iterations of that specific proposal without it being necessary for the engineer to be constantly present.

The states for prototyping were as follows, *Grasshopper* + *Rhinoceros 3D* + laser cutter, assembly, *Grasshopper* + *Rhinoceros 3D* + laser cutter. Part of the prototypes made were to resolve the tab system which Adam had designed. The design allowed for the paper templates to be locked together making the building blocks for the project and would also lock the blocks together forming the geometry. To produce these prototypes, the team created a script within *Grasshopper* which transformed the 3-dimensional model into templates which would then be imported into the laser cutter, a CAM, computer-aided manufacturing tool would later cut it. This process is called CAD/CAM fabrication, as it sees the transfer of data from CAD to CAM which was extremely quick and easy to do. Gramazio Kohler Architects refer to this process as "digital materiality, the coming together of data and physical materiality in an architectural construction" (Gramazio and Kohler, 2015). CAM greatly assisted the process in three areas: ability to rapidly prototype, precision cutting and mass customisation. Rapid prototyping offered the team a quick means of producing prototypes which was extremely beneficial as it allowed for the team to focus more on proposing and implementing design solutions which contributed

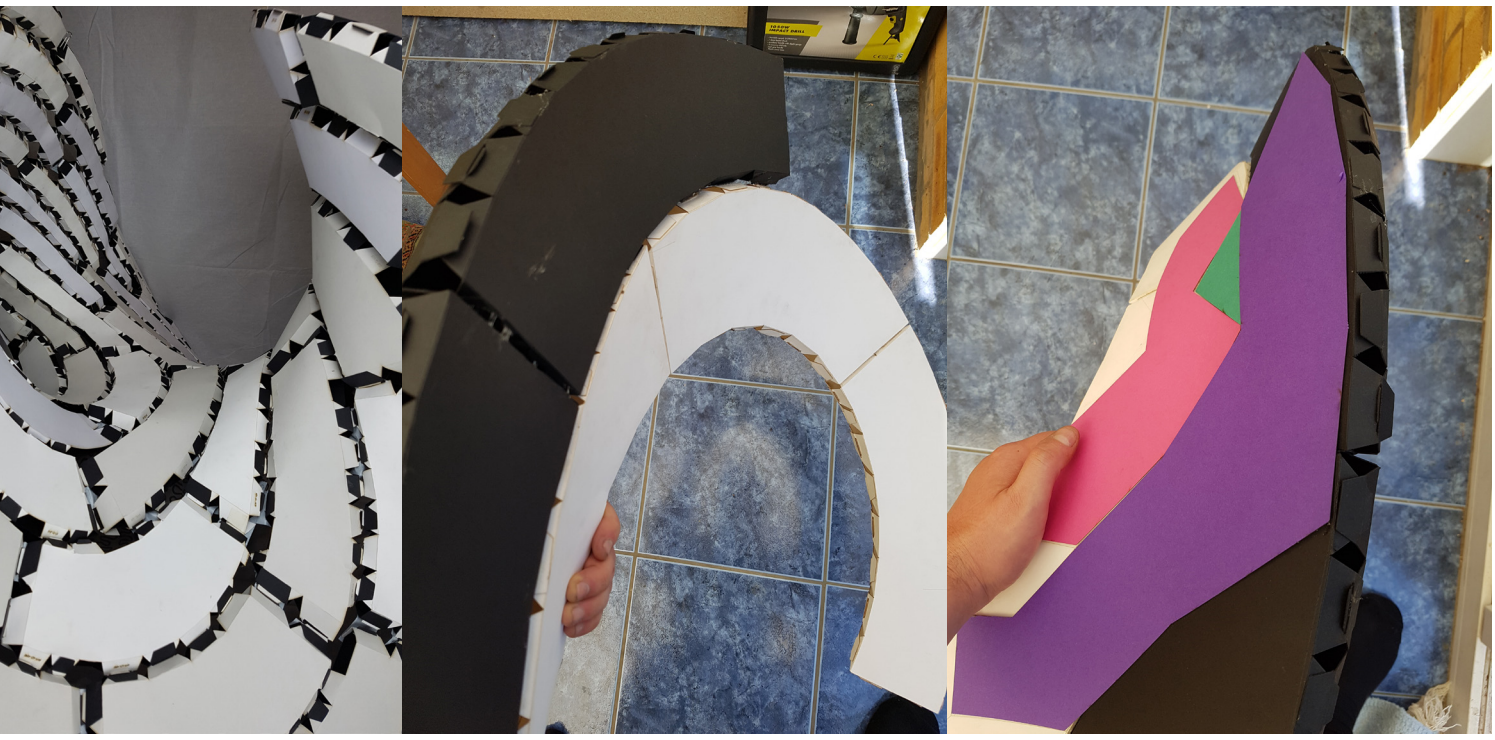
Right. Figure 68.
Prototype example 1

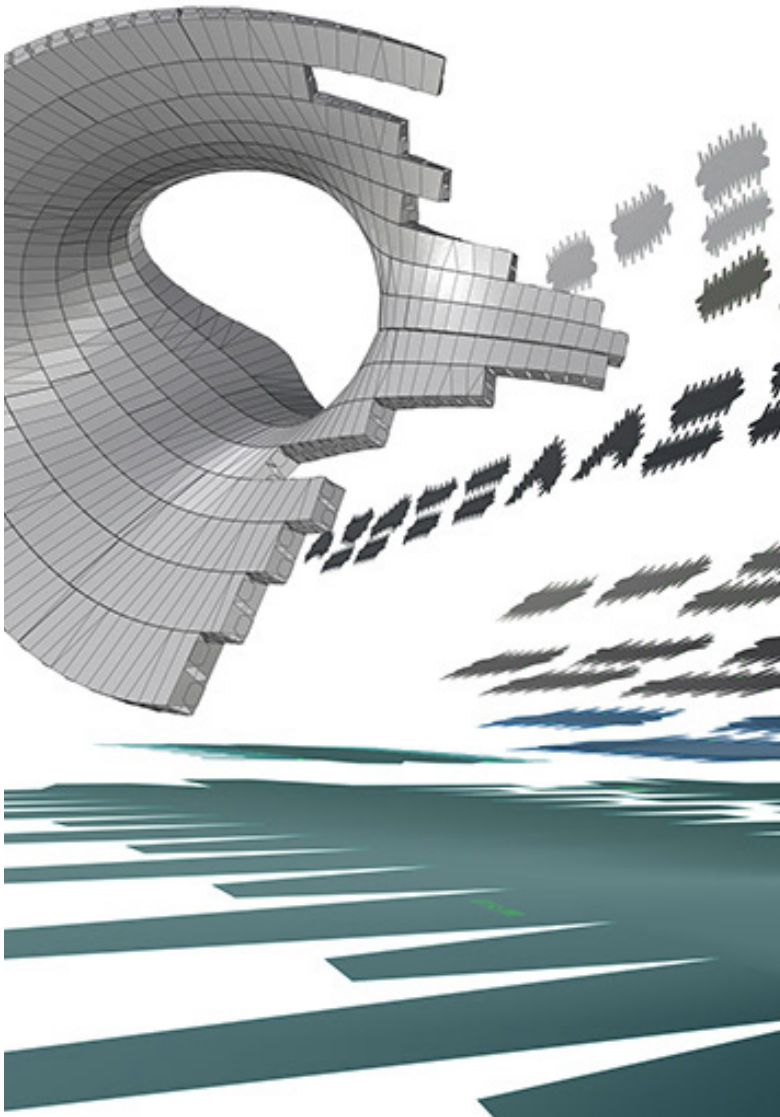
Right centre. Figure 69.
Prototype example 2

Left. Figure 70.
Prototype example 3

to a shorter experimentation phase. The second advantage was that it offered the ability to cut with a higher level of precision and would do so consistently. Which facilitated with the assembly of the templates. It is important mention that the ability to cut quickly and precisely would never have been attainable with analogue techniques. Finally, it offered the ability of mass-customisation (Kolarevic, 2009, p.52), permitting the team to "massproduce one-off, highly differentiated building components with the same facility as standardized parts" (Kolarevic, 2009, p.52).

To summarize, AH generated the complex *Grasshopper* code on the principal fact that his experience within the software ensured sufficient information to successfully generate the geometry. Following this phase, the architect then outsourced a group of students whom had a limited amount of knowledge within *Rhinoceros 3D* to experiment with various forms. Another benefit of using generative design tools, was the ability for the designs to be transferred between various specialists including engineers. Engineers were able to work with the data therefore editing the *Grasshopper* script accordingly. Such approach, permitted the team to explore various proposals with that precise code. The digital data here provided knowledge. Secondly the team was able to rapidly prototype the digital models, through laser cutting. This was made possible with CAD/CAM fabrication techniques. It meant that the team could tighten there feedback loop and were able to work more efficiently.





4.4 Construction

“Construction is the art of making a meaningful whole out of many parts. Buildings are witnesses to the human ability to construct concrete things” (Zumthor, 1998).

Left. Figure 71. Skrei. Blacksmith Augusto
Right. Figure 72. AHA Architect Adam Holloway

Right. Figure 73. Metal Rules

Right. Figure 74. Sketchbook

Right. Figure 75. Pen

Right. Figure 76. Crayola

Right. Figure 77. Metal set square

Right. Figure 78. Metal vice

Right. Figure 79. Grinder

Right. Figure 80. Stick welding gear

Right. Figure 81. Visor

Skrei

Context

Following the experimenting phase, the project entered a phase of making. This phase saw the improving of the design by combining more knowledge from experts and saw the construction of the various exhibition pieces. The team that was assembled for this specific task was an experient blacksmith Augusto Silva and his assistant Odayr Lopes Delgado. For the purpose of this study, the focus will be on the production of the metallic shelves. The first phase saw a meeting take place with Augusto where the prototype was presented along with a digital drawing containing plans and elevations of the shelves. Following the discussion into how to improve the design, Augusto and Odayr manufactured the shelves in one week at the blacksmiths workshop in Santo Tirso, Portugal.

Use

Most architects never actually build their own projects, this responsibility and risk is instead handed to a craftsman or a group of craftsmen. For all purposes, the craftsman are the designer's surrogate hands (Pallasmaa, 2010). These surrogate hands are filled with implicit and explicit knowledge which has been accumulated over years of work. Even in the case of PJ, who is experient in working with a variety of materials and tools, he humbly acknowledges that the craftsman's knowledge is far more superior to his, "they work with the material on a regular basis, they are the material, they are the mediator of the material…" (Jervell and da Silva Rosa, 2021). It is therefore essential to integrate this knowledge into the project as early as possible to improve its accuracy and success. This was the case with the metallic crate design, which is referenced in the modelling phase of the dissertation. On completion of the crate, it was presented to Augusto the inhouse blacksmith. Who under inspection, identified flaws with the design. For example, with the original bottle stands, the prototype used 4 mm thick, 20 mm wide flat bar steel which distracted the viewer from the bottle. Augusto therefore suggested to use 2 mm thick, 20 mm wide flat bar steel as it permitted the bottles to be clearly looked upon and would reduce costs. He also proposed to remove the steel threaded rod and the nut and replace them with a 4mm diameter steel rod which would be directly welded to the supports creating a stronger and more aesthetically pleasing design.

In a world where automation is ever more prevalent, products and methods of construction are becoming ever more standardised (Pye, 2008, p.19), this is evident in a variety of sectors, such as blacksmithing. Originally metal structures were made by hand with the assistance of tools. This method of working is also known as a "workmanship of risk" (Pye, 2008, p.22), with a moderately free "regulation" (Pye, 2008, p.34). Today factories dominate the construction scene, they use carefully calibrated machines to perform repetitive actions. This method of production is considered as "workmanship of certainty" (Pye, 2008, p.21) with a high level of "regulation" (Pye, 2008, p.34). However, the capacity of mass producing also has its own downfalls, as it "lack depth, subtlety, overtones, variegation, diversity" (Pye, 2008, p.19). These discrepancies between handmade and factory made are visible to the naked eye (Jervell and da Silva

Right. Figure 82. Skrei. Meeting with blacksmith Augusto

Right. Figure 83. Skrei. Blacksmith Augusto

Rosa, 2021) and according to PJ this can also be felt, via the energy which the product emits (2021). To better comprehend this notion, PJ explains it being similar to walking from “Porto to Paris, the process will take a long time in comparison on getting on the plane and arriving their on the same day. However the experience that I will have, will be more explosive, I will accumulate more richness between one space to another” (Jervell and da Silva Rosa, 2021). Handcrafted techniques are normally more time consuming, labour intensive and as such the material accumulates more energy. In the case of industrial processes, they are less time consuming and less labour intensive.

The process of constructing saw the introduction of the blacksmith and his assistant into the project. Before construction could begin the prototype was presented to the blacksmith, where his previous knowledge both implicit and explicit improved the design. This saw a decrease in initial costs along with improving the aesthetics. During the phase of construction, the blacksmith and his assistant showed workmanship of risk. The outcome of such workmanship was a product which was both artisan and unique. Unique because by working personally with the material, it gained energy which could be felt. This evidently stands out from its industrial counterpart, whereby the whole process is mechanised.

Right. Figure 84.
Rhinoceros 3D

Right. Figure 85. Grasshopper

Far right. Figure 86.
Laser cutter

Adam Holloway Architects

Context

ThisThis phase saw the resolution of the project within the digital realm, with the continued use of two generative tools *Rhinoceros 3D* and *Grasshopper*. Following the resolution of the project, the data was then transferred to CAM where it was digitally fabricated, producing paper templates which would become the building blocks for the project. This process took place at *Grymsdyke Farm*, a fabrication workshop led by Dr Guan Lee. The team only had one week to digitally fabricate all of the templates. The team assembled for this specific task was lead by architect Adam Holloway, along with master students Aled Evans, Parth Jivrajani,undergraduate student Jack Young and Marco Rosa.

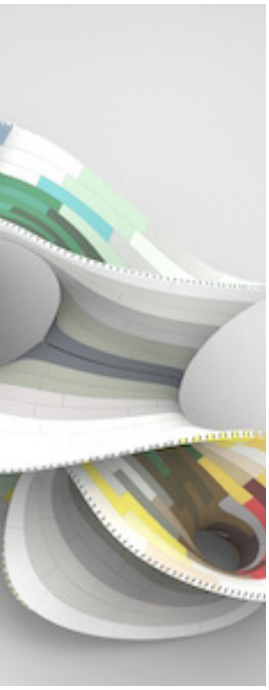
Use

To cut the 1000 paper templates for the construction of the *Apeiron Flow*, the team decided to use the same system from the experimentation phase, *Grasshopper + Rhinoceros 3D +* laser cutter and assembly. To laser cut the templates, the team divided the Apeiron Flow into individual cluster files and created a script within *Grasshopper* which transformed the 3-dimensional clusters into templates which would then be imported into the laser cutter, a CAM, computer aided manufacturing tool where it would be cut. This process is called CAD/CAM fabrication, as it sees the transfer of data from CAD to CAM which was extremely quick and easy to do. CAM or more specifically the laser cutter is classified as "workmanship of certainty" (Pye, 2008, p.52) as it's "operation during production has been predetermined and is outside the control of the operative once production starts" (Pye, 2008, p.52). CAM greatly assisted the process in three areas: ability to rapidly manufacture, precision cutting and mass customisation. Rapid manufacturing offered the team a quick means of producing the templates which was extremely beneficial as it allowed for the cutting phase to be drastically reduced in regards to time needed. The second advantage, was that it offered the ability to cut with a high level of precision and would do so consistently. Finally, it offered the ability of mass-customisation, permitting the team to "mass-produce one-off, highly differentiated building components with the same facility as standardized parts" (Kolarevic, 2009, p.52). This was especially useful as there were 1000 laser cut files to be cut with all individual designs. It is important to mention that the ability to cut quickly, precisely, in any format and do so in mass would have never been attainable with analogue techniques.

Since the era of the Renaissance, architects have become ever so detached from the construction site. Over the years architects have attempted to use various methods to gain control of the construction site, that from distance of course. Firms such as Mckim, Mead and White would produce more drawings, they would also pick the workmanship and the materials to construct with (Davis, 1999). However, the outcome of this level of control was one of distance, that between the architect and craftsman and in turn led to the increasing of influence of the general contractor. In the case of the Apeiron Flow project, this paradigm of control meaning distance was completely altered to control meaning proximity. For instance, the colour coding scheme "was parametrically distributed according to kind of saturation and hue" (Holloway and Da Silva Rosa, 2021). Via the digital the team knew how many laser cut templates there were, the amount of paper that would be needed and the costs. The digital model of the Apeiron Flow would later guide the team in how to assemble this complex geometry. This was made possible with CAD/ CAM fabrication a method of working that see's the architect generate the

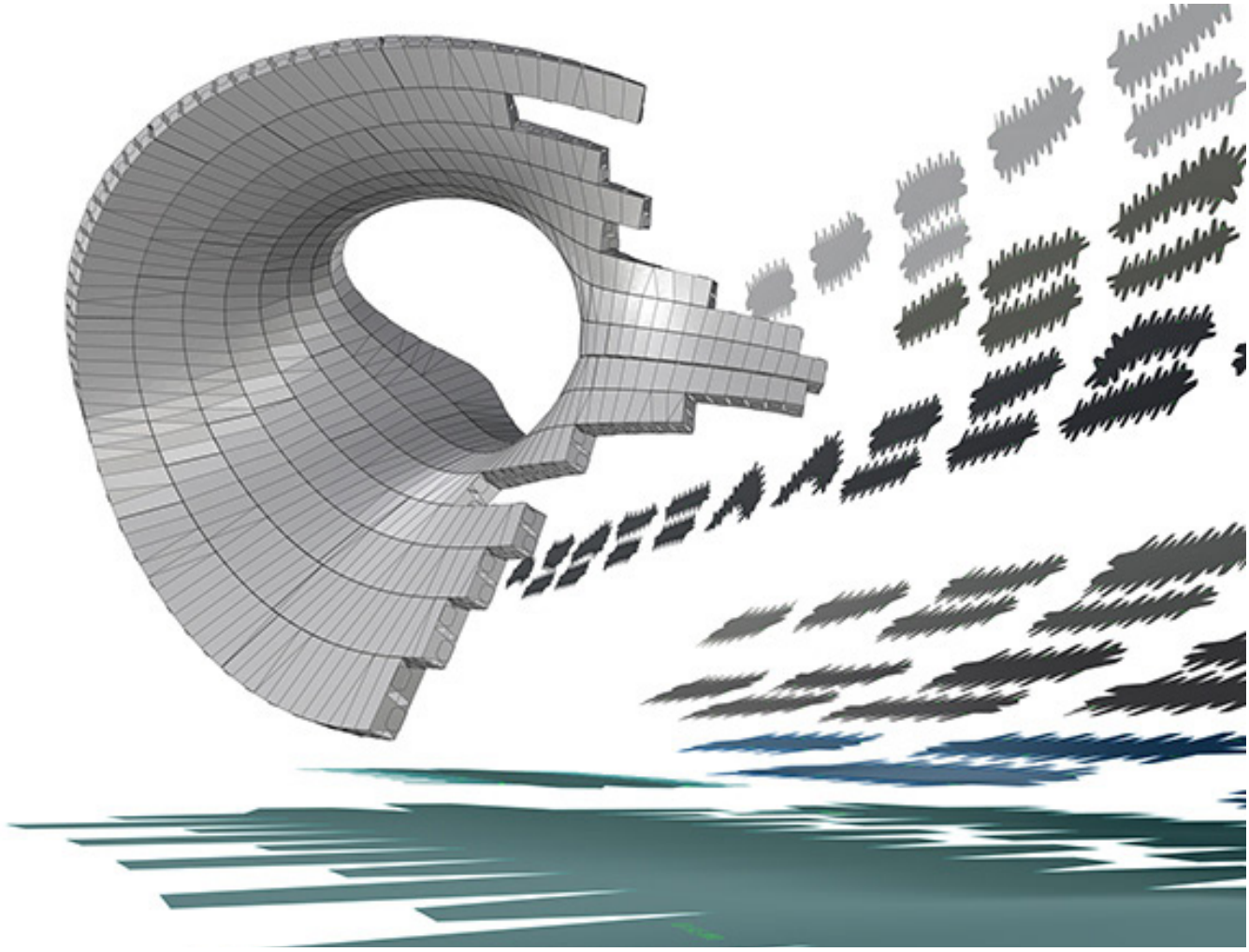
Left. Figure 87.
3D Model

Right. Figure 88. Cluster and paper templates



design data within CAD and in turn this data is used to fabricate within CAM. Architects such as Frank Gehry see this as the role of the architect returning to that of the master builder (Kolarevic, 2009, p.60). Which has led to the rise of various classifications of the architect, such as “information master builder” (Kolarevic, 2009, p.56) and “digital master builder” (Górczyński and Rabiej, 2011, p.412).

Digital fabrication offered workmanship of certainty. It permitted mass customisation which was key to the success of the project; since there were 1000 templates that needed to be cut in a short period of time. To digitally fabricate the pieces, it was necessary for the architect to resolve the design and generate the data within CAD. This phase saw the architect assume the role of information master builder, and consequently gave more control to AH over the fabrication and construction of the project.



4.5 Specifities and complementarities

Understanding phase required students to decipher site, and to do so the tools of pen and camera where used. The research saw drawing be deemed as a more appropriate technique when approaching complex sites as it could more eloquently remove noise, bringing the essence of the space to the surface. Photography, was the most appropriate medium to use when confronting site in an urbanistic manner, permitting a fast and accurate means of documentation. It did also assist in approaching site specific locations. Weighing the strengths of each tool, I believe that drawing ought to work in parallel with photography, combining the strengths of a more refined understanding technique with a highly accurate and detailed technique.

Concept phase must offer the architect the capability of generating ideas and in offering direction to the project. Within the analogue approach, physically interacting with the material allowed for the team to gain tacit knowledge in both the tools and material. Allowing for a more material orientated development. With the digital approach, technology assisted in sculpting the complex geometry which was too complicated to communicate with traditional techniques. The software also assisted in offering instantaneous feedback, via direct manipulation which accelerated the decision-making process. I believe that both methodologies must work in parallel with one another, with working physically with the materials and tools they generate ideas which can be abstracted within the digital offering the opportunity to further push the project in new and unpredictable directions.

Experimentation see's the communication and testing of ideas. At Skrei, the analogue methodology saw the use of drawing and modelling by hand, which was quick and easy to do. Modelling at 1:1 offered an insight into the constraints of the materials and into the construction processes. At AHA, CAD offered the team the capability of transferring knowledge between various professions allowing for a more assimilated communication. It also allowed for precise and customisable rapid prototyping techniques within CAM. To conclude, both of these methodologies ought to work in parallel with one another. Sketching ought to be used to rapidly communicate ideas, this information ought to be transferred to the digital offering a more transparent means of communication to all parties. Physical models ought to also be used in the design process, this can be either by hand or via CAM, depending on the level of precision needed and whether or not there is a digital model present at the time.

Construction see's the making of design ideas into reality. In the case of Skrei this was achieved via the blacksmith, who improved upon the design and produced it.

The outcome was a well-conceived product which was unique. At AHA, the architect become the information master builder who generated all of the necessary construction information within CAD which was later transferred to CAM. CAM offered the possibility of mass customisation and high precision fabrication which was essential for the success of the project. I believe that both of these methodologies ought to work in parallel with one another, combining craft rich techniques and precision fabrication contributes to a enriched project.

In the authors perspective there should be three parameters that the student and architect ought to consider when selecting a tool. Firstly, the complexity of project. If the project is too complex than its preferable that it is resolved within the digital, as it is more capable of facilitating the design process and later with the construction of it. Analogue tools can be used in parallel to further inspire and inform the architect on design limitations which inform the digital. Secondly, the skill set of the design and construction team ought to influence the direction of the project, as it will contribute drastically to the success of it.

5.Conclusion

The intention of this thesis was to situate itself between the tensions of the analogue dominant and digital dominant design and construction methodologies, to therefore explore the specificity and complementarity of both. To do so, it was necessary to fully understand how the tools of the differing methodologies were used in their respective experiences. These experiences were composed of projects which the author participated in, both in academia and in practice. This hybrid choice in experiences was extremely insightful as it offered an opportunity of analysing how the author approaches site followed by how the professional practices operate.

Upon reflection of the interviews with the respective architects of the various experiences and with the architects in *Café com Esquissos*, it became apparent that all parties acknowledged the relevance of the digital with their design process. In reality, the tensions specifically exist in very specific moments, for example JPL, strongly claimed that a physical and digital model are explicitly different. In the architects perspective the physical model has two main advantages, the first being its scale is fixed allowing for the architect to have a more controlled reading of the project and the manner in which natural light interacts with the model can never be fully imitated within the scaleless digital realm (Loureiro and Da Silva Rosa, 2021). Discussing design methodologies with Juhani Pallasmaa on *Café com Esquissos*, it became apparent his approach was one that involved analogue techniques being strongly present at the beginning of the project and at end with its construction, inbetween these two phases he supports the use of the digital (Sobreira et al., 2022). In other words, the architect merely digitises the analogue information and does not use the digital to inform the design.

Upon reflection of computational design thinking tools, such as *Grasshopper*, it has become apparent that it has huge potential in both euclidean and parametrical design. Upon discussing the matter of computational design with Fabio Gramazio from Gramazio & Kohler Architects it has become apparent that students of architecture and practicing architects are code illiterate (Sobreira et al., 2022) which only limits the architectural community. In my personal opinion, faculties ought to be at the very least introducing this tool within the education of architecture as it will not only open the students to new and more efficient manners of working but also new ways of thinking. In practice this will permit for a more competitive studio.

In hindsight, the study ought to have analysed a building which had been designed and constructed in both practices. However, during my short time at AHA a building was never designed or built, there was however an advantage of studying exhibition projects. Firstly, they were less bureaucratic, allowing for more experimentation and secondly the design and construction processes were relatively quick. These factors, offer the ideal opportunity to test

the theories of specificity and complementarity on a similar scaled project. By testing the ideas on a similar scaled project, it will provide the breeding ground for experimentation and will lead to the development of theories. The relatively quick turn over of the project, from design to construction will provide for quick feedback, offering the opportunity for more tests to be done to rectify and improve the theory. This will all contribute to the process of designing and constructing architecture. This will not only be incremental for my own development, but it will also be beneficial for the NEB, with the presentation of tangible results.

As much as the thesis responded to the objective at hand, it also introduced unexpecte topics, the most relevant of these being the fourth IR. Upon analysis, the current IR is already present in all parts of society and within architecture and is set to further integrate itself. In regard to architecture, it is improving upon existing design software's, as seen with Finch which integrates AI for a more personal design experience. It is also proposing new and more innovative approaches to design, for example, architects no longer need to rely on renders to communicate ideas to their counterparts or to clients they can instead fully immerse themselves within VR, creating a multi-sensory experience of the space. It also shows huge potential within construction, with the introduction of automation and AR. These technologies and amongst others are considered by experts as being a long-term solution to the global construction labour shortage. These technologies also have the capacity of greatly contributing towards the NEB and therefore must be integrated as soon as possible within the EU if the EGD objectives are to be reached.

With all these changes taking place, questions of how the education of architecture will adapt arise. Perhaps the most interesting of all, will be to see how FAUP a school of architecture which strongly identifies with drawing and modelling by hand will adapt to the current age. Will it decide to resist to change and proclaim itself as one of the very few schools which still offer a traditional education in architecture? Or will it sensitively adapt itself to the technologies of the current IR? To enhance the education paradigms that are currently in place and not obliterate the relevant and iconic identity of the school.

This observation merely reiterates what Klaus Schwab said, "... building on a shared understanding, we need to develop positive, common and comprehensive narratives about how we can shape the fourth industrial revolution for current and future generations" (Schwab, 2017). Academics and architects must therefore come together on local and international platforms to discuss ideas on the relevance and applicability of the fourth IR technologies. This is to ensure that these disruptive technologies coexist in harmony within each context. These changes do not however bring into the question the relevance of the paper, as the knowledge gained at this phase will provide the foundations to integrate the tools of the fourth IR. For example, the study has shown the extreme relevance of drawing and as such an architect

can use VR to enhance their drawing abilities by creating three dimensional sketches which they can immerse themselves within. Along with the intent of testing the proposed theory, the intention will also be to interact and integrate the disruptive technologies of the fourth IR within the design and construction process.

Attachments

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Artist James Hobbs

Marco

How does the size and format of the sketchbook assist in understanding and portraying site and the subject matter?

James

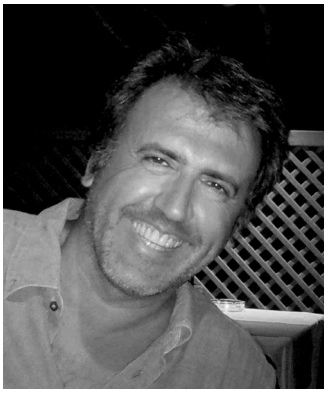
I tend to have to sizes of sketchbook, an A5 and an A6. I can vary between them, there are times where it feels more natural to use one than the other, that is not necessarily to do with the subjects which I am doing. When I went to New York, I did not know which to take. I took an A5 and an A6 and I ended up using the smaller one because I could more quickly. I could work across a whole spread if I wanted to, so it was just an easily carried and more adaptable way and also wanting to do lots. If you work quickly, if you take along time doing a piece of work, so what. Especially in places such as New York, London or places similar, there is an energy and a vibe that you want to communicate through the size of the marks.

Marco

Does the medium and sheet size have to combine?

James

I think it is a combination of not only the size of the sketchbook but the size of the mark. I think that his how those two come together, I feel like I tend to have the temptation to use a larger ‘arena’ to work in, I feel like I want to have a larger object to draw with. A pen that is too thick and too small, I’ve done it, I have a lot of sketches of me using a sketchbook that is too small and it’s a mess. I think, it is more promising to go larger with a thick brush. I feel like I’ve worked to a state where I have fund the right balance with the size sketch book with the pen that I enjoy and work. I enjoy and that I work with best.



Architect João Paulo Loureiro

Marco

What is the importance of working into the model by hand?

JPL

The model is extremely important to the process. I use the model at various phases in various materials. Decisions on material is principally made upon practicality of the material to achieve such objective and its cost. I do not want to fixate too much upon cost but it is decisive. It's a transversal factor, that is present throughout the project. So not to merely talk about the economic factors it is also important to mention other factors such as time, availability of materials these are factors which are present throughout the project.

Essentially I see the model as a tool for working not for representation but that does not actually mean that this element of work cannot be used for debating and representing. It is used for various purposes. The principal of modelling is to offer close proximity to the scale. It permit us to look at the model in various perspectives.

Now with regards to the sensibility of working with the digital, we continue to work with hand. For instance I've made models out of lego, plasticine and other materials. There are various materials, with various properties. At times the project informs the selection of material. At times the model forces us to reflect parallel, the model at times achieves an autonomy.

JPL

For instance drawing is merely the act of reflection of imagining intelligence as Siza says. We can achieve architecture without drawing much, as we know the school enourages students to draw however more than that it teaches students to observe and think. The drawing can be a collage, an image, can be an idea.

At times there is a danger to drawing. Especially students, the drawing at times gains an autonomy from the project.

Marco

The student loses control over the drawing?

JPL

It is merely though experience that we learn what works and what doesn't. To be clearer on the matter we are developing a project and our sketch suggests a proportion that

is real and we are illuding the proportion. The drawing however always had the wrong perspective. Then we work with the model and we see that it is wrong. The sketch needs to be deciphered and with experience we will gain an understanding of it.

The sketch is also a method of searching, which is fundamental in the intelligence and the problems of that register. The model is also registering ideas and may appear at earlier and later stages.

JPL

We need to have a notion of who will produce the project and this will influence the amount of information needed, type of information needed and the precision of the drawing.

Marco

What is the importance of working by hand? What can you achieve by hand, that you cannot achieve with other tools?

JPL

Its complicated, its complicated quantifying this. What I would give importance here of that feeling of being connected to the project, thinking of the project, expressing yourself and confronting yourself. Now when we talk about sketching and drawing, it is a formula a method which seems efficient and eficaz and it useful and can help. I can say that I have a moments where the importance of drawing is variable. It is difficult for me to give it antomamy, a drawing is nothing by itself. What is incharge is intelligence.

Marco

So why is it within the faculty drawing by hand is so important?

JPL

It is exactly for this reason, I would recommend for you to speak with one of the drawing professors from the faculty. Prof. Joaquim Viera was my professor, Alberto Carneiro has also passed away but an amazing professor. Thinking a little about the professor, drawing for him, during the drawing lessons was all about learning how to look was essential to drawing. Not necessarily about drawing itself. Ofcourse afterwards it about how you look and you express what you see is important. How you see, look, registering. Drawing for the faculty at the time, stood out as the tradition of the school is born from the Faculdade das Belas Artes. Tutors came from the arts would teach how to draw and this is interesting. The professors were teachers and not architects. They ofcourse had a vision of the context of architecture but does not stop being essential in

the discipline in drawing, learning how to look, learning how to register, learning how to interpret. You then use these skills in understanding objects, streets and bodies. For instance drawing nude bodies would encourage students to, observe, understand the body, understand hands, do one minute sketches, 2 minute sketches and so much more. This affirmation that all is form, life is form, this phrase is from Balzac. Observe form and register form. Drawing is fast but it is critical, that's the big difference between drawing and photography. Drawing has this critical aspect. We all see things with a different perspective.

Marco

Now in regards to models. Can you please expand a bit about modelling within the faculty.

JPL

There are two reasons for the reason studies model by hand. Firstly and previously mentioned it is in regards to economy. We do not define on what type of material needs to be used, we merely implore that it is white and that is to ensure that all students are all on the same level. Prevent them from diverging, from creating 'noise', prevent them from creating complexity that may not be useful. This is not in reference to the entire faculty; however it is specific to the fourth year. In the fourth year we want to debate form. Especially as the program is one which is public. We believe that doing a public program is beneficial, makes the students think about various complex ideas such as circulation. In this perspective we thought the models being in white would be the best manner of approaching such topic. I participated in a competition in Berlin, the New State Gallery. The competition specified that all models submitted had to be white, it was interesting that they requested this. With the model being white we focus on form, drawing and context. Material within a model can be an illusion can create a different perception.

Modelling by hand is also an act of learning. You have to make decisions, you are working with measurements you enter the problem. Of course that is more useful than ordering for it to be made. Doing whatever with your hands is the act of learning as you must get involved.

Marco

Is there a difference between modelling by hand and modelling within software

JPL

They are completely different. It is the same as you looking at a building online and

looking at model of a building They are very different. Do you understand?. It is not the same, their utility is different. I'm not even entering realism. Between virtuality and the real, between two abstractions of reality one is real and the other is does not exist. The difference is huge. You can touch it, you can observe it and etc. The behaviour of light, even though it is an object it still reacts to the light and space and etc. In an identical form, or very similar to reality. The virtual object ironically, you can contextualise it with sunlight from that specific location at a specific hour. It does not stop being an abstraction. I am not comparing both, I also make renders.

Everything that is approaching, or giving the necessary tools to make decisions. Lets see, the large enigma of architecture is that you have to create something, you're going to execute something that does not exist and generally, generally no. It is a highly responsible profession. A person has been saving money to construct a house and then trusts you with it, you are given a huge amount of responsibility. Anything that you can use to reduce the error and control what you want to do the better it is.

Now you need to understand that everything has a function, it has a purpose. You cannot merely rely on making decisions on one tool.

Marco

Are you trying the difference is touch then?

JPL

No its not touching, touching is important but the touching is approximaty. There is a difference of having an image of a painting and actually having the painting. There is an idea of reality, there is a practical reason. The object permits for you to look at in various methods, the light, the light is fundamental, the idea of scale in a model is very important. I recall having a teacher of visual arts at school and at times would show various images of materials and the people could understand its scale. For example if we look at the image of skin, if we start increasing we lose perspective and loses the essence of being skin. If we zoom in it begins to appear as something else, it could look like moon craters in irregular skin. An object, a model tries in relation to form has a problem in regards to scale but the form maintains itself more permanent. Do you understand? The Maquette therefore becomes more useful as it is an object that does not stop being architecture, as you have all fo the context at the same scale and you can understand all of logic of relations maintains. Alright it is an abstraction of reality but we are not discussing maquete and reality, we are discussing model, model which is an abstraction with an other digital abstraction. Here they are two different things

Marco

So it has to do with scale, no matter how far I move away from the model and close I approach it the scale stays the same. This however is no longer the case when I work within 3d digital software's where I can easily lose myself working from 1:1 to 1:500.

JPL

Exactly, I can give you n examples. You can visit a building and you can say that it is a one to one scale model with material. Then you can compare the digital, you have the same building within the digital. You have David from Michealangelo and you are looking at it, you do not need to touch it as you can go around it or you can look at it on the monitor. It is not merely a question of touch , it also has to do with proximity of seeing the behaviour of light, that idea of scale of form. The essential is the perception of form because the digital 3d element cancels the form, it transforms an object 3 dimensional into two-dimensions and that is a problem. If you use those virtual reality headsets, where you can look 3 dimesionally is different to actually being there. Other than the sensorial part, where your body is feeling the space which assists in reading the space is also important, it is always a big difference.

JPL

Something else which is important to mention is time and had this privilidge of working at Soutinho and noticed this. The fact of drawing by hand was actually drawing by hand, now we sketch and drawing by hand is achieved digitally. Drawing by hand was used from everything from drawing sections, plans, used for sketching and to create perspectives. Today we consider these perspectives to be renderings. Renders have been used a long time, difference is that they were hand made and were made from perspectives and the reason for doing such was to assist the architect in approaching the projects. This is evident with Frank Lloyd Wright, Le Corbusier, the Smithsons. There has always been a worry of approaching reality to anticipate an object which entails a lot of responsibility.

Time has a huge impact, the time for projecting more elonged. The tools were not as fast and this permitted a larger amount of reflection. We would draw within the office and take the work home and this was the same for construction. To achieve execution drawings, it would take a long time. This is no longer the case today, today everything is very past. Sometimes I feel like I need to create breaks. Work with on other projects so that I can turn off from the previous one. Permitting me to return to it at a later point with a critical eye.

Marco

I completely agree with you

JPL

In this entire process, what is permanent is this necessity to make decisions with a maximum of propriety. Drawing becomes a tool of debate within the atelier. All of these mechansims are associated to the process are important. Time is very important. Working fast can be good but has risks. It is important to think and make decisions.

Marco

It is very interesting you say this. During my time in the United Kingdom we would have to achieve two projects within the academic year. This meant we had to work fast and this completely different to the experience I had at FAUP. I Feel like the use of drawing by hand, being able to sit down and discuss with yourself and my colleagues' ideas where we would all draw on the same paper permitted for the project to improve. These moments time would slow down, and we stopped merely producing work and instead questioned it. The tool assisted in doing this.

Architect Pedro Jervell

Marco

What are the benefits of interacting with the material from the beginning from the concept phase?

Pedro

It's his mystery I would say. Within each material there is a load of energy of knowledge of intelligence, I would say, because everything that is matter has a load of energy of history and knowledge whether you want it or not. Whether the human being is capable of reasoning or not. It's the mystery behind or hidden in those in those floats. And this is what moves us to use our body, physically and mentally our body to approach that mystery, you know, remember how we did this you know, we had this body imprints contact with material we expose ourselves within the landscape, even though the hole we made in the quarry was like exploring how we how absent the body is to the landscape and how close it is. So the only way to get to it, approach these mysteries is really to test them and to test them you have to put yourself in a position that is not a really a certain answer. There's not really a certain logic. There's always a mystery. And through that mystery, you allow effects to happen.

If nobody had a chance to boil an egg. He would not know what was the effect after being boiled. But he had to boil it, to know. Today we know, it is common knowledge. But if you, if you had in mind to imprint the human body, onto stone you will never, you'd never know what's the result of the effect. So the only way to do that is actually doing it. And in order to do it. You have to go through a lot of difficult issues, how to do it, you know, normally you think how can I. How can my body with his physical properties, his physical gravity and and physical condition is able to really introduce the body and the matter onto the very solid and all the various rough material as the stone.

Marco

What is the benefit of really interacting with the raw material at the conceptual phase?

Pedro

So the conceptual phase is very distant, or very close depends to the to the very to the practical one. I think that the better, the more the more abstract you travel this process the more rewarding the result will be. That is to say that it's difficult because we as humans, we are expecting, we have this we have our own expectation upon the effect you are, you know, wanting to happen. So normally a kid that wants to have an ice cream his father buys him an ice cream is an immediate process. Yes, because he's

thinking about it. And he's having it. Appreciate it, straightaway. When, you want to make something which is very difficult to happen. You have to go a very difficult process and the expectation that you have has to be sustained through that process. In that period of time. It's where things accumulate the answer the result? So he had to take two years, two years for that specific piece to be made into that two years period of time. Our expectation was that thing the key of this process because we never, never gave space or gave away the idea of being abstract to the to the to the project, the process itself.

I don't know if you understand, but if we want it to happen very quickly. It will never be the same it will never be the same because because he will, he would, he would it would accelerate things to happen. So in this time, it's very important to respect the quality of time of things that happened. So you can never break a stone in the fraction of second and transforming it into a kind of rendering. We knew from the beginning that we will take a lot of time to produce these things. So the only way to achieve the result we wanted to have was to accept the time issue that had to happen. So for us, time is a key factor for things to happen in our process or our objectives. You see some for me. Yeah. So, but nevertheless, it doesn't mean that it is that it takes a lot a lot of time.

Marco

Yes, it depends on the object or the idea.

Pedro

It's really, it's very relative. The relative equation, yeah, it's universal. It's true. So it's, it's a difficult thing in our days in our practice, to work with, with clients. With, with the workers with the constructors with everything, you know, everything we surrounding us as architects, the time issue and the expectations that this time issues imply it's very it's very important to coordinate the expectations of the client though of ourselves. So, but it's, it might be the key of people to appreciate and to understand the advantages and then the potentials of this.

Marco

I recall during the conceptual phase we were dipping grapes in beeswax and then we created other objects. Can you talk a bit about the purpose of this phase?

Pedro

In a certain way. We were decoding the coding. To really understand, to really fulfill our expectations, we were trying to decipher what was hidden, as I was saying earlier, what was happening within the DNA or the atomic structure of everything.

So, yeah, so in a way, the other scenario you were saying showing me the coding (Computational design thinking) in this one. These are tools that enable us to avoid time to be decisive on our decisions. I would say this helps us, this procedure this methodology helps us not to think too much and to not really know exactly what's behind our decisions, I think.

This one (Skrei's) is to really have a full understanding. When you look at it. There's a certain distance between you and the object. But then there is a proximity which you don't know which is hidden and this is what we were trying to do. There's a certain familiarity, you know, there's a certain proximity but you don't know quite where it is. So, how to do it. You have to decompose it. You have to really go on to what is known as the atomic on the nanoscale, to really find out what's the composition of this whole thing. And the only thing the only way to do it is to really expose yourself as much as possible physically and mentally.

Our body is the vehicle to test and to consume consumed all the effects of the process you're doing because you're our bodies as well as everything is it's a mystery. You know everything is a mystery in this fundamental. So if you accept that you work on that, on that platform instead of okay forget about this, about us forget about what we are forgot about our our condition, and let's just move for a system or to work for us and that don't really know what we really are. But where that will create an imaginary and imaginative scenario that could you know, at least give us some direction instead of accepting. We are never happy of something that give us an answer. Or don't use ourselves as part of the process.

For example, I think in a way the project we did together, gave us an idea or an equation of numbers or elements. Because it was what it was. I mean, we went on to knowing or seeking the most smallest scale is possible, existing within that material. So we had to go from the stone itself, the molecular scale of it, atomic scale of it. And when we reached that point, we discovered that, indeed, that element that material was is animated.

Marco

The same way we approached this exhibition could be said for approaching a project. What was the benefit from you coming up with an idea and jumping straight to the material?

Pedro

An idea can come from can come from a material itself. A detail, construction detail come from a cultural, social behaviour of a place everything has its intelligence, everything.

It's an accumulation of layers. For example, a place any place on Earth as its own local intelligence, which is built upon culture, history, architecture environment found for everything, although all those layers squeezed together form a local intelligence. If you I mean, you can, you can just avoid that. Or you can accept that to understand to construct your process, but sometimes after you make a survey of all these layers that compose this local intelligence, straightaway, you will understand which one of them has its more potential. Effect on the place itself. You know, for example, where we are, you have the fisherman's and you have the agriculture, big impacts on all the dynamics of its place itself. So it's a matter of understanding which one of those have a more impact on the project that you have on your hands. That one, this one, this exhibition, the program was to find out what was the best way to express or to describe the region of the Douro. So we have to build up the sequences of logics of realities that exist on which compose better at this exhibition. You know, so but the way we did it was not by using what was naked to the eye. It was exactly the contrary was going to see what was behind the reality that exists there. To find out more answers, find out more logics find more value. People don't really see them. Not so this heading you know, this is I think what you're talking about is the tools that you use.

Marco

What is the difference then between computational design thinking and interacting with the material early on?

Pedro

The latter you're not dealing with rules, instead you're dealing with possibilities.

I would just like to mention that as an office we like to use technology, when we deem it necessary and when it is an advantage for our work. Now, the human body is and will always be in my view, the beginning and the end in all processes. At whatever scale, from an atomic scale, urban scale, community scale. It is always the human body. Always.

Marco

Now this question is in regards to the process, it is in regards to the metallic structures. I recall you approached this phase of the project via a hand sketch. Why did you opt for this method?

Pedro

The drawing is a discovery, is it not? For example during palaeolithic era, humans would use their body and drawing as a method of imagining what would happen in the future. Drawing is an act; it is an experience that uses the human body. When somebody is

doing a drawing they are not using their hand, they are using their body. The body is completed attached to the brain, where we can imagine. A drawing is an event fixed within a moment in time and the body is the mediator. Just with that can, I mean I believe, I think that only through drawing or via a physical gesture. For instance, you can grab some clay and you start working into it or you grab a rock and you start scratching into a wall. Their needs to be a physical act, that comes from a necessity, a mental necessity or physiological and there is a revelation. There is always a revelation.

Marco

After doing the sketch you had made a physical prototype. What was the benefits of already interacting with the material and tools for making it?

Pedro

The advantage of working with others is that, when you can get a group of people to answer to a problem more responses are found. By acting in a group the answers become more assertive, somebody who dominates more the materials and the tools and somebody else who dominates the part of imagination. We help each other. Augusto helps with destroying boundaries and I helped Augusto discover new languages. Who says Augusto, who no longer works with us, but it can also be said for Joao, Samuel and etc.

Marco

Do you see yourself as a master craftsman?

Pedro

I wouldn't say craftsman however I am comfortable with using a wide variety of tools and materials. In reality though craftsman are born with knowledge, they work with the material on a regular basis, they are the material, they are the mediator of the material. When you see Joaquim (carpenter) or a stone mason working the rock. They is a affinity they spend more time with the materia prima then they do with their family. They sleep with the material. For us however, out profession makes us lead with a variety of people. What becomes rich is when we architects, hand over our information and they transform into reality.

For us however at the studio we want to do what they do, exactly because that way we can arrive at the point that they arrived. We want to know the material, we want to swim in the material. Only then do you understand the limits of the material. When a person imagines a certain problem, then there is a barrier which is how will I make it. So you will speak with the people who work with the material, they will give solutions.

You, if you are knowledgeable on that base, then your imagination and thoughts will … expand much more. It flow much more. A lot more really.

Marco

What is the difference between hand and robotic methods of working?

Pedro

I believe them to be valid, it is a question of interest. You can see the difference in e.g a mug. You can see the difference of what was made with robotics and the other that was made by hand. The final product is completely different. The visual difference between both is hige, they are completely different. It is not the visual but more however the energetic charge which it occupies the space

Marco

Does this energy come from the human body that interacted with the raw material to make it?

Pedro

Yes! You can perceive this energy. To better comprehend this its like walking form Porto to Paris, the process will take a long time incomparison on getting on the plane and arriving their on the same day. However the experience that I will have, will be more explosive, I will accumulate more richness between one space to another.

Marco

What about the final product. The difference between both is that one contains human error?

Pedro

What is error? I find it interesting talking about error, I made a mistake, that is mistake. It is not something bad. We are so use to looking at something and saying ah that's bad. However it can be interpreted as a benefit, its an improvement. People today however look at a product, it must correlate with their conditions and expectations. The same as a wall, society today looks at a wall and are use to seeing it straight without cracks however if there is a wall that is a bit wonky then its wrong.

Photographer Lara Jacinto

Marco

Does the type of lens make a difference in regards to the reading of the space or of the object which you are trying to document?

Lara

Yes the lens does help, it's like any other thing that you place in front of you. For instance a car window. From the moment in which something is conditioning your vision and exists between you and the object which you are looking at, always conditions because its not only in the head, or the manner in which you look at things that will influence your reading it is also an object which has a physicality. In my case this interferes, for example I photograph with two different cameras, with Hasselblad 500 and a Canon. In the case of the Hasselblad 500 my method of looking is completely altered to that of the Canon. For instance the camera forces me to position myself above the camera, this is instead of looking directly at the subject matter which I intend to document. When I am above, it changes everything.

Another thing which comes to mind is the fact when I am photographing, principally with that camera I become more enclosed within myself. In other words when I am looking without this intermediate, this mediation of looking directly I am more alert to other things which interfere with my thoughts. When I am photographing, when I am looking via the camera I am more concentrated, more conscious of what I am observing.

Marco

The lens, a wide angle lens or standard angle lens change your approach to the place which you are documenting?

Lara

I don't know if I am the best person to respond to this. As I don't permit this to happen or try not to let this happen. In other words, the lens and the optic characteristics alter what I want to do. I want to take control of my camera. The pick the lens on the principal which one will be able to capture my vision most accurately. For example in my case and the type of image I produce, the wide angle lens is not appropriate. It has to do with the way in which I see. I have a bigger affinity to a square format instead of the rectangular format above all the horizontal. I believe this is because, the way in which I look is more rounded. Hence why when I get a chance I decide to use the 6 x 6 as it better represents. I have the same mentality for everything, what film I use or the objective I choose. The digital is the same, I try to adapt the characteristics of the materials that I work with to

my way of looking. I went in the end for the image to represent what I see.

Marco

What are the benefits of using a standard lens?

Lara

When I am giving lessons, I normally tell my students that the 50 mm lens, which is the normal lens is considered to be the closest in proximity to the way in which we look. For me however it is not very clear how it can be so, however perhaps on a technical level it is.

Marco

What is the difference when you are using the analogue and digital camera?

Lara

Well when I am using the analogue camera I am more thoughtful when I am photographing, I might take 2 or three. The digital I might do this process more on the camera, whilst I photograph. There is a phase where I am merely testing in the digital, however in comparison to the analogue this is not the case.

Marco

Digital permits you then to take a variety of photos without having to worry about cost and storage.

Lara

Yes.

Marco

What is the advantage of using the camera as a form of documentation?

Lara

It depends on the person. However in my personal experience, my greatest interest is knowing, investigating. Perhaps it is for that reasons that I identify with this medium, which is in closer proximity to reality.

Marco

I normally on a site visit take photographs. At times I take photographs of things that I do not understand it is only at a later point when I review the photos that I begin to understand what I was of interest. In some cases I even see things which I would have

otherwise missed. Does this normally happen with you?

Lara

Ok, I normally tell my portrait students, even if I'm with a person for only a short period of time the photograph is always a result of a reflection. I am a photographer so my view is conditioned. Ofcourse photographing is a reflective process, I am not photographing without not knowing what I am doing. Perhaps for others it is there method. When I am reviewing images, I normally see things which I had not noticed that were there when I took the picture. This is normally because I don't look back at the images which I am taking whilst I photograph. Hence why I like the difference between the analogue and digital have. The analogue does not permit you to look instantly at the image. For me, when I receive the films, as its been a long time this reviewing of the images with the distance of time and physical distance of the space is very enriching and at times it is even a surprise. When you look immediately at an image, it means that the relationship that you have with the image is not the same.

Marco

Do you use the settings on the cameras when photographing?

Lara

You know I use new and very good cameras but I photograph on the principle that the camera does not have any of these capabilities.

Marco

Do you normally edit images on photoshop?

Lara

Its funny that, I don't edit. Especially with the analogue camera, there I don't do anything. I might edit here and there the contrast or uniformise the colour but other than that, nothing. The films that I normally use, are the ones that I like very much. For instance the kodak porter, it is more yellow and warmer. Even the paper I choose to print on have a certain temperature or finish. The digital I use it very little.

Architect Adam Holloway

Marco

Did you get a chance to visit the site? Or did you get a reading of the space via photography?

Adam

We had a type visit before the project started, and they showed us five different sites. And then we could pick which one I wanted. So I guess there must have been eight sites, but yeah anyway so they showed us a few sites and then we put requests in sites for work.

Marco

How did you document it? Photography?

Adam

Yeah through, photography and took some measurements, just key measurements.

Marco

Did you make a rhino model?

Adam

And they also sent us plans. So we got DWG files of the spaces. And yes, I made a Rhino model from the DWG and then sized pieces of the proposal to therefore explore the circulation movement around the piece.

Marco

How did you approach the conceptual phase of the project?

Adam

I normally begin with sketching when the designs are more conventional. In this case I cannot actually draw the geometry that I designed. Well, I guess that's not the right way to say it, I mean I can't sketch it, but I explored it through algorithmic testing, geometric testing with 3d model. With this kind of geometry, it's, it's not something you can necessarily predict fully before you start the process. So you have to kind of adapt it and sculpt it as it grows or as it develops.

Marco

What is the difference then between conventional and parametric forms of designing?

Adam

The key difference between computational parametric design and more conventional design that is that in some way you can't necessarily imagine what you're going to design, when you cannot sketch it entirely, maybe you can sketch parts of it. I guess the method of design enables you to imagine things that you can imagine by yourself, so that the designer working with the computer is more than the kind of vision of the designer by himself, or maybe something like that, or maybe it's just me. I guess in a way that also, when you sketch something, you know act of sketching allows you to imagine something you can maybe just imagine in your head or just talk about, so it is about the medium.

Marco

This goes back to our first conversation. You made this really nice statement that when we look back into history of architecture, the architects would seek inspiration and references from the past. Now, you don't need to think in that manner. Architects can now really experiment, with the use of technology. Both with assisting with the creation of an idea and with the fabrication of such idea.

What becomes apparent is that the digital almost becomes another architect and builder within the process.

Adam

Yeah, yeah, feeds back into your design process there's a kind of a dialogue with the medium, but I mean it's not, it's not completely different from sketching. I think there is some one of the many mediums. With any medium you work in there is some feedback from the medium.

Marco

On to the next topic. How did you initiate the design process?

Adam

I knew that there was this way for growing geometry, I had seen the work of nervous systems which explored this. I was interested in that way of creating differential geometry. Also looked at the work of Ether Hill a ceramicist. Two inspirations for this.

There is the digital side which is inspired by the way, plants grow. Plants with these kind of ruffled edges of the leaves, achieve that roughly kind of stiffness to the ruffling by growing some cells faster than others at the edges of the leaf. So as as the leaf grows and the faster growing edges start to warp the plane of the leaf as this keeps going and then it creates ruffles. That was inspiration for the nervous system.

Ether Hill's a ceramicist, had a similar technique for working with clay, where she would start off with maybe kind of a flat plane, and then she would add more clay to the edges and would add more and more to the edges until it created the shape and then she would join some of the edges together which were close to each other creating a new type of geometry. Which is similar to some kinds of minimal surfaces, but the topology is something that she discovered along the way. It's kind of an ad hoc process but she has a definite kind of set of rules that she's following when she kind of adds weight to the edges and corners and the edges so that besides that, that kind of joining together out of geometry as it grows as a new direction to test out computational forms by using the digital and differential growth system, but then added in this project when surfaces became close together they would join together and create a new typology and continue to grow. So starting from that logic I did a lot of experiments with different starting points different kind of parameters for growth and joining distances and modules and things.

And then I settled on a certain kind of formula I guess, for the best for these things and then I tried to sculpt it. It was a little bit ad hoc to fit into this space, but it's primarily driven by this growth thing, which growing the edges and joining certain edges when they were close together create cylindrical tubular parts.

Marco

So how did you go about experimenting these ideas? Did you jump straight into the grasshopper model or did you model by hand?

Adam

It's always in parallel, and back and forth so I did some tests in Grasshopper first to simpler forms, and I tried to make those out of paper. And then I discovered some limitations to what, what the paper could do. And there's certainly logic for how to subdivide the forms to make them into these paper strips, and then I push it a little further to try and make more complex forms and larger shapes. And that's why we did that one, black and white one that was like the first one to one.

There's also a lot of experimentation with different tab types different ways of joining things together. So the other innovation in the project, was the box, tab system. I started off as single strip joining and that worked to a certain extent but then it becomes more difficult to assemble as the objects became bigger. So I needed this kind of box system which allowed the pieces to do self form into the curvature that they needed to be and then you could slot them together.

Marco

So, it's literally about creating the recipe in the beginning, much about experimenting. At the same time, creating the recipe on how you're going to build. Did Parth participate in this phase?

Adam

He jumped in with the kind of initial experiments with tabs and strips on simpler geometries. And then I think from his experiments I developed this box type system to help us build bigger strips, because the single strips were going to be a bit floppy, I think, when they became a larger shape. But remember, there is the, there is a certain challenge in scaling it up, which required the box tab system.

Yeah, but I mean, I don't know if you know, these different kinds of knowledge, explicit, implicit, and tacit. I have been talking about this with my students about different forms of knowledge in terms of how we transfer knowledge or information from designer to builder.

Explicit knowledge is knowledge that can be codified and drawn and can be kind of read and interpreted without me experiencing it. Architecture we don't have this knowledge because every drawing that we do must have an experience interpreted, you need to know how buildings are put together to be able to read architectural details. So builders will have some implicit knowledge, they will have experience before of how they built things before and that is what they will use to interpret the drawings and will build in another way than what the architect originally intended because the architect may have never built that detail before but the builder has.

Then tacit knowledge, is what cannot be communicated except through experiences, so think in this process of kind of trying to rationalise and make this complex geometry there was a kind of, things that you had to draw for yourself in order to understand the limitations of what the material could do. This passive and implicit knowledge fed into the digital modelling. The digital modelling, drawing more specific knowledge because in the end we could cut these pieces out and people new from the shape, there were some numbers on the tab but there were not many numbers. People could tell from the tabs.

Marco

So you bring into the project Grasshopper and Rhinoceros, did you continue to then experiment with the digital model via digital fabrication?

Adam

Yeah, so there was still some rationalization to the model that had to be done to kind of

create these strips that could be unrolled without too much precision. And there was some design work in kind of where the colours would go. I mean part of the brief is to use all the colours in the company's catalogue. So there was that was parametrically distributed according to kind of saturation and hue.

Marco

Grasshopper was used to organise the colour scheme, along with breaking up the design into strips which were turned into laser cut files with the tab system.

Adam

Yeah, so first I had to create strips that ran along the geometry, and those strips has to be developable. And then we divided those strips into the components, and then the strip created tabs were on the shared edges of those components. And that also informed the number, tagging system. So, each unique shared edge, each unique shared edge had a number, and then each piece had a shared number. There is also two sides to each piece.

I mean I'm actually quite proud of the tagging system because it simplified to the extent that you only needed, you didn't even need a tag on each tab, because you could know which tab joined with which over tab, by looking at which edge they were on. Right, so, I mean that was significant in terms of cutting down the laser cut time. Obviously with 1000s of times, I think there was a 1000 pieces and each piece had 12 to 15 tabs. So a lot of tabs, so to laser cut each tab would have made the laser cutting time much longer. Three of four times as long.

Marco

Play is part of the design process and is mostly associated with working by hand. Can you still play when your working on Rhino or Grasshopper? Are you still able to unlock your imagination?

Adam

Yeah I think so. I mean, I guess you have a certain idea in your mind what the code will do, and then it can surprise you with what comes out of these rules and these variables and things, and then kind of respond to that so there is a certain back and forth, which is likely. I would say yes, it is play. Because you're experimenting and testing the limits of things, enjoying the process I mean.

Architect Jack Young

Marco

What was your role in the team?

Jack

I came in and Adam had done the scripts, and he just needed to basically work through iterations basically test. What form do you want to make and what looks cool. Is it possible?

The part that I was doing was just working in Rhino, making sort of low poly, a low polygon version of what the final outcomes were going to be. Then I could play around with it, and I could see, live Rhino updating and relaxing. The upside to doing a low poly model is it's very fast, to work with it, and then having the grasshopper over there it just meant that he was very fast. In, in creating what I was aiming for. You give me a really good, real time feedback, which I think is, that's the key thing in design, you need. You can't sort of make a design decision and then to wait for a while to sort of to see you know what's effective was it not ideally, You want to get immediate feedback. So that was what grasshopper was good for. It allowed for fast modelling, iterative modelling in Rhino, but it was then you were immediately getting feedback.

Marco

Rapid prototyping?

Jack

And it also means that you can have something very Adam scripts, complicated, but the people who use it, don't need to be proficient grasshopper users, basically started off from the grasshopper script and then just worked in Rhino. A few of us working on it, me, Aled, Parth we already done some grasshopper, but basically it meant we didn't need to know the goings on behind the scenes we would just model and test stuff physically and that does not require a huge amount of skill to be able to do that on Rhino. After an hours tutorial you would be probably be able to do it. So that is one of the really good things about it, it means that it's really fast to make these design decisions.

Marco

Explain me the process then?

Jack

We would reference the geometry from Rhino, we would see if it works, does it look

good? If we found an iteration that we thought that this would be quite good we would save this and move onto another one. We would bake the geometry from Grasshopper and we would save the geometry we were working on in Rhino and we would move on making another layer and this would be iteration 2. Then we would keep working.

Marco

What are the advantages of using digital?

Jack

In digital you can just pack more and more information into a smaller and smaller space, whereas drawing, you know, there's only a finite amount of blank space once you draw on it that's it can only fill up so much. Whereas with Rhino you just go in and work ever increasing levels of detail, which, when you run this through the whole relaxation strip, it means that there's a lot of complexity in there which is not necessarily useful. It also very, very easy just to get really carried away with the minutiae.

Marco

What are the advantages of using digital and analogue tools?

Jack

When you start modelling in Rhino you have complete control and you can go down and right to the nuts and bolts, but one it means that you only have one person's perspective. If you have a big team working on it, one comes up with the broader idea and the rest of it are refining this one idea. Perhaps they may set something out and actually all these decisions further down the line would be better if it was done a little bit differently. But because it's already fixed in that there's not much room for shifting and yeah I think with drawing there is at least when you're, when you're sketching. There's a lot more room for play, whereas in digital the lines often cannot blur anything. Well at least not with Rhino.

Meshes in programs like Houdini and Blender they maybe better for iterative kind of stuff. They may be better for us to sketch this kind of stuff because meshes naturally aren't accurate to any type of precision. You can take a mesh and smooth it, smooth it and smooth it. You can be accurate to within a quarter hundredths of a millimeter if you wanted to, but it's not actually perfect. But when you're designing cars, there has to be nerves, because we have to be able to get a perfect mathematical surface, not this one where there's actually loads and loads of triangles. Also when you come to site, especially if you're designed everything within centimetres tolerance. You also have to bear in mind the people who are building this, there are going to be different levels of

tolerance on site, and also on site things are also are not going to be exactly the same as you've got them.

Marco

Peter Zumthor does not draw every element of a project. He permits the craftsman to interpret and do as they seem fit. After all they have more knowledge.

Jack

I think for any good project, that must happen. You need to get the best people to com up with this kind of solution. The upside of Rhino is that if you have a clear vision, you can dictate exactly what happens, but if you're not making from start to finish and if you don't have all the knowledge then it seems stupid for you to resolve something to the finer detail when the person who is making it may know a better way of doing it. The key to the digital tool is using the tool for what it is good for and being aware of its limitations and your limitations when working with it. At times it is easier to explore an idea via the physical model as there are limitations to the tool that you cannot really explore that here. Or it is very difficult, or if you want to do material study. It is much easier to do that physically than it is to do it digitally. So, if you want to test these larger ideas than its great. As soon as you get into materiality… well as soon as you get into the question of materiality and fabrication you need to be out of the digital. For instance if you say the bending angle of this steel in 92 degrees, well actually you cannot actually achieve this as you will get spring back, so realistically it will bend back to 89 degrees So there is that limitation which in the digital is not achievable.

For instance if I wanted to design a wood joint, I could do that on Rhino because I know that if I am using a chisel, I can do this type of cut, if I am using a saw I can do this and I know roughly the level of accuracy and I know roughly the sort of how much the wood will expand so I need to leave a bit of tolerance and then if I were to just take that and make that in wood, I am pretty sure that it would fit together. But let's say I was going to do something cast in metal, I have never done that so I would have to figure that out. So I know that if I had to make two pelts in metal and tried to put them together I am pretty sure that they would not fit the first time with a massive amount of tolerance.

It's like using a chisel you may not be, when you are carving away at something you're not thinking about this one cut that you're doing, you're envisioning 3 or 4 cuts and what it's going to look like. You're planning ahead. In the case of digital tools, you can plan further and further ahead or do this and that and that until I get the result that I am looking for. Drawing you build up, you start with a simple sketch and you work into it and you know what you have put on paper is not the final thing, you know why you're

putting the lines and you what the limitation is. The difficulty is when you're working in the real world it's very easy to remember that there is a width to the line, there is a size that you're seeing and that size actually corresponds to one to one and you can draw it to scale and you can have a real appreciation for it. The digital you can just zoom as close as you like, there is no real restraint so when you use a digital tool you just have to be aware of the fact that when you move into the real world there are limitations which you don't have in the digital world and then again in the real world there are limitations that you have which you can overcome in the digital. Just be modelling intelligently and there you can gain insight into geometry and angles and that kind of stuff that if you tried to fabricate that physically that it would just be impossible but in the digital you can just do cumulative stuff and that is very easy and you can create some amazing stuff. And you can iterate very quickly. So if a design iteration is one thing, then it's good that you have tools that you know how to use them. Then for design refinement, you know you're taking this to a building site then you know that the metal workers have this limitation, the woodworkers have this limitation, I know that these parts must come together. These are the areas where they have said that there are going to be some issues, you can then go into the digital model, refine it.

You plan ahead. With digital tools, you can plan even further ahead. Or I can do this or that to get the result over there. If these teams are distant, then you can be the middle man and test stuff, figure it out before it comes to site. It is here where the digital can be useful, it can mediate between all of these different fields and you can put all that into you're digital model. Whether that is through rules on Grasshopper or is that rules on Rhino. There are ways of working around it and really work out all of the minutiae of all these different things coming together before they actually do and spot problems before they have happened.

Marco

Robotics and Craftsman

Jack

When a craftsman is working there will be infections an that appeals to people. Except, when you don't actually having a person working on it and you have a machine you're that step removed from the craftsman, I don't think you can get that same feeling from it.

Marco

Precision?

Jack

Exactly, where do you want the precision because if you're having to cast some concrete, for like a concrete roof and then you're going to have some glass work underneath. That needs to be precise, the manner in which glass is manufactured it is precise, it is bang on. Son you'll have to frame and you'll have a tiny bit of tolerance. So when you're casting this concrete you cannot have any of deviation, so you need for it to be perfect. If you have any convex curves that is where the digital will come in and take those convex curves digitise a tool path where you can mill it out and you can cast it. You are picking where the precision is. Lets say you have a wooden decking ontop and that deosn't matter cause you can just have a few points that stick out the concrete and you're just anchoring it. Picking where you want to put that precision. Also working with concrete it is very difficult to work back into it. Wood is easier. So for all of our wood pieces we are going to make sure that they are little bit longer than they need to be and that way we can cut them down on site to accommodate whatever has been made before. So we know where it should be, these are the guides that we are going to need to try and make it as perfect as possible. But we know that there will be some room for error. And that is where the digital can be useful because you can say that this interface here, you're got concrete here, you've got the flooring coming in and you've got some metal work that ahs to go underneath. All of these different interfaces, some of them have to give. Steel work is the hardest to alter, that maybe will be our base point that is what we are going to work on the you have the concrete and etc. We are already looking at a hybrid system with offsite manufacture and that kind of stuff. Just time of delivery, like Wikihouse.

Digital does not discriminate between 100 things the same and 100 things differently.

Marco

What happened after the process of iteration?

Jack

We sent designs to engineers. You'll have to ask Adam but we sent a few options we wanted to try so he sent those to get some feedback to know what works and what doesn't. Then we picked the final one and refined it.

Marco

How would the team go about editing?

Jack

We edit directly onto computer, they would send back the digital model and it would

have the rhino model which we would import. It would show different areas of stress and of deformation and this kind of stuff and actually it was a grasshopper script. We were able to run it live, to see these are the areas that aren't working, these are the areas that are. Again, this was the upside of Grasshopper, they don't need to set. It's a way of them outsourcing their intelligence. They have set a tool that says and that tool will tell us this will stand up and this won't so they don't actually need to be there. They have put this intelligence, in a tool for us to use so then we are then able to play around with this. As if they are their looking over our shoulder telling us that will work and that won't. That is what digital does, if you can provide these tools to people its just a way of giving a lot of intelligence to someone who does not know a huge amount of what they are doing.