Ornamentation in the digital age

Ornament i den digitala tidsåldern

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Abstract

Decoration has been central to architecture throughout history. Since the beginning of the 20th century, the question of ornament in architecture has been oscillating between the positions of redundant and essential. With rapid advances in computational technology, the practice of architecture has been provided with new tools for designing buildings. This thesis aims to examine how digital design and fabrication methods can contribute to the creation of ornamentation in architecture, as well as to investigate the roles and functions of ornaments. In this context, ornamentation is defined as decorative elements enhancing the appearance of an object as well as the action of making something more aesthetically elaborate.

A design study was conducted, using methods of digital manufacturing to design an ornamental facade for a building. The methods included were, respectively, a "file-to-factory" approach, parametric pattern generation, random growth, using representational objects, and material simulation. The resulting design iterations were then compared and evaluated.

The results suggest that architectural ornaments can be conceived through digital means, allowing for high levels of geometric complexity, and able to produce new aesthetics in forms. The design study also shows how decoration can converge with performance, and how ornamentation can function in multiple ways at once. This confirms the computer as a powerful tool for shaping architecture, and ornamentation as a relevant strategy in design. Further research is needed to provide more insight into the physical implementation of digitally manufactured ornaments on a large scale.

Keywords: Ornamentation, Digital Manufacturing, Digital Design, Architecture

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Ornamentation:

“Decorative elements added to something to enhance its appearance.”
“The action of decorating something or making it more elaborate.”

(Oxford Languages, 2022)

Introduction

Throughout history, the issue of decoration has been central to architecture. Since the birth of the Modernist movement in the early 20th century, it has been pending between the position of either essential or redundant (Hearn, 2003, p 271). In recent years, digital design in architecture has led to other things than the smooth blobs of the 90s. Whether it is flagship stores, covered in stylised versions of company logos, neo-baroque experiments with 3d printing or robotic brick-laying, it is clear that new expressions are emerging. Theorists such as Oliver Domiesen (2018) and Antoine Picon (2016) write about a possible "return of the ornament", fuelled by the possibilities of the computer.

The aim of this thesis is to investigate how digital manufacturing can be used to create ornaments in architecture. I delve into the design processes, ways of fabrication and theoretical arguments surrounding the topic. I set out to discover how digital and ornamentation can intersect and lead to new aesthetic consequences for architecture.

In this thesis I conduct a design study, as an experiment for pinpointing aspects of how digital manufacturing can enable architects to produce ornaments. I aim to encounter and to highlight the potential and challenges within this field.
In the experimental design study, I will try out five different iterations of a facade. They will all have different approaches in terms of design, fabrication techniques and theoretical motivation.
I am taking a wide approach, to encounter characteristics prevalent in digital manufacturing as an overall phenomenon rather than one specific technique.
I used an empty site in Malmö as my testing ground for the design, providing a scale of the building and municipality plans to relate to. This is to be regarded as a strategy to enhance the design study, rather than a proposal for a specific site.
I selected one of the design iterations to examine closer in its convergence with the spaces of the building design, shown in floor plans and sections. In this selected iteration I also take a closer look at the details of fabrication and assembly.

The design study aims to encounter the questions that arise from the attempts to create ornamental effects through digital means. Learning from these experiences, I reflect on how the future might look like for ornament in architecture and digital manufacturing in my conclusion.

Subdivided Column (Hansmeyer 2010)

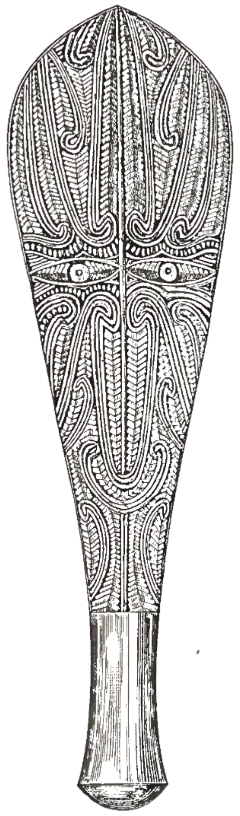
> **"Ornament is not truth – it is mimesis, material transubstantiation,deception, artifice, pleasure and beauty that render utility acceptable."**
> **Oliver Domiesen** (Domiesen, 2008a)

The many functions of ornament

It is safe to say that the definition of ornament and its uses is not easy. Ornaments can serve the purpose of decorative enrichment, accenting of features, identification of use or communication of ideas. Ornaments can be used as a means of blending into a context or to stand out by drawing attention. Patrik Schumacher (2009) writes that the opposition of ornament to function is a false one, citing classical architectural theory's division into three fundamental, complementary tasks for architecture: distribution, construction and decoration. Decoration can be a form of articulation that contributes to making spaces readable, helping the navigation and uses of spatial order. Organization as well as articulation have both formal and functional aspects. Examples in classical architecture include ornamental patterns emphasizing the symmetry axis of a building, ordering movement and focus points. Ornamental patterns can be received semi consciously rather than in focused attention, as the relevant information is perceived quickly, orienting the user about the space and the social setting (Schumacher, 2009).

In her defining bok "The Function of Ornament", Moussavi writes, "Architecture needs mechanisms that allow it to become connected to culture" (Moussavi, 2008. p.5.). Architecture captures the forces that shape society and expresses them through the physical materiality of buildings. These expressions, affects, allows us to engage with the city, society and the world in new ways (Moussavi, 2008. p.5.). Oliver Domiesen is of a similar opinion in his statement that ornament has the ability to communicate ideas or to present symbols beyond a building's mere expression of utility, it has the ability to be a sign of its time (Domiesen, 2008a). Domiesen defines ornament as a language through which a building can express ideas, ethos and memories in material form (Domiesen, 2008c). Historical examples of this include ornament in religious architecture, portraying complex happenings like suffering or rebirth for an illiterate audience, with pictures instead of words (Humphrey & Vitebsky, 1997, s. 48). Ideas such as the perfection of God can also be expressed through geometry, like in Islamic architecture (Humphrey & Vitebsky, 1997, s. 167). The use of ornament was historically also a way to reflect the purpose of the building as well as the hierarchies of society, with palaces, mansions and ordinary houses easily readable and distinguished through decoration (Picon, 2016). Apart from the communicating aspect, ornamentation was historically the strategy of blurring the boundaries between building elements, and highlighting the unity of the whole (Malé-Alemany & Sousa, 2005, p. 452.), often as a concealer of joints and seams (Ferguson, 2008, p. 59). Ornaments tended to be located in-between things: the keystone of the arch, the capital of the column, concealing joints and framing openings. Just as the ornamentation of picture frames or in the border of manuscripts, ornament in buildings sits comfortably between the real and the fictional, realism and abstraction, mechanical objectivity and artistic subjectivity (Domiesen, 2008a). It has the ability to integrate almost any symbol or shape, such as fantastic beasts or human bodies, into architecture.

Platonic Solids (Hansmeyer 2008)



(Jones, 1868)

“Man’s earliest ambition is to create. To this feeling must be ascribed the tattooing of the human face and body, resorted to by the savage to increase the expression by which he seeks to strike terror on his enemies or rivals, or to create what appears to him a new beauty. [...] the highest ambition is still to create, to stamp on this earth the impress of an individual mind.”

Owen Jones (1868)

Has ornament returned?

The concept of ornamentation as an universal instinct has been brought forward by many theorists, such as Gottfried Semper and Owen Jones (Picon, 2016), (Jones, 1868). Semper believed that ornament has its origins in an universal impulse that takes different forms in different societies and times (Picon, 2016). Domiesen describes the decorating of buildings as “our timeless desire to bring inanimate material to life” (Domiesen, 2008c). Even in the early industrialized society traces of this primal impulse to ornamentation are to be found, as the mass-production of terracotta elements, especially in the United States, suggests (Picon, 2016). The Modernist movement also viewed ornament as an expression of a basic impulse, but only to denounce it more thoroughly (Picon, 2016). In Adolf Loos’s famous 1908 essay “Ornament and Crime”, ornamentation is associated with women, children and criminals (Loos, 2002). Today it seems the basic impulse of creating ornamentation is taken up again by new generations of architects. After being marginalized for over a century, ornamentation is experiencing a renaissance (Twemlow, 2005). Among the terms being used to describe this tendency is “New Ornament” or “Contemporary Ornament” (Sedrez & Celani, 2017). This return of ornament is made possible by new technology: the digital design and manufacturing methods (Strehlke & Loveridge, 2005). It is propelled by the capability of the computer to handle complexities.
Using the word “return” would suggest a historical dimension and connection, yet it is not always the perspective in studies of contemporary ornament. Focus has instead been centered on what is going on today, through the use of digital tools, not trying to link past and present (Picon, 2013). The revival of ornament in recent years is of a different kind than its predecessors of the past. Before Modernism’s dismissal of ornament as a minor or unnecessary element of architecture, ornament had predictable characteristics. That might not be the case today. Our current period tends to develop new signs in ornamentation, shunning the Doric and Corinthian styles, used from antiquity through renaissance and in Postmodernism. These signs are often related to popular culture or brandings of global companies (Baltus, n. d.).

Face tattoo (Jones, 1868)

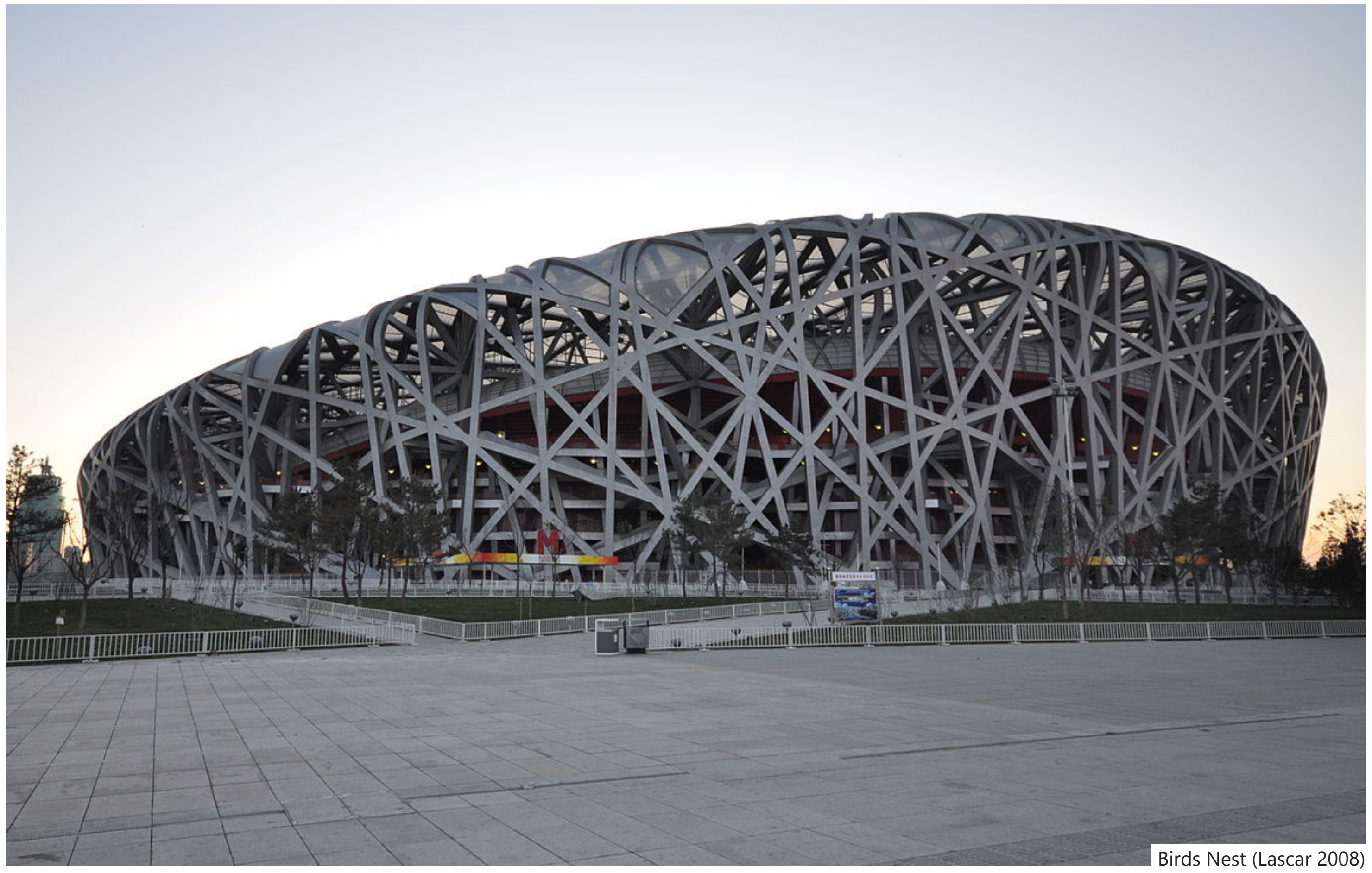
What we call contemporary ornament today seems to represent something quite different from ornamentation of the old days, despite historical resonances. The role of ornament to express social values, hierarchies and order no longer seems evident according to Picon (2013).
Moussavi (2008) states that in today’s cosmopolitan and multicultural society, it is harder to succeed in symbolic communication as we don’t have a common set of symbols and icons anymore. This gives the conclusion that representational forms of ornament might be unable to connect with culture. This leads her to the viewpoint that the most successful ornament today, is in the buildings that can produce sensations and affects in a way that seem to grow directly from the matter and structures itself. In this way, these buildings might be timeless in their expressions (Moussavi, 2008, p. 7). The direct sensations can bypass the need for a unified language, and can transcend time and space.
I do agree with Moussavi in that the visceral, immediate sensation is more important than communicative icons. Yet, I do think that representational shapes and images can create both rich direct visual expressions and more subtle symbolic meanings.

(Dalbera 2018)

(AsVL3 2008)

One way in which contemporary architectural ornaments differ from traditional ones is in its distribution. Throughout history, ornaments often were concentrated to certain well defined places of a design, where today’s ornaments tend to be a general feature of the building envelope (Baltus, n. d.).

In the past, ornament was often viewed as supplementary in the way that it was expected to be superficial, there was no conflict in the fact that it was “tacked on” to the real structure of the building. At the same time, it was essential to the building and architecture as a whole, unthinkable without it, both in buildings and in discourse (Picon, 2016). Today’s ornament is often not possible to remove from the facade or the structure itself, blurring the lines between structure and ornament in a way much ornament of past periods did not (Picon, 2016). Some of the most acknowledged building envelopes, for instance among the Beijing Olympics stadiums, are probably successful due to the ability of the architects to create a plausible alibi for the patterns wrapping around the otherwise mainly unarticulated volumes. In the Birds Nest, the structural elements blend with those of the purely decorative nature. Thus, a union of literal performance and affect has been reached (Pell, 2010).
This is not without historical predecessors. Venturi describes the Renaissance pilaster as an element performing the phenomenon “both and” (Venturi, 1977). Simultaneously physical structure and symbolical, emphasizing rhythm, and adding to the complexity of scale in the giant order. It is a structural element used in a nonstructural way.



Birds Nest (Lascar 2008)

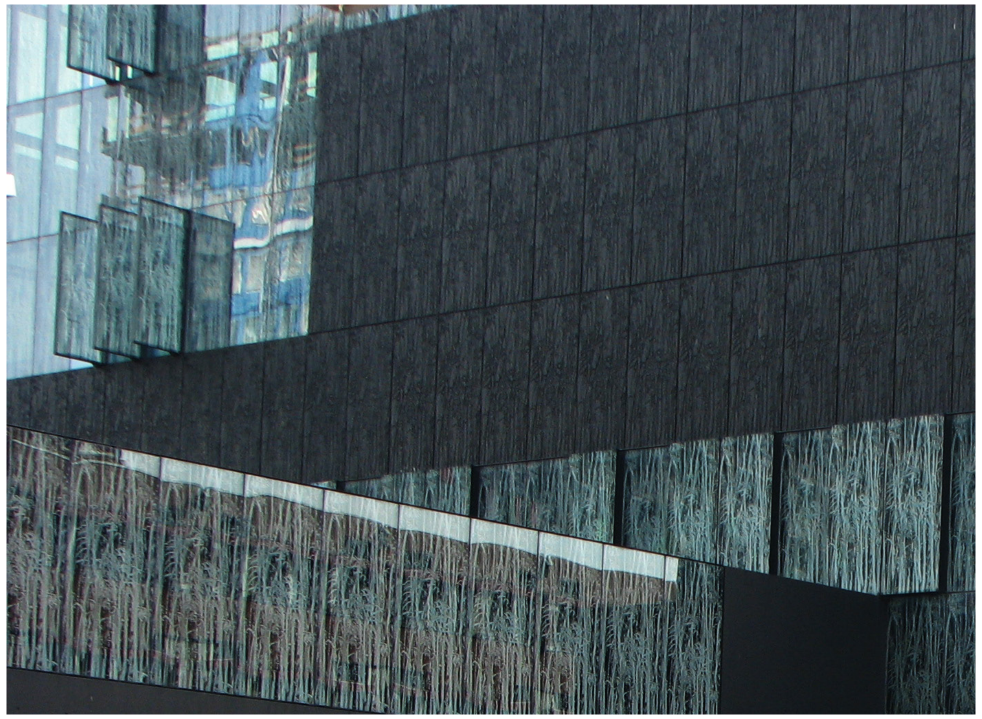
It could be argued that much of the contemporary architectural ornament stays on the surface of the building, rather than becoming three dimensional, like the projecting sculptural elements of traditional ornament (Picon, 2016).
Water Cube (Lascar 2014)

Pilaster (Perez 2011)

Architects today use digital methods for ornamental exploration, merging design with fabrication information, thereby connecting digital and physical. To me, the thought is thrilling, of a way to create something as fantastic and intricate as the ornaments of old, but with totally new technology and new meanings and uses. This backward-forward thing sparks an interest for me. Ornament introduces a detail level and a complexity that adds variation in scale to the building volume. Ornament can provide an elaborate scale of intricacy, adding to the visual experience of surface and form.

Eberswalde Technical School Library
(Giel 2005)

Eberswalde Technical School Library, where the artist Thomas Ruff was involved. (Heathcote, 2015). The library is characteristic of the return of ornament in its play on the frontier between abstract and representative. (Picon, 2013)



Utrecht University Library
(laurenatclemson 2008)

Nottingham Contemporary
(Murray-Rust 2010)

Digital Manufacturing: A new paradigm

Design and fabrication technologies have almost always been parallel in evolution. A typical example is the Baroque architect's development of new geometries, which was closely connected to improvements in stone cutting abilities (Steele, 2008). When redefining the materials and tools that are used in architectural production, the forms and structures of contemporary architecture might take new characteristics.

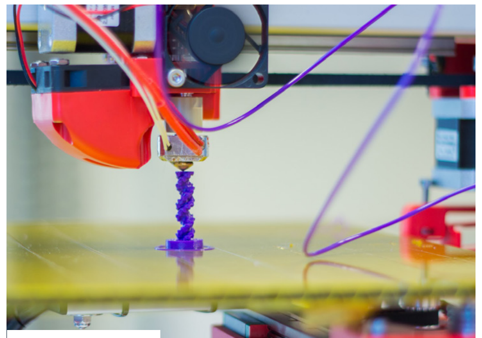
At its core, digital design tools(CAD or Computer Assisted Drawing) can be used in two ways:
A helper for realizing already formulated architectural concepts, doing what the pen and paper was doing essentially.
As a generator of forms, a co-player which helps the architect to create designs that couldn't have been predicted, and that wouldn't have been possible to materialize with earlier design methods.

The limits of complex geometries are set by the properties of materials used rather than the difficulty of generating and describing the design (Marin, Lequay & Blanchi, 2011). The possibilities to realize complex designs have been increased by digital manufacturing.

Digital manufacturing can be divided into three main types:
Additive manufacturing: creating objects by adding materials, usually in layers. 3D-printing is the prime example of this.
Subtractive manufacturing: removing materials from a solid shape, through cutting, drilling or grinding. Computer Numerically Controlled (CNC) mills are a good example.
Robotic manipulation: manufacturing processes that do not add or remove material: bending, folding and weaving. Brick laying robots are part of this process, not in its fabrication but in its assembling (Sedrez & Celani, 2017).

CNC Milling (Delcam Plc n.d.)

Using CAD/CAM-technology opens up the possibility to the production of building elements with highly specific forms, which could not be designed nor built manually (Naboni & Paoletti, 2015).
The material defines the production process and therefore determines the expression of what shapes that can be used in the aesthetics. It is easy to create complex shapes in the computer space, the challenge is how to implement this in physical reality. With digital manufacturing, the characteristics of the fabrication, materials and construction are defined early during the design process, redefining the process and the roles of architects and engineers (Marin, Lequay & Blanchi, 2011). Since digital manufacturing techniques are inherently digital, they can easily be communicated and transferred between actors in the process of a project's development. This can provide the design process with a more direct interaction of material properties and production constraints. Architects seek to direct how materials form a building, but also how to affect our senses, on a more aesthetic plane (Larsen, 2014). Interestingly, when technology evolves, style often lives on, as shown in the famous example of the ends of wooden beams becoming triglyphs in Greek classical architecture, or early steel architecture imitating stone columns (Humphrey & Vitebsky, 1997.s. 161).



(Juursema 2014)

Digital manufacturing has the ability to operate outside the logic of mass production. Flexible fabrication methods through CNC machines, 3D-printers and laser cutters allow for variation among components previously produced through repetition of copies. Combining the capabilities of industrial production with the craftsman-like ability to make each product unique, the process is called mass-customization.

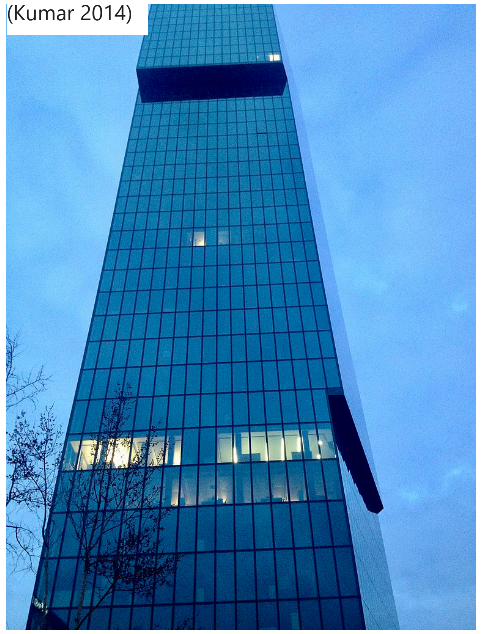
The building sector is one of the few remaining fields of the production industry which has not fully embraced pervasive automation. Although brick, timber and concrete are produced in completely industrialized processes, the assembling of these materials into architectural works are mostly controlled manually. The building industry therefore essentially is a hybrid between craftsmanship and the high-tech fully mechanized manufacturing of for example modern steel structures (Søndergaard & Borup, 2014). Traditionally, design and production have only been bridged by visual representation in the form of architectural drawings and models, used to "instruct" craftsmen and construction workers how the design should be carried out (Steele, 2008). Today these two worlds can be connected in new and direct ways. This is done through the information modeling used by designers, such as machine programming of different digitally integrated tools.

The development of new fabrication methods, such as robots and 3D-printers, are constantly pushing the production in the building industry towards fully integrated mass-customization, becoming ever more capable in operating in different scales and in its seamless translation from design to production (Naboni & Paoletti, 2015). The computer allows the creation of highly complex geometries, stimulating the exploration of new design possibilities, rather than emulating forms that were produced under totally different production logic and have lost their meaning in today's society. This applies both to modernistic aesthetics and hand-crafted classical motifs. But a similarly high visual complexity level can be reached, as well as new ornament sometimes filling the role that old did, especially when it comes to the visceral experience and as a bringer of detailing levels on different scales, large to small.

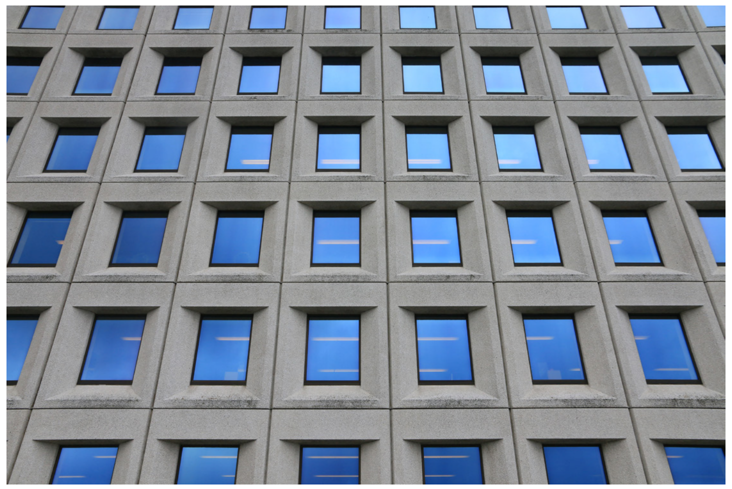
Complexity and scale

Visual complexity can occur at many scales, and ornamentation can serve as a bringer of complexity and a tool for differentiation and adding a variety of detail levels. Complexity is commonly held as a variable that influences people's response to environments and objects (Heath, Smith & Lim, 2000). It may be impossible to say what beauty is or come up with a formula for interesting architecture, but tools of analysis can help us to talk about it in more advanced terms. Thinking in scale levels serves as a tool for understanding ornament and form, and the perception of buildings. Ornamentation can occur at various scales, both as surface decoration and 3 dimensional objects, as part of structure or independent element, repeated pattern or singular motif, in the curvature of a concrete wall as well as the intricate engravings of glazing (Domiesen, 2008a). Regarding buildings, perceived complexity comes down to two aspects: the silhouette and the articulation of the facade as described by Heath, Smith & LIm (2000). These two factors are often intersecting. The overall shape of the building and its silhouette can be envisioned as polygons. The articulation of the facade of a building is its subdivision into individual elements (Heath, Smith & Lim, 2000). Ornamental objects protruding from the facade, such as finials, break up the silhouette of a building into a larger number of divisions, as well as being visual features in themselves. From far away, these detailed elements cant be read out fully, but their forms are perceived as figures attached to the main form of the building (Heath, Smith & Lim, 2000).

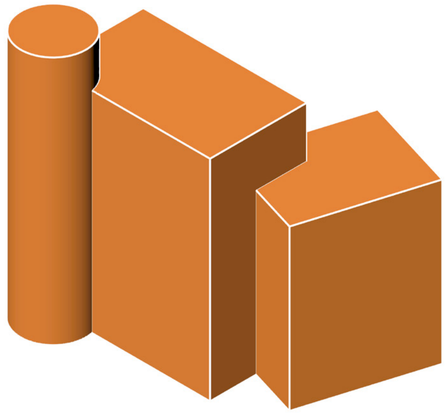
(Kumar 2014)



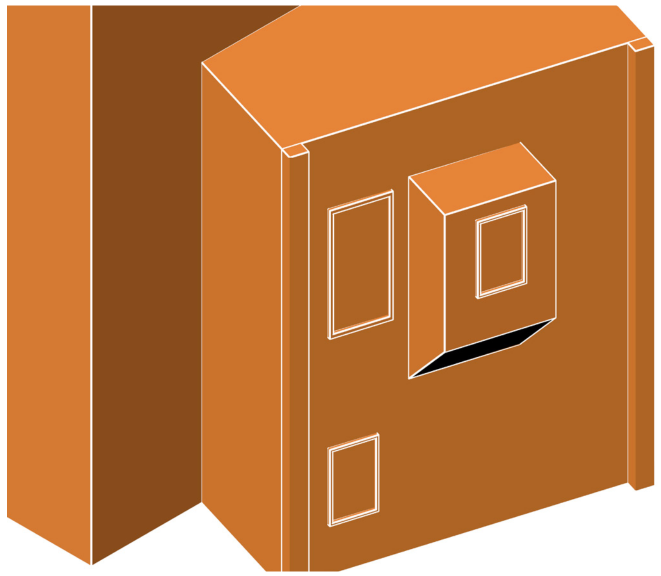
What constitutes an element is not easy to define. For example are small elements perceived not as separate elements but as a texture or patterned surface of a larger element. This is especially true when the elements are similar, like windows in modern tall buildings (Heath, Smith & Lim, 2000).



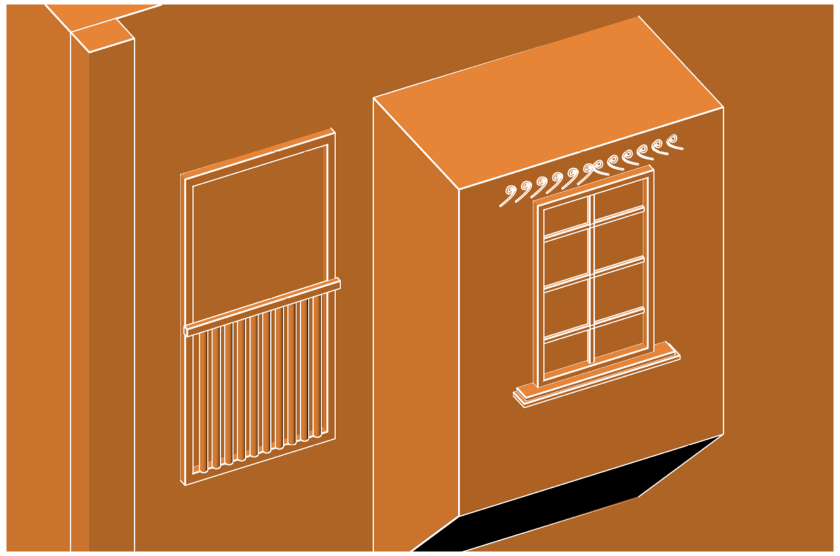
A repetition of windows (Holmstad 2017)



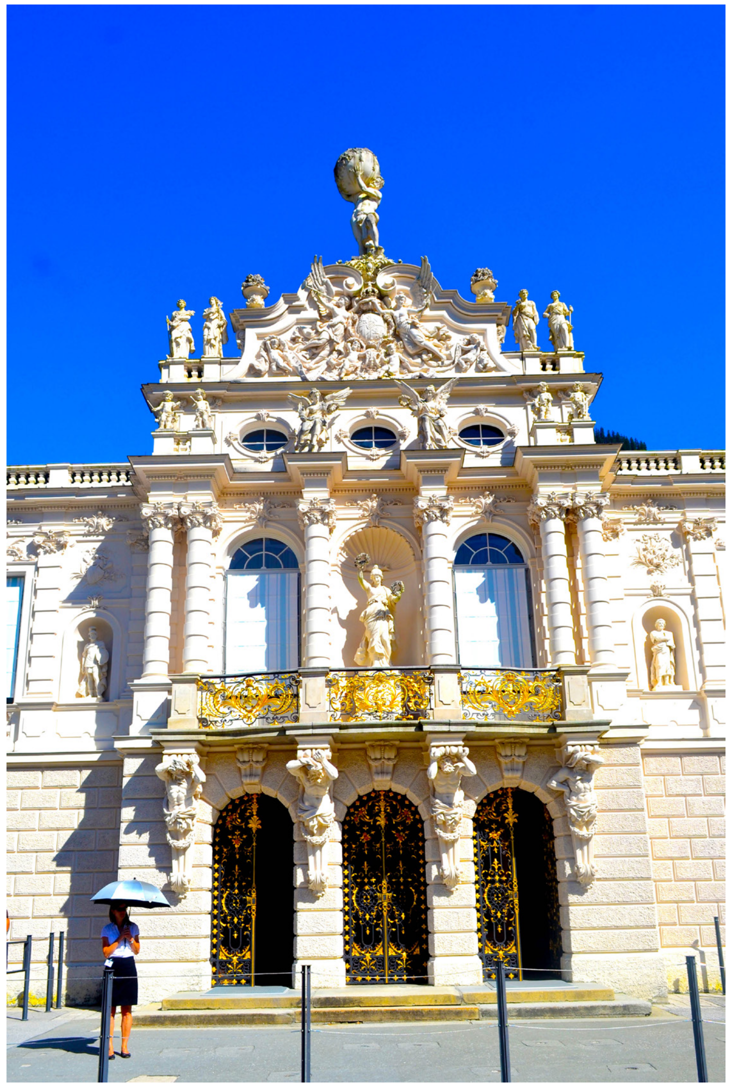
From a macro scale level...



...to a meso level...



... to the micro level, where often smaller scale ornament are found. Divisions of windows are not ornament, but adds to the complexity in that it adds divisons, more distinguishable elements.

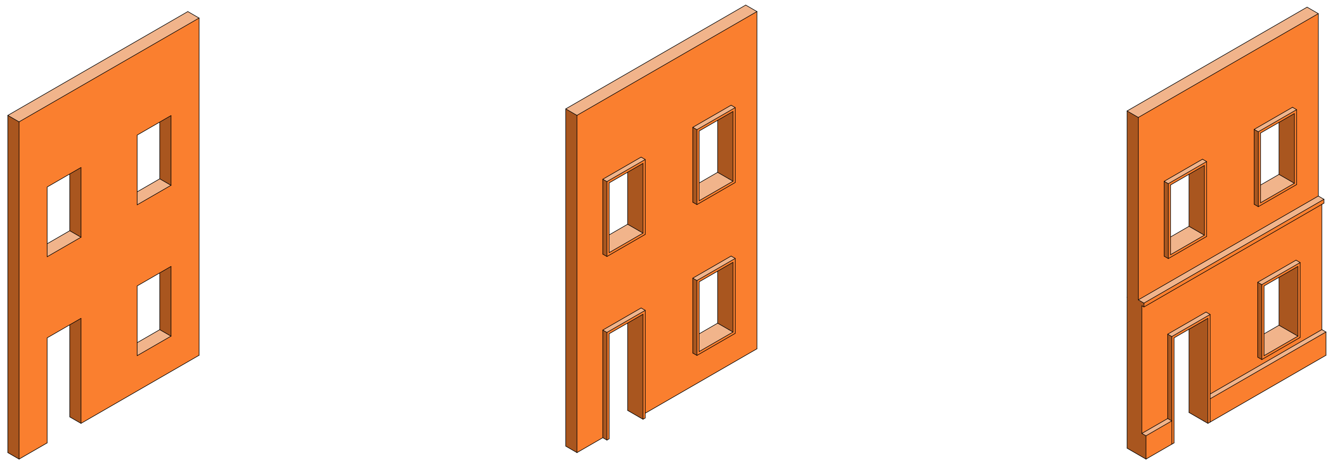


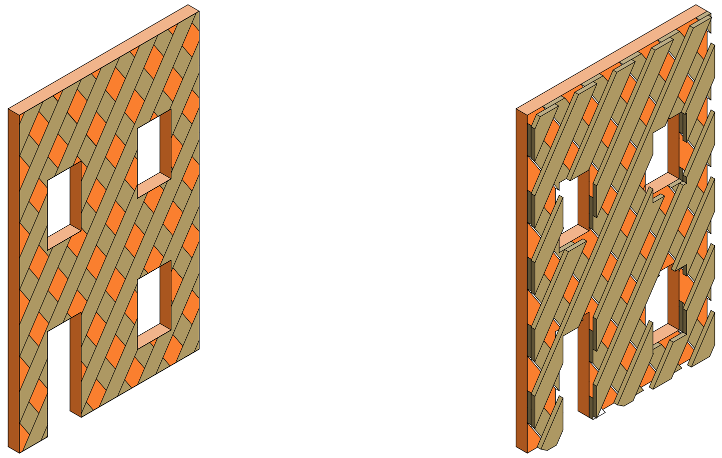
Rococo, (Chakraborty. P 2017)

Many styles before the modern era showcased a high complexity due its handmade origins. Domiesen defines the highest degree of geometric complexity in ornamentation to have appeared in the rococo (Domiesen, 2008c).
Buildings today, such as The Gherkin undoubtedly have a structure that deliberately gives an ornamented effect, but its complexity often occurs at a macro scale level. To me, it seems the complexity of the smaller scale is largely missing in many buildings today. It is not that it is impossible to make ornamentation or complexity today, it is just hard to defend from an economical and intellectual standpoint. Intricate details add to the cost of buildings justifying the elimination of ornament from buildings, on economic grounds, both for Modernist architects and budget-focused project planners of today (Balik & Allmer, 2017). As fabrication methods become cheaper, the chances are that we will see more examples of its uses in architecture.
To avoid the pastiche and the stagnation of expression, new technology bears a potential of finding new modes of creating beauty and complexity. To make patterns or construct ornaments, a certain level of intricacy is necessary, leading to more attention on the manufacturing process and the detail. Complexity and detail are key to any kind of decoration, and the computer makes that possible (Twemlow, 2005). New technology could make it affordable and easy to achieve a visual complexity we haven't produced for over a hundred years.

The Gherkin (Paste 2007)

When ornament is given depth, its three-dimensionality becomes active in play of light and shadows and optical effects when looking from different angles. Some common features especially in older architecture are the articulation of openings and the ground floor.





Patterns can be flat or three-dimensional

1800s

Before industrialization, society was characterized by craftsmanship, with artisans making components by hand and according to customized specifications (Christiansen, 2016).
The mass production of components was a result of industrialism. Instead of being made to order after customized measurements, products were pre-fabricated in fixed sizes. Taking advantage of the capacity of the machines in a controlled factory setting, the production of as many copies as possible was an efficient way to reduce the price per component, once the machinery was set up to a specific product. Standardization and repetition were the mantra of the era, and architecture reflected this industrialized production. Architects no longer needed to know how components were produced, as the task was to pick them from catalogs, and assemble them into a building (Christiansen, 2016).
The early Industrial Age also affected ornamentation in its mass-production of prefabricated elements, often in cast iron and terracotta. The assembling of these uniform ornamental components favored repetition and patterning as opposed to the variety of individually stone-carved elements common in gothic architecture (Domiesen, 2008c, pp 15-16).
The terracotta elements combined the qualities of craftsmanship with the virtues of machine production, through its manufacturing in rectangular units with intricately detailed motifs.
(Hearn, 2003, pp 276-277). The development of the machine made all kinds of decoration more affordable, but further away from the hands of the craftsman (Twemlow, 2005).

In the 1800s, the intellectual debate on ornament focused on the meaning of decoration and its most appropriate uses and sources of inspiration (Twemlow, 2005).
Around the turn of the century, the existence ornament itself became the topic of discussion. This depreciation of ornament, called for by theorists in the early 1900's cannot only be explained by the industrialisation overtaking production from craftsmen, as the industrial revolution had been going on for almost a hundred years. Only in the aftermath of the First World War, in a context of social revolutions, "White Modernism" could emerge victoriously (Schumacher, 2009).


Mass produced ornament (Crocker 2010)

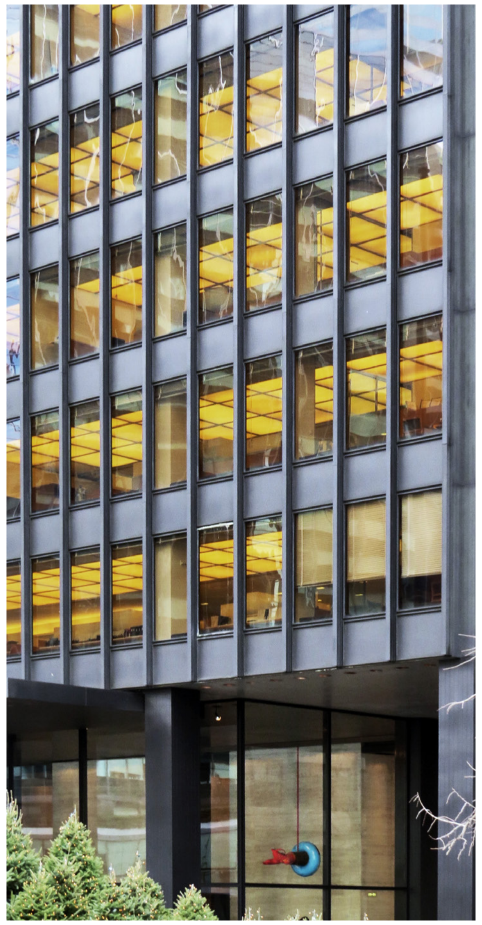
Modernism

Through much of the 20th century, ornament was seen with skepticism, if not downright hostility, after Adolf Loos's essay "Ornament and Crime" relegated ornament to the periphery of architecture in 1908. Loos was opposed to ornament, based on the argument that the creation of ornament added cost in the form of labor and material. Ornament was a mask, hiding the weak points of workmanship, material and design. (Hearn, 2003 p. 279).
The industrial revolution and machine production made decoration cheap. Before, it was luxury. The more lavish its ornamentation, the more labor that went into the production of a building or any other object, and the more expensive it was. Mass production, enabled by the machine, constitutes the opportunity to produce larger volumes of, in Loos's mind, useless crap to sell to the masses. When ornament becomes cheap, the elite taste moves on (Heathcote, 2015). When decoration is easily produced affordably, the object that is plain suddenly becomes valuable. This is the advent of Modernism, exemplified by the stripped back aesthetics of Bauhaus, where the effort goes into making the building or the object look simple, rather than decorated (Heathcote, 2015).

Modernism...(Praefcke. A 2007)

"The evolution of culture is synonymous with the removal of ornament from objects of daily use"
Adolf Loos (1908)

"..this taste for decorating everything around one is a false taste, an abominable little perversion"
Le Corbusier, 1925 (Domiesen, 2008b)



Seagram Building (Fernandes 2015)

Le Corbusier was strongly influenced by Loos's essay, but emphasized his admiration of the machine in his arguments against ornament. (Hearn, 2003 p. 279). As a whole, Modernism was characterized by a self-proclaimed spirit of progress, related to the fascination with new technologies and innovations of aviation, automobile and shipbuilding industries. In this progressive ambition, they rejected the perceived excesses of decoration and styles, opting instead for a search for the essence of architecture. This essence has been defined as either the function, the form or the structure of a building and its elements. Any excess besides that was almost always seen as dishonest, wasteful or downright sinful in the eyes of the canon. (Pell, 2010, p. 8). A reduction of complexity is also necessary for mechanized mass-production. This simplification is based on the consideration of what "purposes" each element fills. This simplification is not without aesthetic consequences, as for example minimalism. There is however an undeniable decorative value in the "pure" unadorned structure, as critics and historians have recognized (Hearn, 2003, p. 280). The generality and repetitive nature of much facade cladding, up until our days, is a result of this rationality of production (Leatherbarrow & Moustafavi, 2002). While getting rid of the stylistic excess of the 19th century, the rejection of ornament effectively dismantled the very means which architecture used historically to relate to nature and engage with popular culture (Pell, 2010, p. 8). Yet even within the Modernist movement, ornamental elements of architecture can be found as the Modernists in reality rejected some ornaments, rather than all. Seagram Building, designed by prominent modernist architect Mies van der Rohe is such a case. Here, structurally unnecessary elements on the facade are expressing the inner logic of the steel structure enabling the skyscraper's existence. Hence, ornaments related to tectonics (the expression of construction's logic) work as a way to make the building structure readable and communicate its function. Modernists viewed this transparency as a way of making architecture more sincere, and stood in sharp contrast with the bourgeois practice of decoration. Architecture was supposed to show the functions of the building rather than disguise them (Moussavi, 2008, p 6).

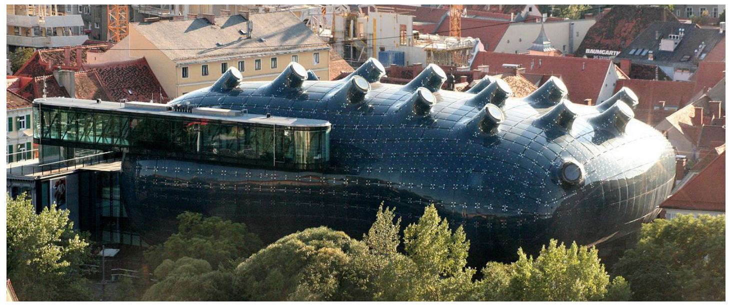
Postmodernism and the 90s

Post-modernist theorists Robert Venturi and Denise Scott Brown proposed to replace the Modernist paradigm of transparency with decor, to integrate buildings with the urban environment and give them meaning (Moussavi, 2008). They saw a source of creativity in the contradiction of space, structure and program on one hand, and representation on the other (Moussavi, 2008). Venturi and Scott Brown argued that the potential in the "ready-made" cultural expressions to communicate with a wider audience was neglected by Modernists, as their ambition rather was to express internal orders of buildings (Moussavi, 2008, p. 7). Venturi saw the combination of old cliches in ironic ways as a way of criticizing a society that directs its technology and money in other areas than architecture (Venturi, 1977).
Postmodernism fast became passé, due to its lack of a common language or mode of understanding. The inherited symbols couldn't survive being placed into another time and condition. Soon, Postmodernism became replaced by other forms of expressions in architecture, many of which celebrated the formal purity of modernism and the air of luxury in simplicity. The social ideals of Modernism had become a luxurious style in "White Minimalism" or "New Simplicity" (Maak, 2008, pp. 94-96)

PostModernism...(Ahsmann 2014)

PostModernism...(Romero, 2017)

Blob architecture, Graz Art Museum.
(Schneider & Aistleitner 2008)



Minimalist pattern in
Herzog & de Meurons
Ricola Storage Building
(Spiluttini n.d.)

In the 80's and 90's, computers were instrumental in transforming the architectural language, developing three-dimensional modeling (Marcos, 2011). Mario Carpo (2014) writes that digital culture and technology could be seen as the ultimate version of postmodernity. It represents a post-modern dream come true in that variation could be mass-produced at virtually no extra cost, as the pioneers of digital architecture have claimed since the 90s (Carpo, 2014). When digitally fabricated ornaments are produced effortlessly, requiring little human labor, the remarks of Adolf Loos are renounced. The mass-customized style did, however, not become the dominant force in the first era of digital design and architecture, it was instead something else that became the hallmark of early computer-aided design: the blob, a style that lives on until present days (Carpo, 2014).
Curiously, it was from within the Minimalism movement the embracing of ornament emerged in the 1990s, through the return of patterns, challenging Modernist strictures against decoration (Schumacher 2009).
Deploying artificial surface treatments in almost graphical ways, the formal repertoire of architecture was expanded. This was done without returning to the traditional ways of decoration and their meanings, instead elaborating on new associations. The Minimalist patterns were however limited in its deployment, by wrapping around highly simplified structures and that its surface was two-dimensional, giving a wallpaper-like application (Schumacher, 2009).
Meanwhile, at the end of the 1990s, Deconstructivism had led to an avant-garde experimenting with "folding in architecture" and fitting panels onto complex surfaces, creating patterns to ornamental effects (Schumacher, 2009).

White Minimalism (Michelpost 2005-2008)

The contemporary era is affected by digital technology, providing the means of producing integrated and dynamic surface effects. This use of computer-aided design and manufacturing is a strong factor in the reappearance of ornament. Ornament was inseparable from the history of styles until its relegation to the periphery of architecture in the early 20th century. Today, by using digital technology, ornament has again taken an important role in architects experimentation with form, surface and structure (Balik & Allmer, 2017).

"The architectural minimalism of the 1990s was modernism running on idle: the aesthetics of modernism over-refined and honed until there was nothing left."

Niklas Maak (2008, pp 94-96)

Design Study

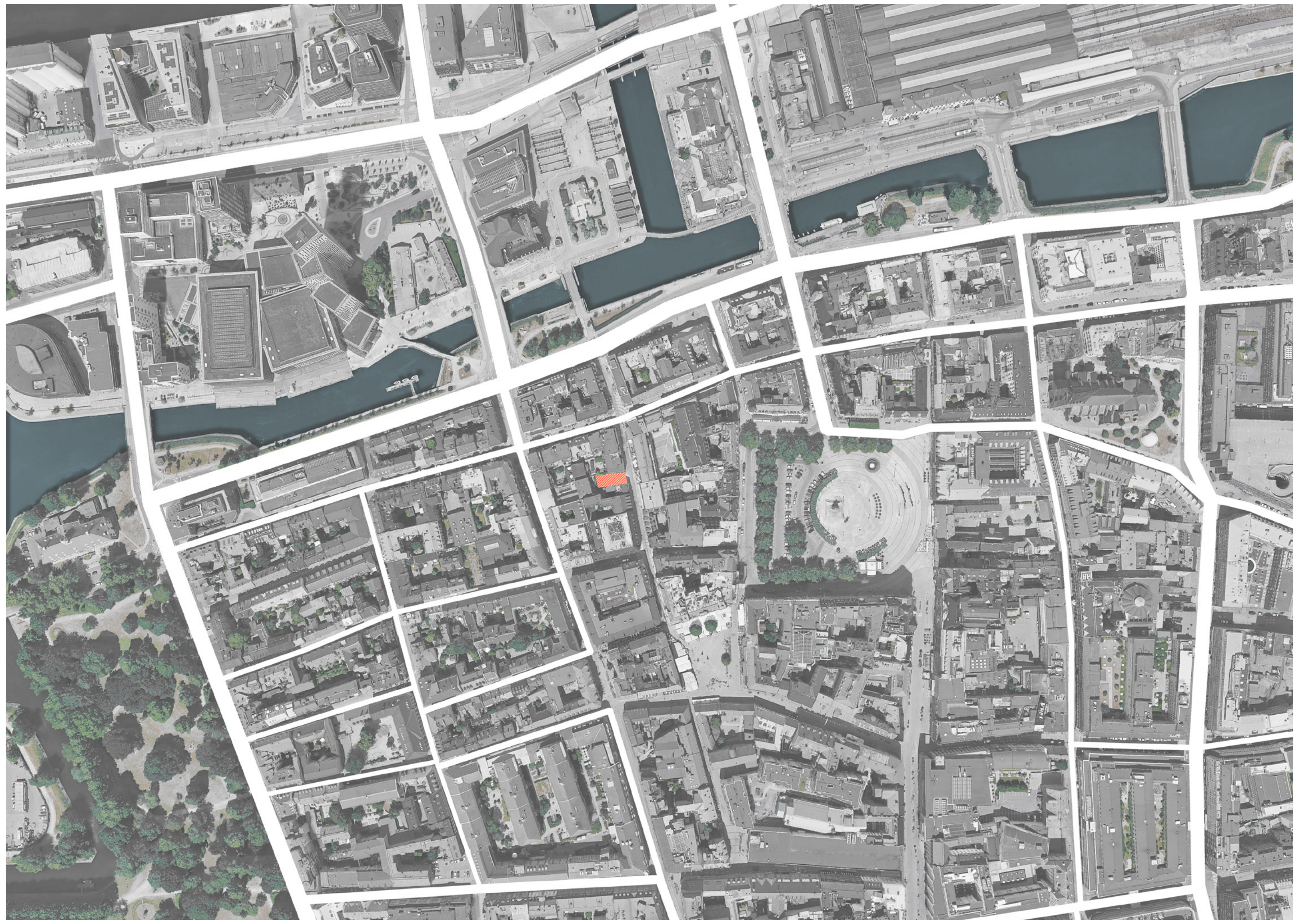
To investigate how digital manufacturing can be used to create ornaments in architecture, I conducted a design study. With this design study I wish to examine and highlight potentials in creating ornaments through digital means, as well as the possible challenges.
By conducting this design study, I aimed to encounter the theoretical questions that arise when producing ornaments through digital manufacturing. As the question of ornament has been highly charged throughout the last hundred years, I believe it is relevant to find the arguments justifying its existence, as well as acknowledging the arguments against ornamentation.

There are a multitude of methods to design and manufacture ornaments through digital means.
When starting this research for the thesis, I tried out a number of design approaches before settling on the five methods used in the design study. These five methods were selected to ensure a spread in approaches, with their different characteristics, such as being partly or fully digitally integrated throughout the whole process, using additive or subtractive methods, or using robotic manipulation of elements. The different design methods each produced one iteration of a facade design.
The five iterations can be described as using the following design approaches respectively:
1. File-to-factory as guiding principle
2. Using representational objects through "Kitbashing"
3. Parametric patterns
4. Randomness as an aesthetic tool
5. Form-finding by material simulation

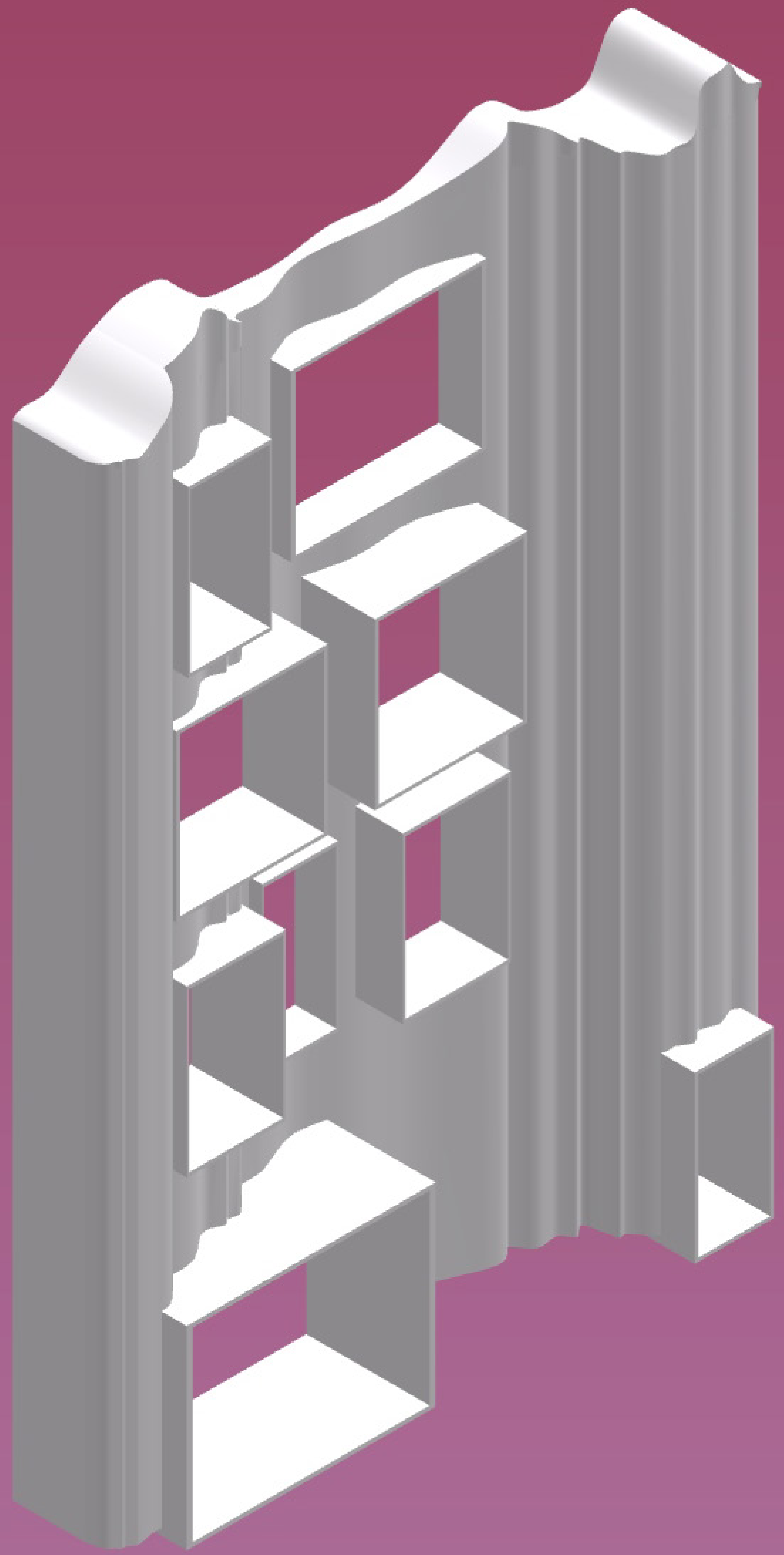
There are plenty of other design and fabrication methods, through computational means, that are not used in the design study of this thesis. Among these are robotic brick-laying, CNC milling, voronoi structures and casting concrete against forms, creating surface relief. In the same way, the ways I use the design and manufacturing methods are not the only ones, as for example parametric patterns or 3D printing can be used in a multitude of ways.

To provide factors that the ornamental design could correlate to, I used the municipality guidelines for an empty plot in Malmö as a testing ground. This provided scale, functions and space for the design. I designed the floor plans first, as well as taking restraints such as the maximum height of the building and used it as information for the ornamental facade to relate to.
Municipality plans state that the plot is supposed to be developed with a building, including storefront ground floor and a minimum of 4 apartments. It is not to be taller than the buildings of the surrounding area, limiting the building to 4 stories tall (Stadsbyggnadskontoret Malmö Stad, 2021).
To further investigate the convergence of the interior spaces and an ornamented facade design, I selected one of the iterations to convey through floor plans and sections. With this selected iteration I also look more closely at the details regarding fabrication and assembly, as well as the theoretical considerations of its design choices.

Volume of new building



Prototype 1: **File-to-Factory**



A 3D facade, potentially printed in one go

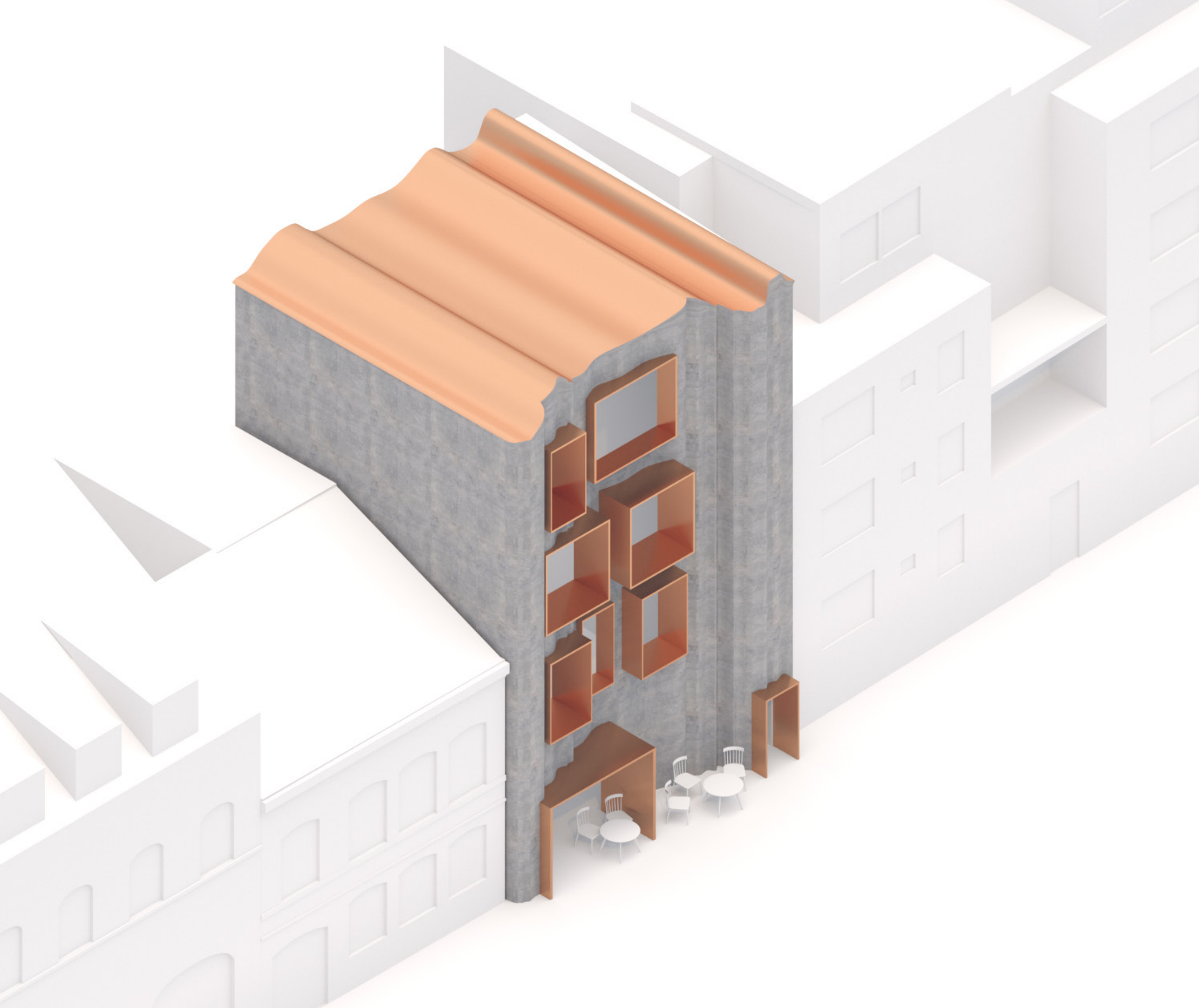
Expression of production logic

3D-printing is very much talked about today, and impossible to ignore when examining the new modes of producing architecture through digital means. I choose to adopt a design approach where the whole facade is 3D-printed, potentially in one go. There are obviously endless possibilities to 3D-printing, such as producing separate elements and assembling them at the construction site instead.
The design and manufacturing process are almost one in the case of 3D-printing, where a file-to-factory approach is the medium of the architect rather than line drawings. A script controls the way a robot or a 3D-printer will behave. This script is made directly from the design software, and the conditions of the production methods and materials are already integrated early in the design process.
Replacing the construction worker as well as the medium of 2d-drawing as translation from design to built product, a file-to-factory approach encompasses the actual instructions for the machine, the script that controls it, putting the architect in a position much closer to the actual production. This approach bypasses many steps of the conventional building process.
Domiesen suggests that the file-to-factory approach of digital manufacturing is a potential for architects to regain control over the built product. Hence, developments in the digital field may lead to a closer connection with the material reality of architecture. (Domiesen, 2013)
Expressing the logic of its production, the design should emphasize the condition of itself if it wishes to become a sign of its time. Printing in concrete limits the angles of extrusion, practically only able to print straight upwards. In the footprint however, it can be as complex, irregular and organic as it wants to. This is an example of how the material and manufacturing process is influencing the design early on, setting the limits and possibilities of the architecture. Boxes are inserted to form the support for openings. The contrast of the flowing lines of the walls footprint and the rectilinear metal boxes gives tension to the facade composition. The scale of the facade and the curves makes the facade in-between the ornamental and the spatial. A more stable structure for the wall is reached when it has a curved form. The design expresses the logic of the robot as a guiding design principle, where variation and complexity is no longer difficult to obtain. The architect's expertise is expanded to include scripts and codes in place of traditional forms of instructions, broadening the language of architectural practice.

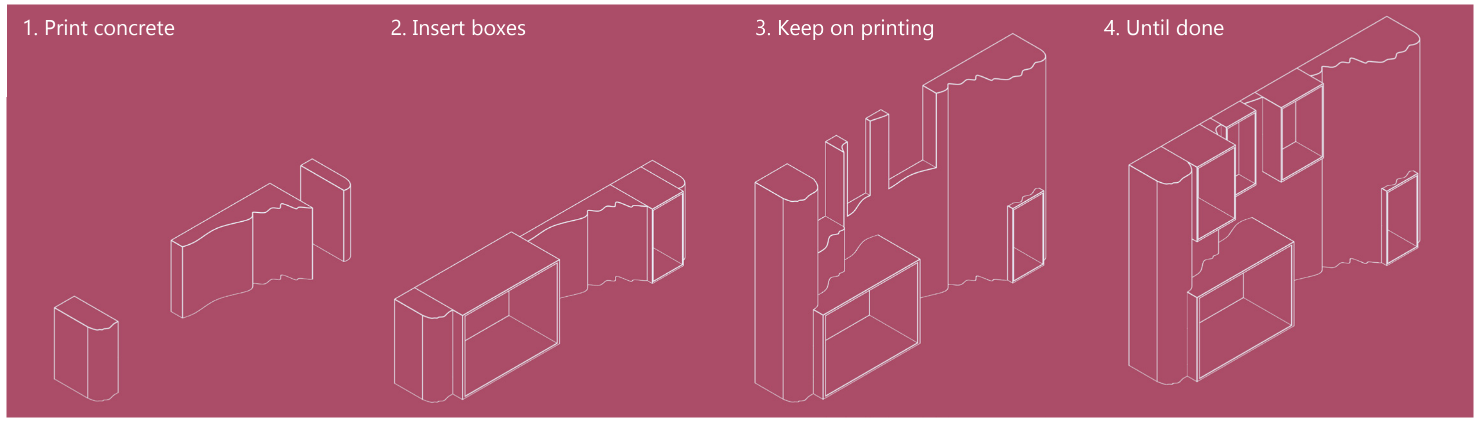
3D-printing (Milano 2021)

3D-printing (Heidelberg Cement n.d.)

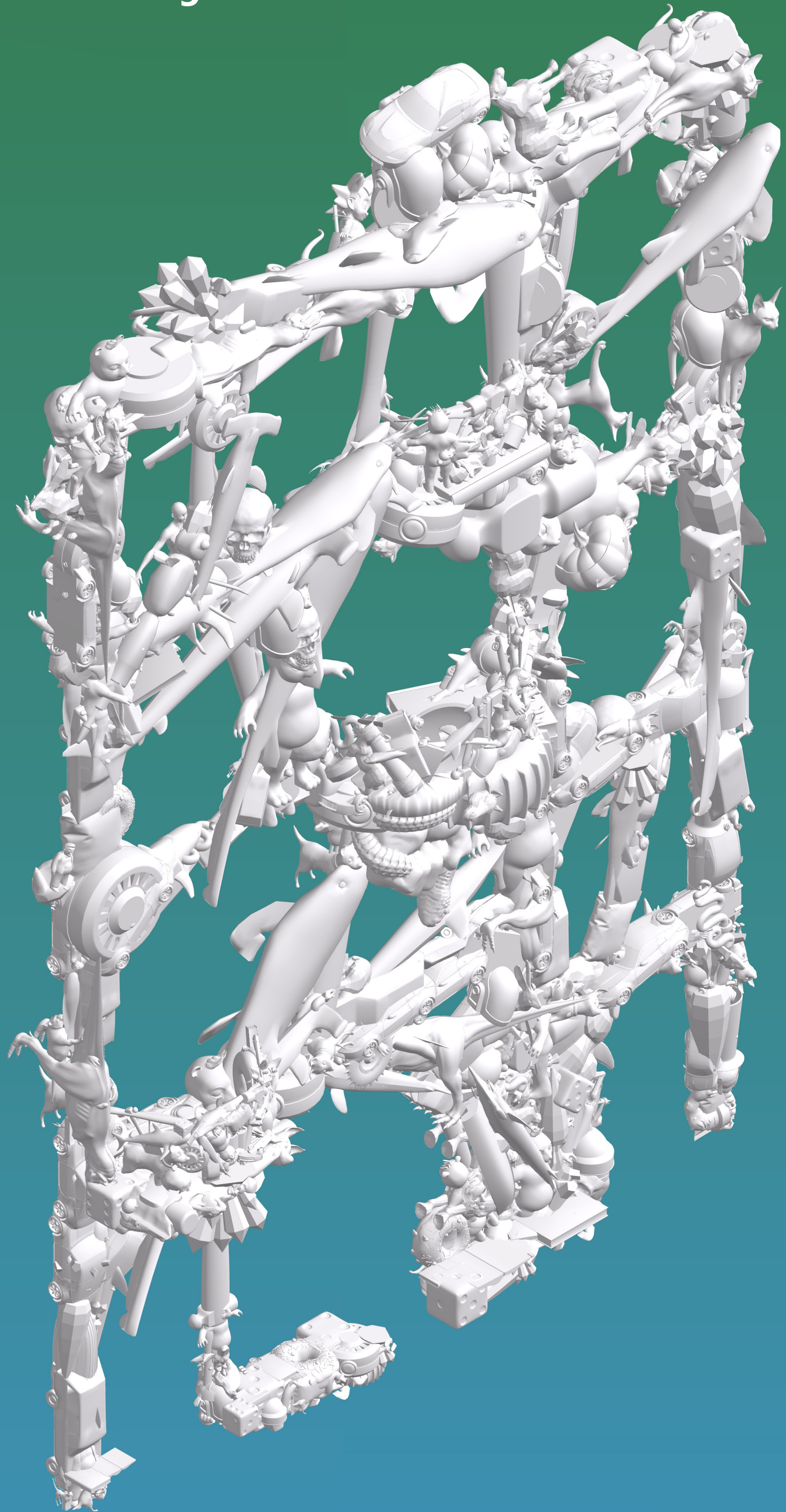
Prototype 1: **File-to-Factory**



A large scale 3D-printer is creating the facade, potentially all at once. The roof is covered in conventional metal, adapted to the curves of the top of the building.
By exploiting the artifacts of the tools, a surface that is not smooth and featureless is realized. This surface can give an interesting and highly decorative effect. Homogeneous material becomes highly textural, so that the visual value is not in the material itself but in the way it is printed and layered. The raw surface of the material is seen as a feature, leading away from the smooth side of digital design to the more rugged appearance.
One might see 3D printers or robots as replacements for craftsmen and construction workers, or as a tool for the architect (which also in effect eliminates the builder). Regardless, the consequence will be a reconnection of the practice of the practice to the actual craft of building.
When the skills of the craftsman have been digitized and taken over by the machine, who is the craftsman of today - the machine or the operator? Perhaps the definition of craftsmanship could be reinvented by robot technology.
The benefits of using digitally controlled robots in the production of architecture are both of the pragmatic sort and of natures that go beyond the rational. The fact that robots are fast, can work day and night, during weekends and holidays, and without risking illness or work-related injuries are aspects that are good for the economic side of things. Other benefits are more related to values, such as the potential of customization, giving a high degree of individuality, akin to a revival of craftsmen-like virtues in an industrialized incarnation. Due to digital integration of the process, possibilities are improved for consistency between drawing and fabrication. Optimisation of processes and the use of materials, from early in the design to late stage execution, can be accomplished by the computer's calculation skills, adding to the sustainability (Christiansen, 2016).
This way to use 3D-printing is just one example of how an additive manufacturing process can be implemented and potentially change architectural practice as well as the built environment. The use of 3D-printers and robots may lead to the medium of the 2D drawing being replaced with 3D drawings and code, the language of robots, which the architect needs to learn and master to become fully capable in his new role.



Prototype 2: **Kitbashing**



The design plays on the border between representational and abstract

Representational objects, downloaded and merged

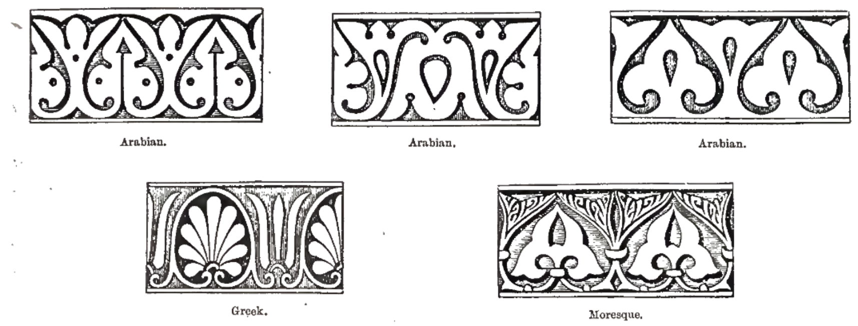
Today, after the decline of ornament in the last century, it is possible to use digital images or 3D objects as the basis for ornament, in a similar way as the artisans catalogs were used. Only now, the internet is providing an unprecedented volume of freely available digital material to use as inspiration (Strehlke, K. & Loveridge, 2005).

Accessibility through open source download 3D objects or 3D-scanned real life objects makes this otherwise tedious design possible. New ways of combining objects can give meaning, create juxtapositions or lead to the abstract. This example uses the approach of "Kitbashing" where digital objects are merged together to build structures.

While decoration traditionally imitated nature or took an abstract approach, digitally conceived ornamentation of today often blur these tendencies. Digital media offers a scale-less environment that can embrace mimetic and abstract languages simultaneously (Malé-Alemany & Sousa, 2005). The kitbashing method of salvaging ready-mades from the internet and assembling them in new ways is akin to how Venturi (1977) describes the Pop Art artist changes the context or size of common objects, and thereby gives them an uncommon meaning.
The Internet is however not the only possible source of inspiration for this approach. Instead of finding the digital objects online, one could use real life objects and turn them into digital 3D versions of themselves through 3D-scanning, allowing for editing in scale.
The re-use of digital files and the potential symbolism of objects chosen is interesting, and adds dimension to the direct visceral experience of the complexity of the facade. There is also a potential here to use a theme, one can envision a facade built up by objects relating to the use of the building or the cultural context of the site. This communicative aspect is however not needed to intrigue a viewer, since the mere complexity and detail level is enough to spark interest.

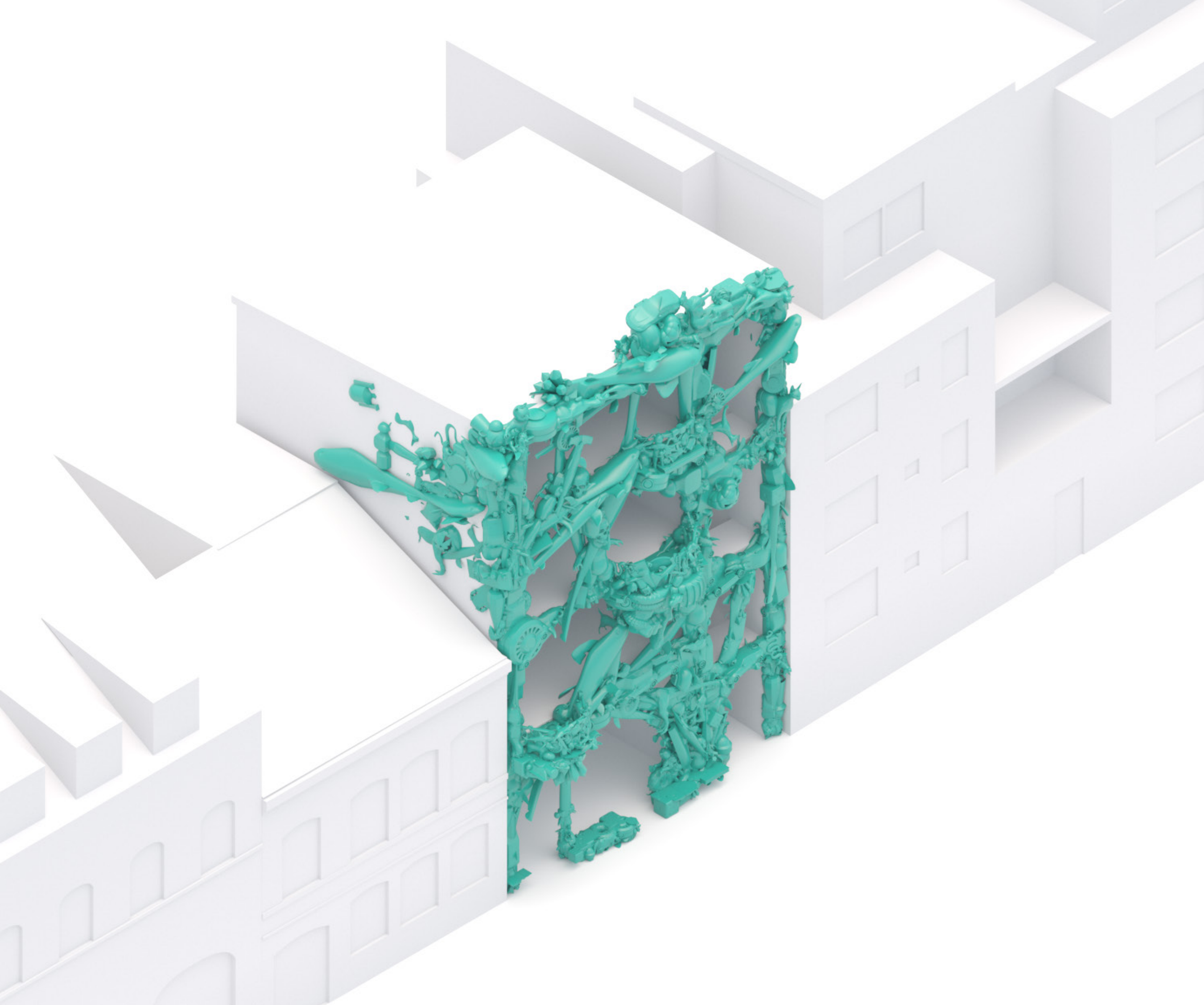
Kitbashing (Mark Foster Gage Architects 2014)

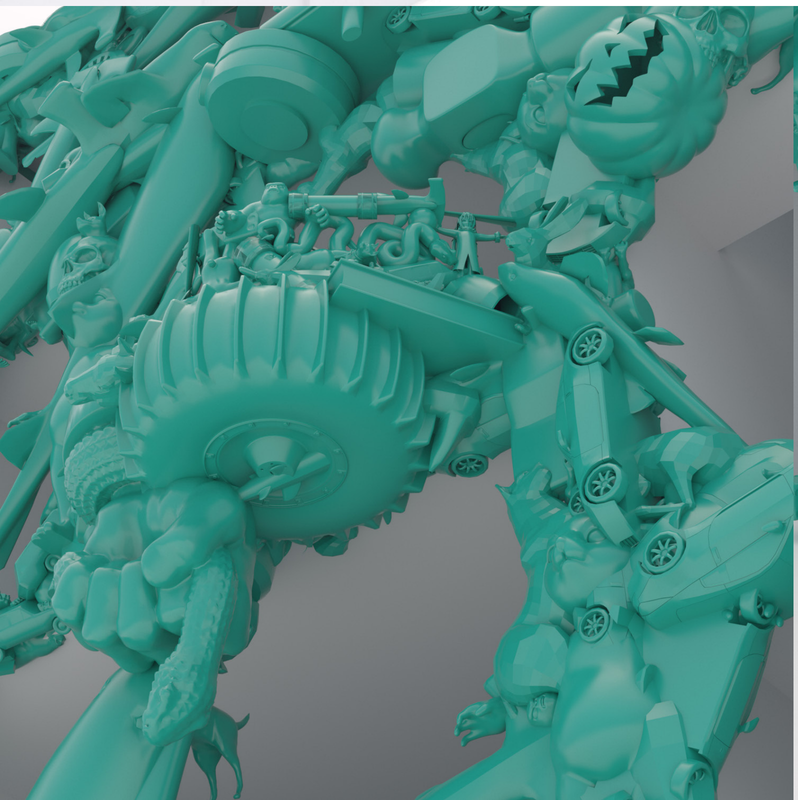
Sunny Hills (Kengo Kuma and Associates 2018)

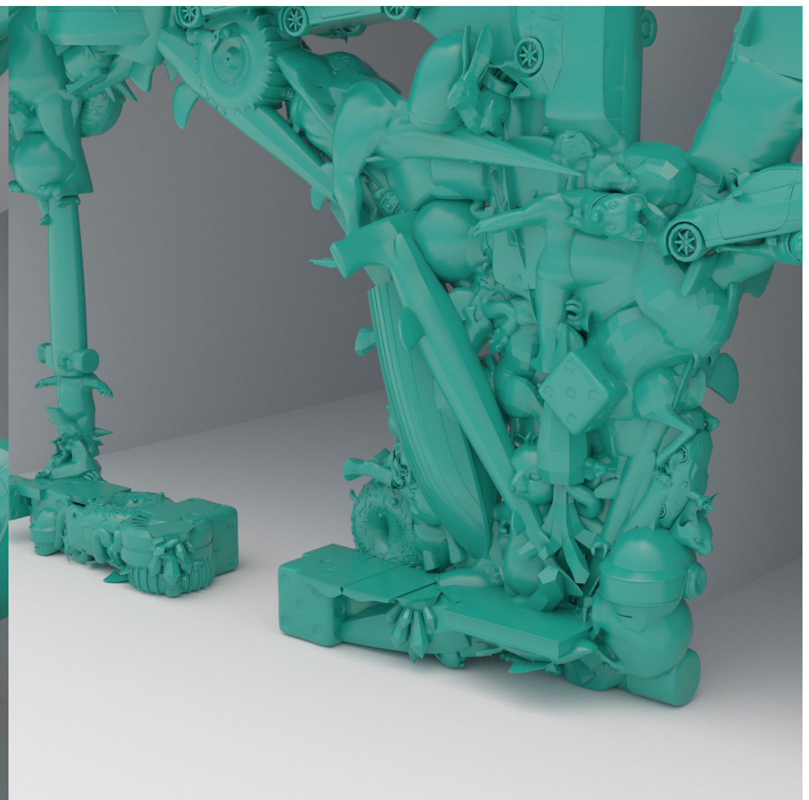


Historically, ornament and styles were cataloged, and used as the basis for most ornamentation. (Jones, 1868)

Prototype 2: **Kitbashing**





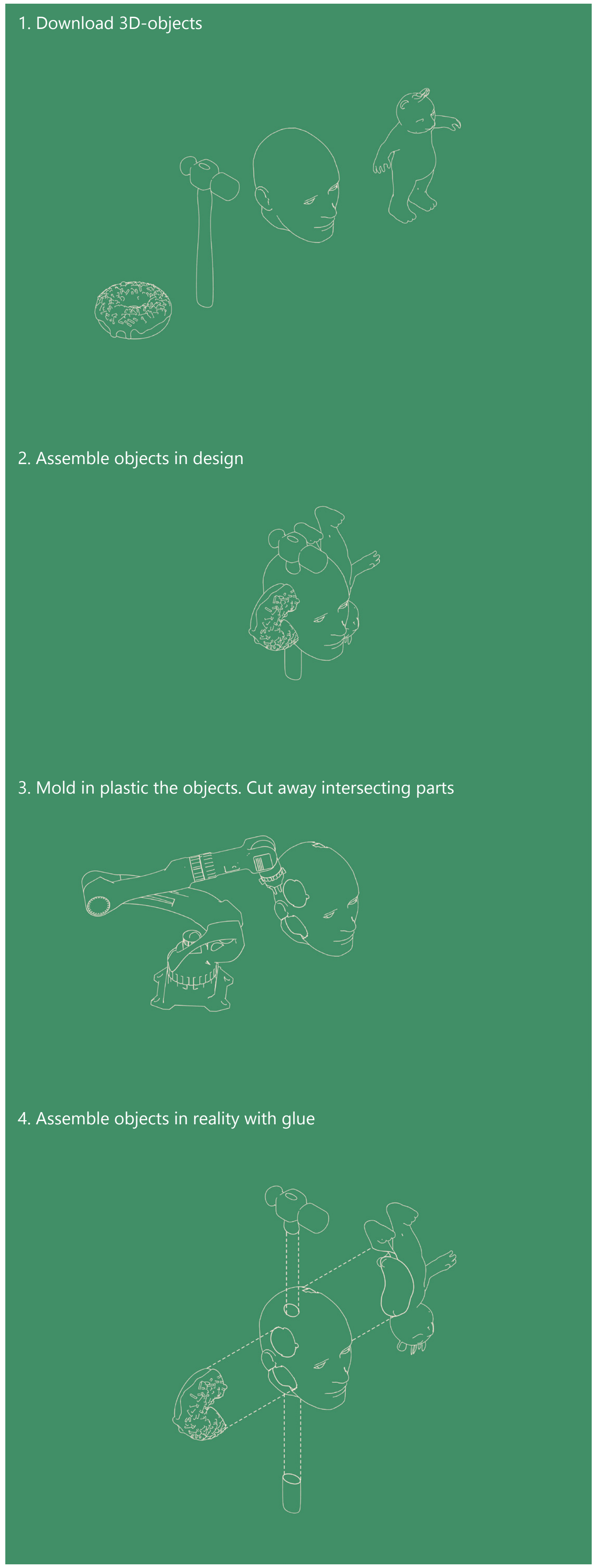


Since the digital objects are re-used and not new, I thought it would be appropriate to reuse something for its physical version as well. Recycled plastic is a great material for creating objects with high complexity, cuttable with CNC mills.

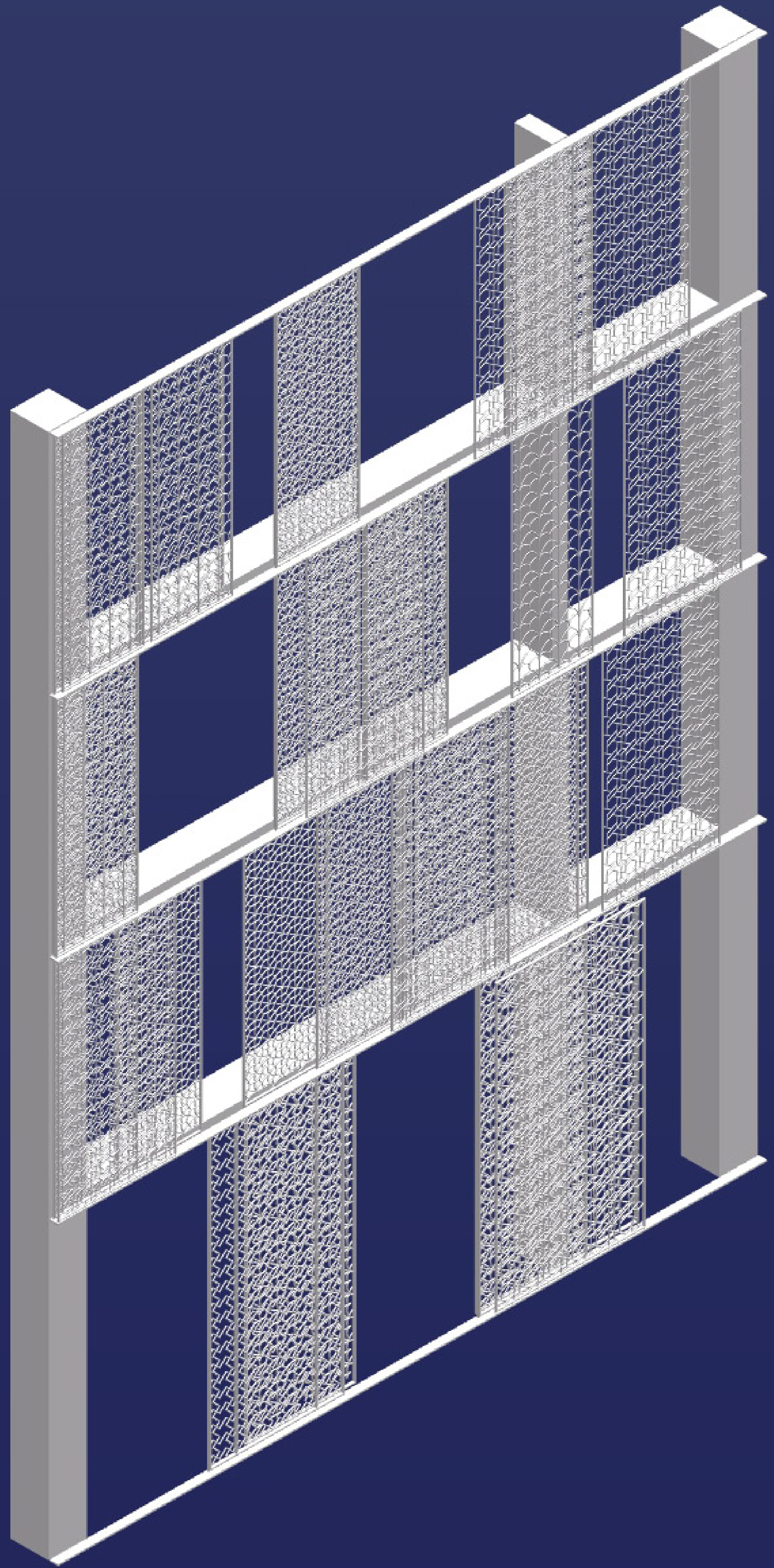
Molds to create these shapes in physical versions can be made in metal from offsetting the digital objects in the software. Plastic is poured to create independent objects that later will be assembled to construct the facade. In the digital software, the seams connecting the 3D objects can be found. These can be precisely cut by CNC robot arms. The objects can then be glued together at the intersections. The ornamental structure will be fastened at multiple places with bolts into the building's structure. This process allows for a light structure made from a multitude of hollow plastic objects merging together visually.

According to Louis Sullivan, an ornamental design is more beautiful if it seems part of the structure it embellishes, rather than if it looks "stuck on" (Sullivan, 1892). In this example, the kitbashing structure is literally built up completely by ornamental elements, making them impossible to remove without destroying the branching structure altogether. The shapes not only create the facade but also the balconies, railings and benches. Here ornament acts as a unifier, merging different elements of the building together.
In the history of architecture, ideas of beauty have been inseparable from ornament. Despite this, ornament has always embraced monstrosity and metamorphosis, such as gargoyles of the gothic and renaissance grotesques, described as obscene at one time or another (Domiesen 2008c).

Technology and the internet are shaping the way that we interact as humans, this digital culture is part of today's society, bridging physical and digital worlds. Digital architecture cannot be thought of as outside of this digital culture, as it belongs to its time and is sustained by the same inputs (Marcos, 2011). This is not only limited to this example, but the influence of the internet and cultural layering is perhaps most directly communicated here. Kitbashing is thus a sign of our times, where digital and physical coexist and merge.



Prototype 3: **Patterns**

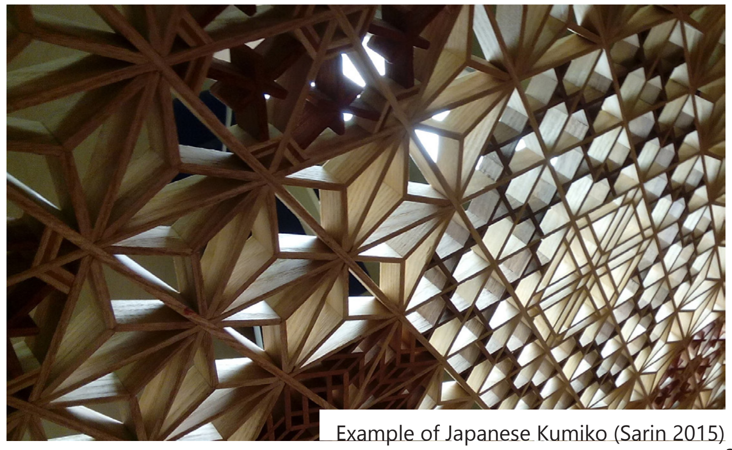


Layers of screens create a denser surface together, allowing for variety in openness and closeness

Correlation between performance and decoration

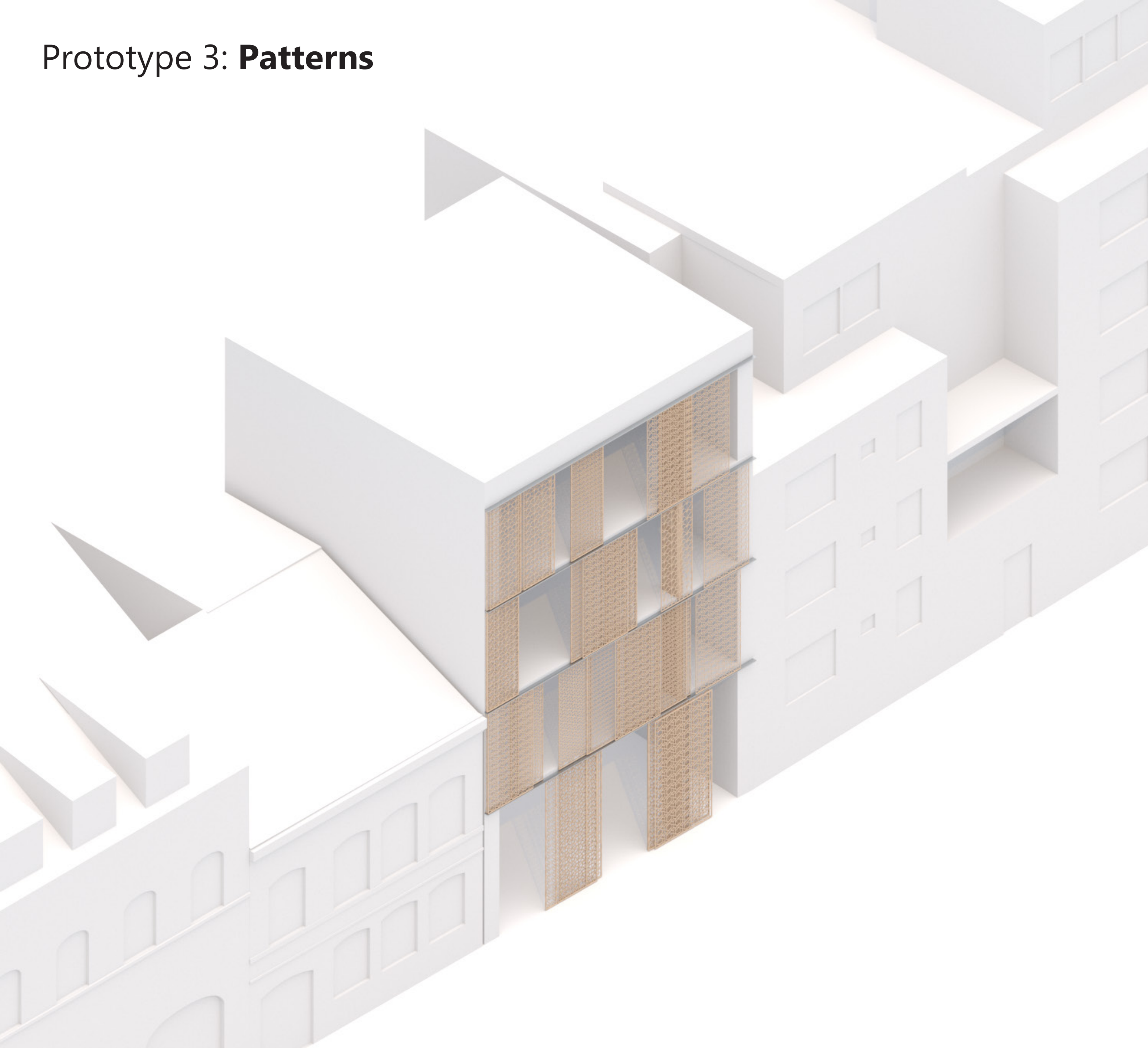
In the Modernist school of thought that dominated the 1900s, ornament is stripped of meaning and separated from function, thus making it superfluous and redundant (Twemlow, 2005). By making ornaments have a performance other than for decoration, the dichotomy of function versus ornament is bypassed. In this example, sunscreens are made from wooden sticks, arranged in elaborate patterns, to give extra value and a smaller scale to the performance of blocking the sun out. Making ornament meaningful in other ways than for its own sake, makes it less prone to criticism. I think it is more fruitful to think of performance and expression as correlating aspects, rather than seeing function as the alibi of decoration. For a building to be fully successful, it needs to perform both functionally and aesthetically. The blocking of sunlight could surely be done in a less elaborate way, but not to the same expressive effect.

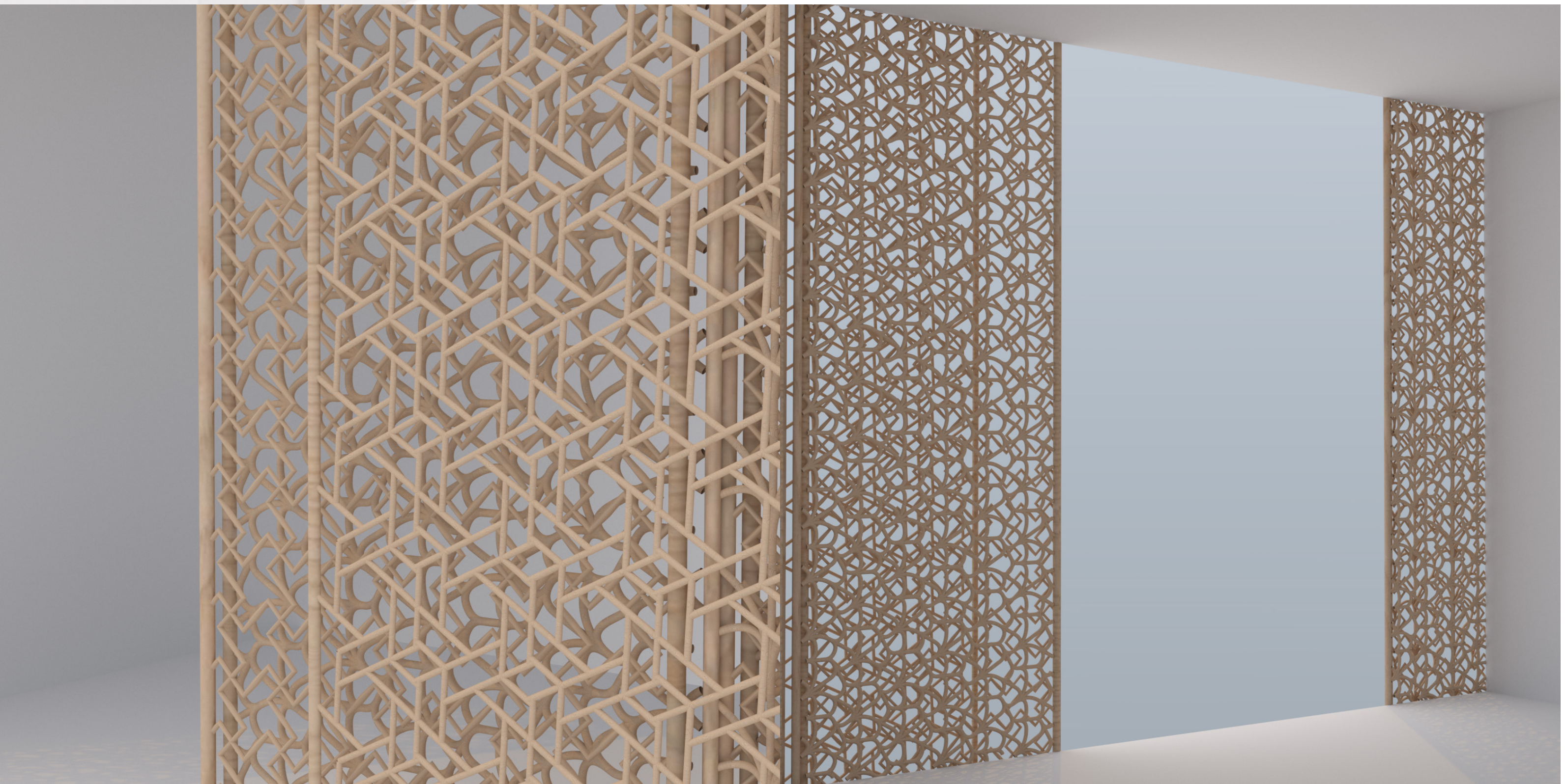
With digital software, a multitude of patterns can be generated and adjusted, until fitting solutions are reached. The patterns are derived parametrically, giving a high degree of control. Parameters such as how large the grid boxes of the pattern are, or the denseness of the pattern are manipulated until a desired result is achieved. Using parametric design to find form allows for an iterative design approach, fast and responsive in giving design options. The patterns are akin to Japanese wooden screen design. In our case, digital design and manufacturing acts as an enabler, making something very difficult, easy. It is a question of accessibility and enabling, rather than creating something that was impossible to achieve before.



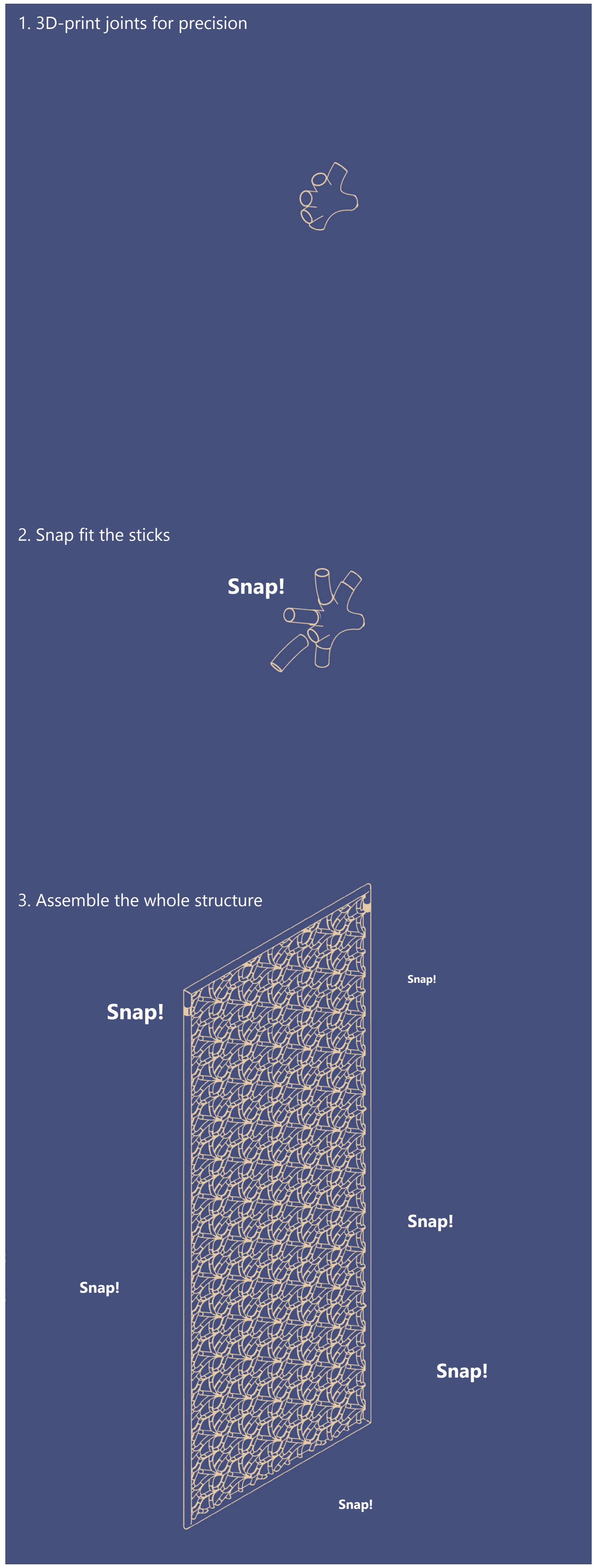
Example of Japanese Kumiko (Sarin 2015)

Prototype 3: **Patterns**





The formal complexity of its shape and ornamental intricacy could be made easy to construct by digital tools helping in the creation of joints with a low tolerance for error. The critical point is the conjunction of sticks. The form and angles of these joints can be found in the digital design, and printed in 3D, allowing for an extremely low tolerance of errors. Then the physical assembly process can be done very easily at the construction site, potentially by even a non-professional.
No matter if there are many unique joints, it is not a problem in the logic of digital manufacturing, with 3D-printing. It is also a process that is streamlined, from design of pattern, to extracting positions and geometry of joints, to creating a mesh that can be 3D-printed.
The computational technologies allow for a very low tolerance for error. By 3D-printing the joints, and making them snap fit, the most difficult step of the process is eliminated. From then on, it's just about putting sticks into fixed joints, creating a rich pattern.
The four different types of panels are placed in individual parallel tracks. The sunscreen panels are adjustable, and can move along the facade and even be layered, making the denseness and positions a matter of choice for the resident. In its most layered state, a few panels layered becomes almost solid, and a space shaping element. At its most open, only one, or no panel lets a large amount of sunlight in. Residents can control the sunscreen panels automatically, providing a flexibility that gives a lively facade that might have changed each time you pass it by.



Prototype 4: **Random Growth**

Computer as co-designer

In this prototype, the structure was achieved by digitally simulating a parametrically controlled growth onto the base form of the facade, with openings and bulges for where balconies could be placed. Just as in the patterned sunscreens design iteration we looked at earlier, a parametric approach is used for generating the pattern. This time however, the architect has less control over the final result, in that an aspect of randomness is introduced through the help of the computer. The chaotic randomized pattern has some parameters, like maximum and minimum distance between lines as well as starting points from which the pattern grows. The digital simulation allowed for a high level of complexity, and was possible to re-run several times with new parametric values, until a satisfying result was reached.
The computer becomes a form-finding device, rather than just a digital version of the pen. With this approach, the role of the architect changes, becoming a designer of processes, setting up the parameters of the script. The architect also effectively becomes a chooser of design possibilities, with the computer making the alternatives to pick amongst.

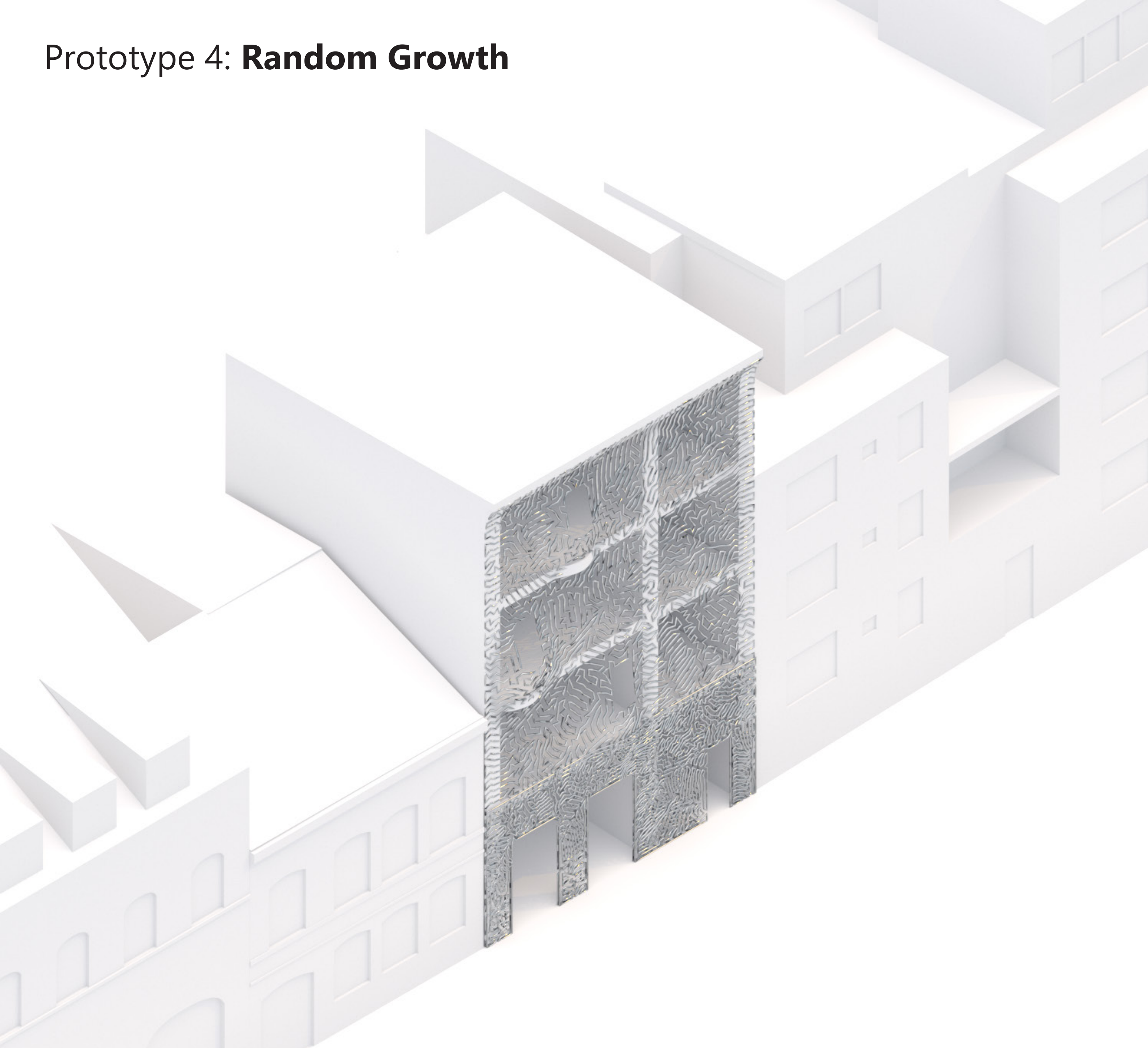
In this example, the computer's power is not used as a way to solve any logical problem like the optimal configuration for loads or the perfect layout for a plan, but to introduce randomness as an aesthetic component. The computer's random and chaotic ingredients can generate forms that don't have any direct cultural predecessors, therefore as a design tool, aesthetically avoiding the risk of getting accused of making a pastiche. At the same time, making possible the creation of something with a detailing level and a complexity that is often found in architecture of the craftsman days. It is relevant since this is done without resorting to any kind of reactionary copying or ironic distorting of architectural motifs of other times and other societies, which is a minefield in architectural practice and discourse.

Ornamentation can be a way of achieving differentiation and articulation. Articulation is a strategy to order the visual field and to guide the eye and distinguish focus points and configurations (Schumacher, 2009). In this design example, we see the ground floor having a higher intensity of complexity, a differentiating factor used in countless examples historically. The scale level of detailing makes it stand out from the rest of the facade, emphasizing attention drawn to the commercial functions of the building.

Antoni Gaudi used analog form-finding in his hanging chain models for his vault and dome structures. Digital form finding is likewise about extracting a shape rather than drawing it yourself. (Taylor 2009)

Herzog & de Meuron used a similar approach to the design for 40 Bond Street, but with all manual design and fabrication. (Beyond My Ken 2011)

Prototype 4: **Random Growth**

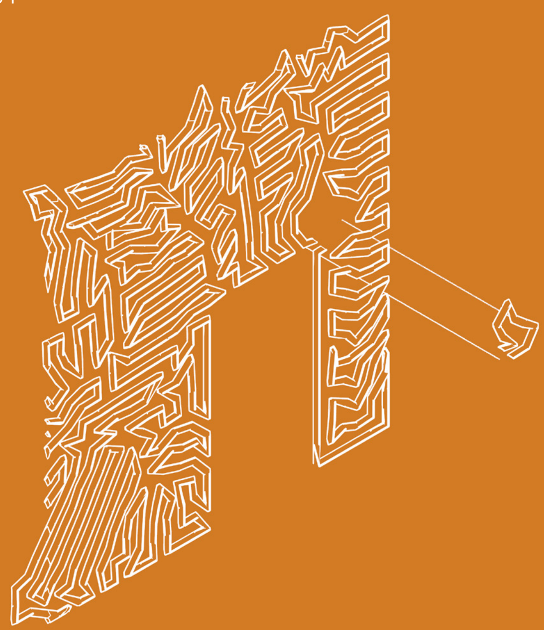


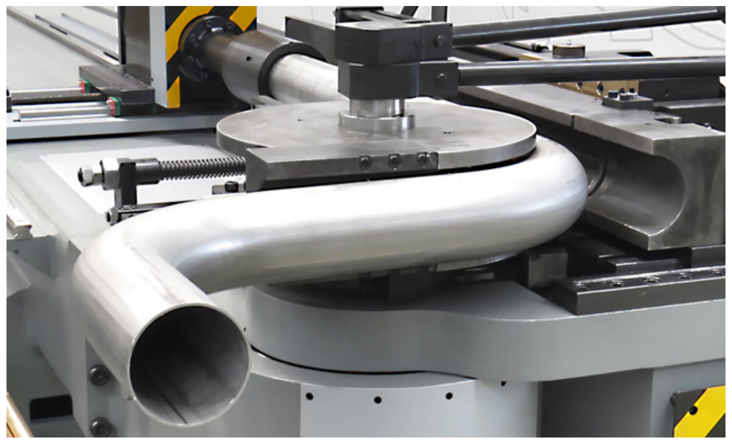
Through the bending of metal pipes, the random growth pattern can take a physical form. The data gets sent to a CNC Pipe bending machine, controlled by the computer and potentially fully automatic by robotic means. There, a metal pipe gets bent into the shapes of the random growth pattern. This process allows for the creation of accurately defined bends, yet it is nothing revolutionary. This is basically the same technology used for the pipes you hold onto in a bus, only now combined with a more radical aesthetic approach. This is an example of robotic manipulation, where new and often ornamental effects can be created from otherwise mundane components.
Information such as thickness of the pipes and possible angles of the bending machines can be inserted into the design process early on. To ensure that it is possible to implement the shapes through the machine, one could analyze the lines and find weak points such as which corners are too narrow for the machine to produce. There you make a cut and continue producing the pattern in pieces, to be assembled at the construction site.
The metal pattern is placed in front of the glass that stretches the openings of the facades, and fastened into the structures with bolts.
This way the growth pattern becomes a visual experience from the interior and the exterior both. This is an example of how the articulation of a facade correlates with other functions, such as allowing or blocking views into a building on a narrow street, or the flow of sunlight into the interior.

1. The computer simulates growth

2. Bending pipes according to lines

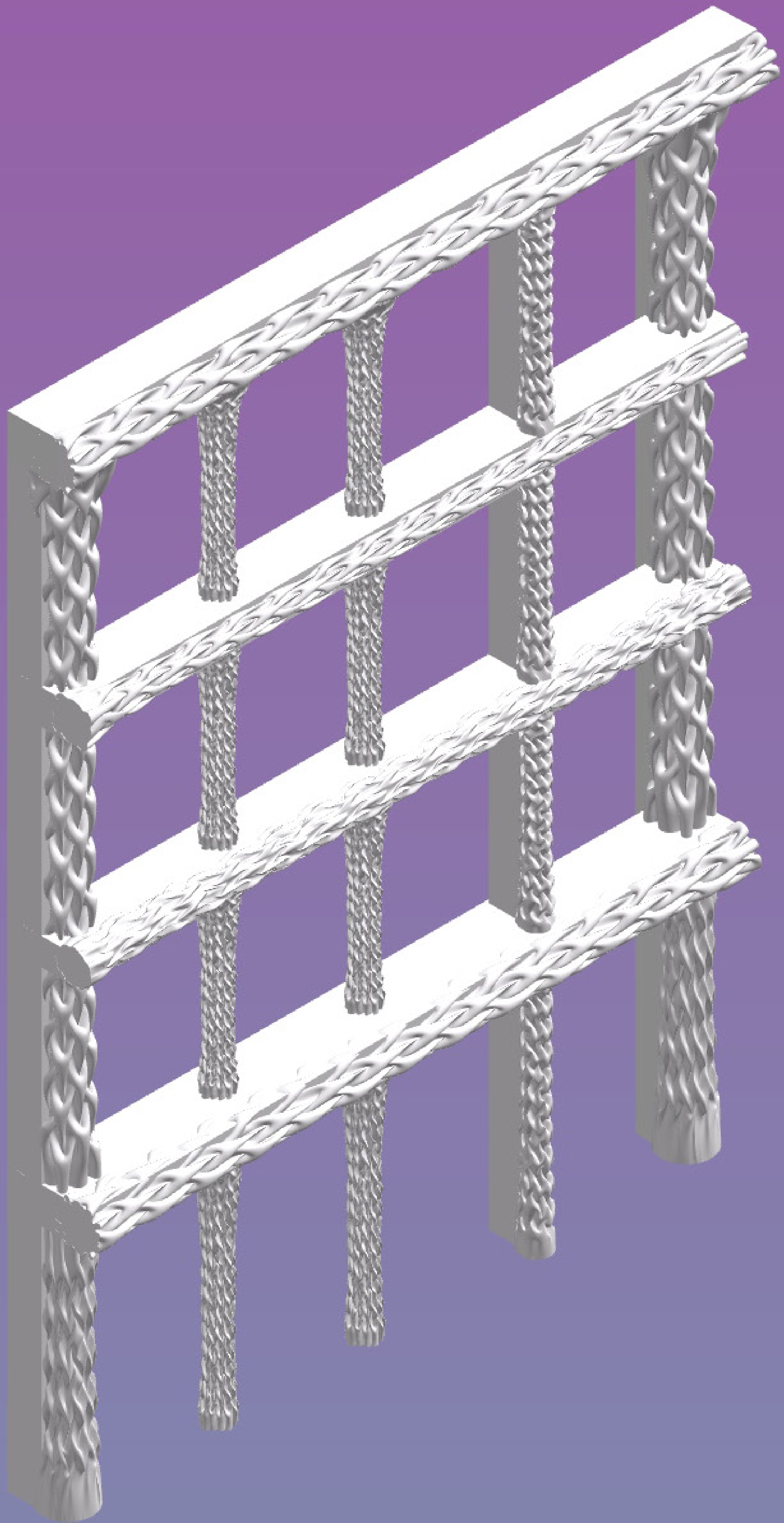
3. Assembling parts into a whole





Pipe bending (Amob Group 2016)

Prototype 5: **Smocking**



Columns and pilasters re-imagined

Simulation of material properties

By simulating how concrete behaves, when poured into textile, aesthetic exploration can be done without having to try every single design in reality. Annie Locke Scherer has in her doctoral research shown how smocking can be used as a technique for forming concrete (Locke Scherer, 2019). Smocking is a technique for patterning in textile, often used for dresses. When applied to concrete formwork, it constitutes a way of using flexible fabric as form. Complex and highly decorative patterns can be achieved through this technique. A crucial part is the ability to predict the final form of the concrete elements. Locke Scherer has in her research shown how this can be done, as the correlation of simulated 3D-model and physical concrete object can be calibrated.

The computer provides the possibility to simulate material properties, giving a high tech approach early on and allowing for a low tech way of assembling in later stages. We see here a direct integration of material properties and production constraints into the design process. The 3D model does not, as usual, just show the abstracted image of the requested result, but rather simulate how the material would behave in a given situation. This means that it could be ensured that the design would work in the physical world as well.

The possibility to digitally simulate material properties enhances the potential for the understanding of structure in architectural systems. This leads to a new direction for digital culture, where material and the description of material can coincide to a higher degree (Søndergaard & Borup, 2014).

Smocking (Rhode Island School of Design Museum of Art 2016)

Columns... (Tomascastelazo 2011)

...and columns (MartinD 2008)

Elements such as beams and columns are already part of architectural grammar, and will be read as such, even when created by new means, this will probably apply to most elements created in new architecture, no matter how revolutionary their processes might be. There might however also be completely new add-ons to architectural language, objects outside of the idiom or in-between established elements. How we read an architectural object is always related to its context within an architectural grammar, not only by its performance or its tectonics (Marcos, 2011). The column will in its essence basically always be a structural element supporting vertical loads. At the same time, it will also be an element within the language of architecture, interacting with a heritage. The classical origin is always recalled by any column. Its referential precedent can be recalled or criticized, but it cannot be taken away. It can't pretend to be a new syntactic element within the vocabulary of architecture. However, the expression of the column goes beyond its tectonic justification. It can take the form of a Doric column or a cruciform steel pillar a la Mies van der Rohe, but it cannot be naturally reduced to an engineered type object.

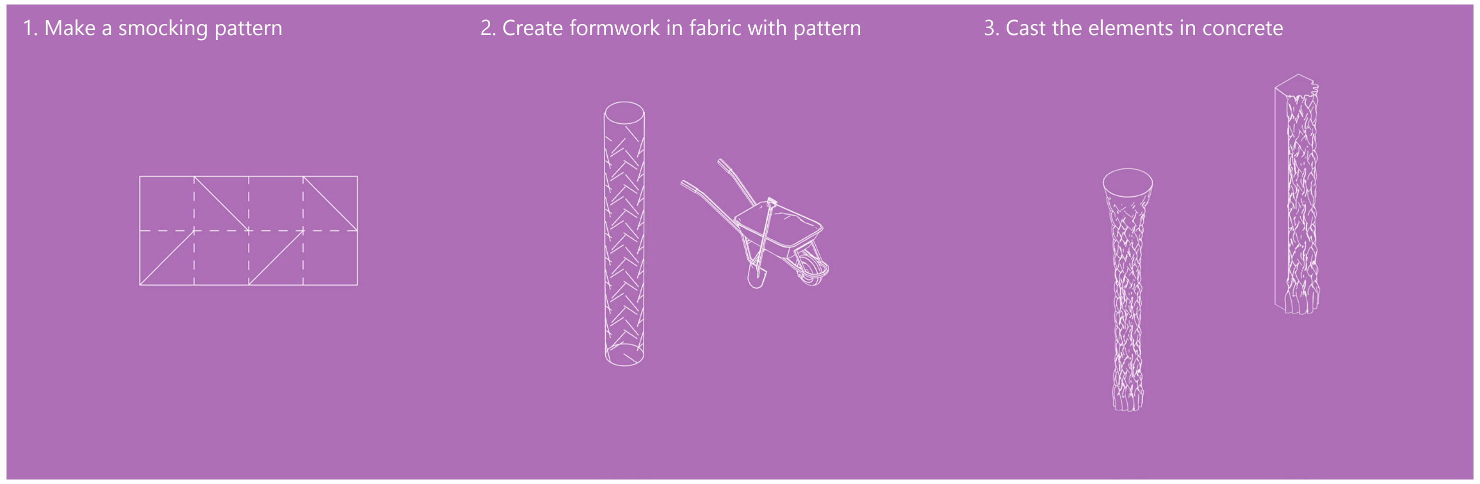
Smocking in concrete (Locke Scherer 2021)

Prototype 5: **Smocking**

At the construction site, concrete is poured into molds made out of textile, with the desired smocking patterns. Making one or more sides of the component flat and inflexible, ensures an easy conjunction with conventional building elements such as walls and floor slabs. Thereby they are following the shape of the load bearing structure, enhancing the aesthetics of the construction. There are also some pillars with smocking patterns going all around. These can be experienced from the inside as well. While not part of the direct articulation of the structure, I think they blend in with the overall aesthetics, perhaps in a similar way as The Birds Nest by Herzog & de Meuron.
Making the smocking "pillar" merge with the side of walls essentially turns it into a pilaster. Returning to the thought of Venturi, this is an element with a structural predecessor, used in a non-structural, symbolic way (Venturi, 1977). More than being any kind of symbolic element, communicating tectonics, I think the smocking elements adds to the visual complexity of the facade, with form in various levels of scale.

Shaping concrete with fabric is not new maybe, but through smocking, a much higher level of formal complexity is reached and a more refined ornamental expression can be achieved. After finding the forms in computational simulation, forms in fabric are made and the ornamental elements are cast in place at the construction site. The high tech-low tech approach allows for a possibly extremely low tech approach later on with textile as mold, in the on-site creation of elements. A calibrated computer at the start of the process allows the use of a shovel at the end. Smocking is only one example of an approach that institutes a hybrid between high tech and low tech, unthinkable without the wide-spread availability of digital technology today. If the materials behavior can be simulated correctly, the need for previous experience is not as crucial, making the manufacturing technique more accessible and implementable even for inexperienced users.

Pillar in concrete(Locke Scherer 2021)



Design Study

To examine more closely how ornamentation can relate to interior and exterior spaces, and what functions it can have, I selected one of the iterations to investigate further. This functions as a way to explore how ornamentation can provide value to architecture in several different ways. Ornament might contribute to architecture by serving various purposes and performing different roles. Through plan and section drawings, I merged the ornamental facade with the interior spaces of the building design made earlier, as well as the urban setting of the exterior. I also went deeper into the details surrounding the fabrication and assembly of a digitally designed ornamental facade.

The design iteration I chose for this further evaluation was the kitbashed facade. I deemed that this design approach had most things to address, both in terms of construction, but also in its aesthetic choices and theoretical considerations. Since I had looked at reference designs that used the kitbashing method, mainly from Mark Foster Gage Architects, I had noticed that their method of implementation in reality was not always clearly defined. This made me intrigued to explore what possible ways there are to realize a radical design like this in physical reality. Nothing hinders it in terms of laws and regulations, as I followed every part of the municipality guidelines.
The kitbashing approach led to the design iteration that was most explicitly ornamental and maybe the most controversial out of the design iterations. Therefore, it was potentially the best tool for my research for finding theoretical points regarding ornament conceived through digital means. Especially since it was the only design approach in the design study that used representational objects as opposed to abstract patterns and forms.

Design Study

A building expressing the hot new invention of the 1800s: the camera. (Image: Author)

As with several of the other design iterations used in the design study, the kitbashed facade interacts visually with both inside and outside. However, it also engages physically with its users, as the ornaments are part of benches and balconies. This is not without historical predecessors, with examples ranging from caryatids supporting building elements, or ornaments being indistinguishable from the structure of baroque balconies.
This tactility, not only possible to look at, but to touch, gives the ornament an additional dimension.

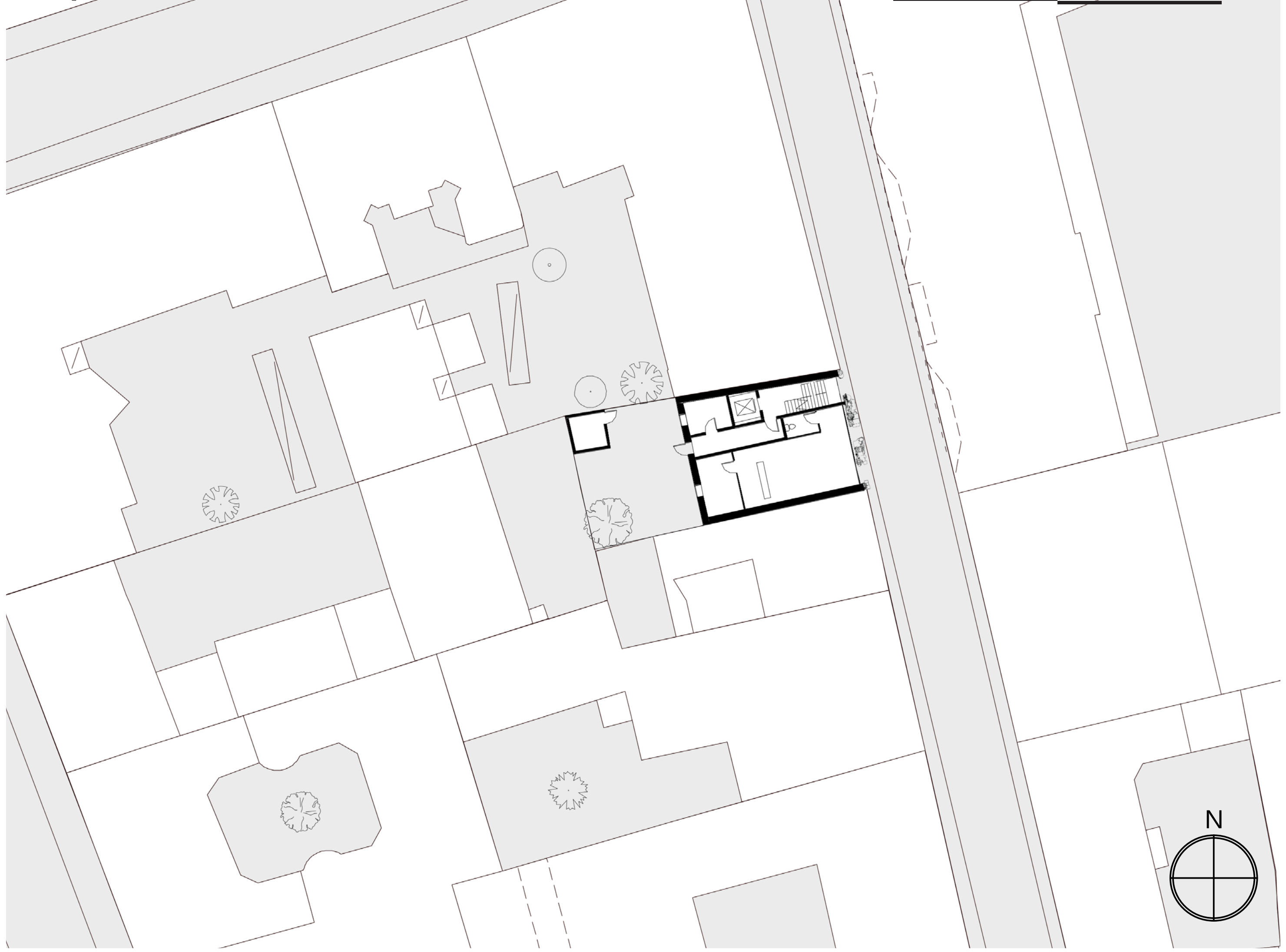
When choosing what objects to use for the composition of the ornamental structure, I browsed through the 3D objects freely available at various web pages. Since ornaments historically often depict natural motifs, such as plants, animals and humans, I thought it would be interesting to use those kinds of objects. Amongst the objects used are sharks, carrots and skulls. I did however not only restrict myself to that theme, but also included everyday objects such as cars, cups and baseball bats. I also used elements from popular culture, such as characters from animated TV shows. I included these kinds of objects to investigate what ornament could look like when using motifs from our present day culture.
This choice also firmly places this design iteration in a more forward-looking position, rather than a reactionary one, merely wishing to imitate the formalism of pre-modernist ornament.
As noted by Pop Artists, new meanings and interpretations can emerge when putting objects in new settings and combining them into juxtapositions. The three-dimensional aspect of the kitbashed facade makes this multitude of meanings even richer, since looking at it from different angles can result in very different views.
I do however think that the strongest quality of the facade is not in its ability to include recognizable objects or to send explicit messages through signs, but in its visceral effect. The overall result when merging all these representational elements together is an abstract whole. In itself, the high level of complexity created by the multitude of elements gives a direct visual sensation. In this regard the facade operates at several scales, from the smallest detailed objects to the shape of the whole branching structure. Personally I find this facade design exciting and I think there is beauty in its chaos. To emphasize this, I deliberately made the branching structure break away from the underlying grid of walls and floors.

The choice of recycled plastic as a material was due to the relative ease to use it for highly detailed objects. I took inspiration from Greg Lynn's BlobWall, using it as a reference for the construction. The material choice was also due to plastics potentially recycled nature, since it could add an aspect of sustainability to the topic of ornament, which otherwise might be seen perceived as unnecessary and wasteful.

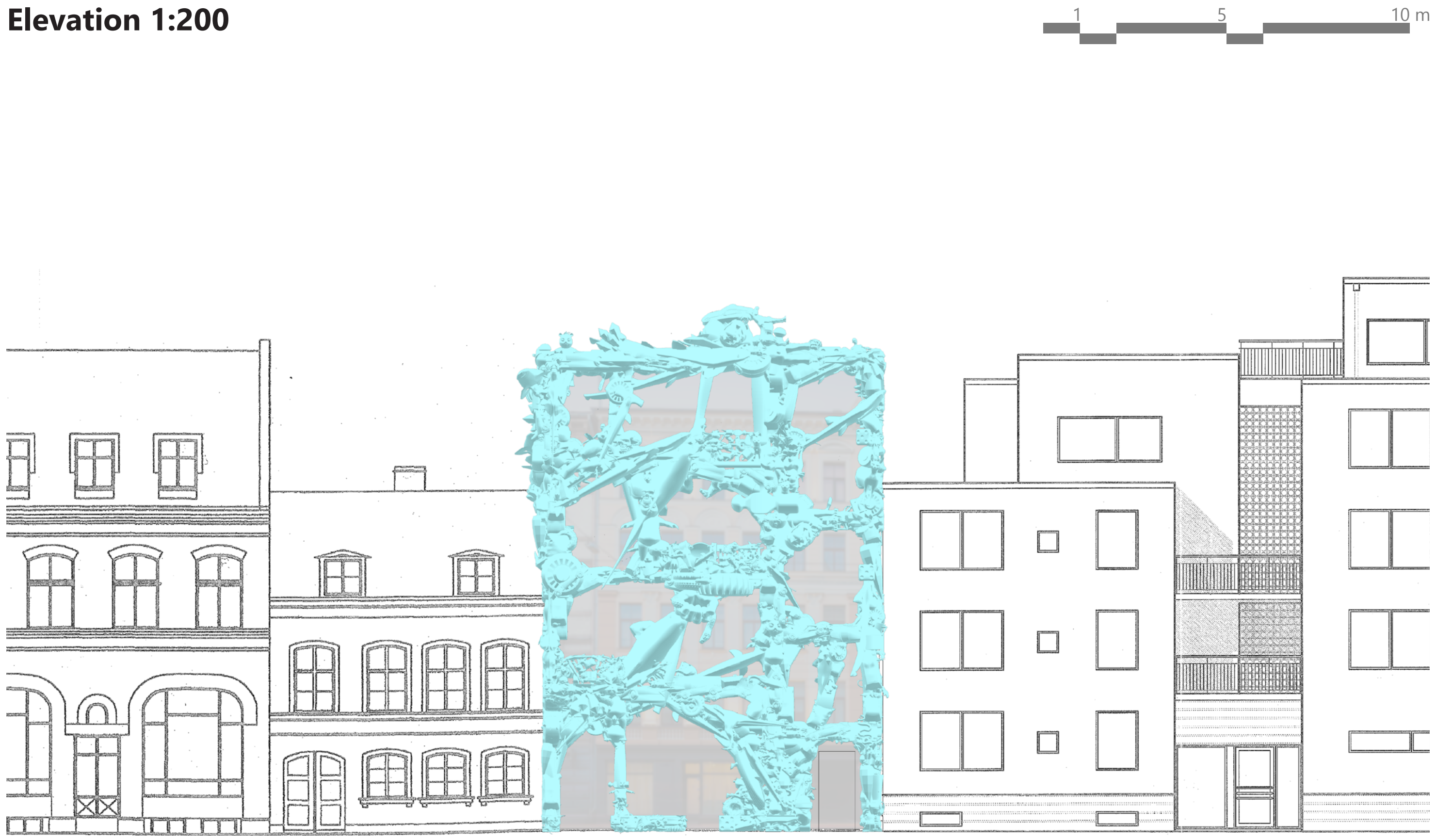
Design Study

The facade structure hides the mullions at the meeting of two planes of glass in the window-wall. In that way it is curiously reprising its role as a concealer of joints, as was often the case in the past. It is also acting as a unified device, hiding the connection between window and wall, as well as draping around the facade, even on its sides to some degree.
The strategy of incorporating the ornaments into benches and balconies could obviously be used in other types of digital design as well, benefitting from making ornament part of the structure, as well as engaging directly with the user when you can sit and stand on the ornament itself.
Not far from the "ready-mades" in the writings of Venturi and Scott-Brown, the digital downloadable 3D-object is the "ready-made'' of today's digital culture, available for use in new contexts and new combinations.

Site plan 1:400



Elevation 1:200

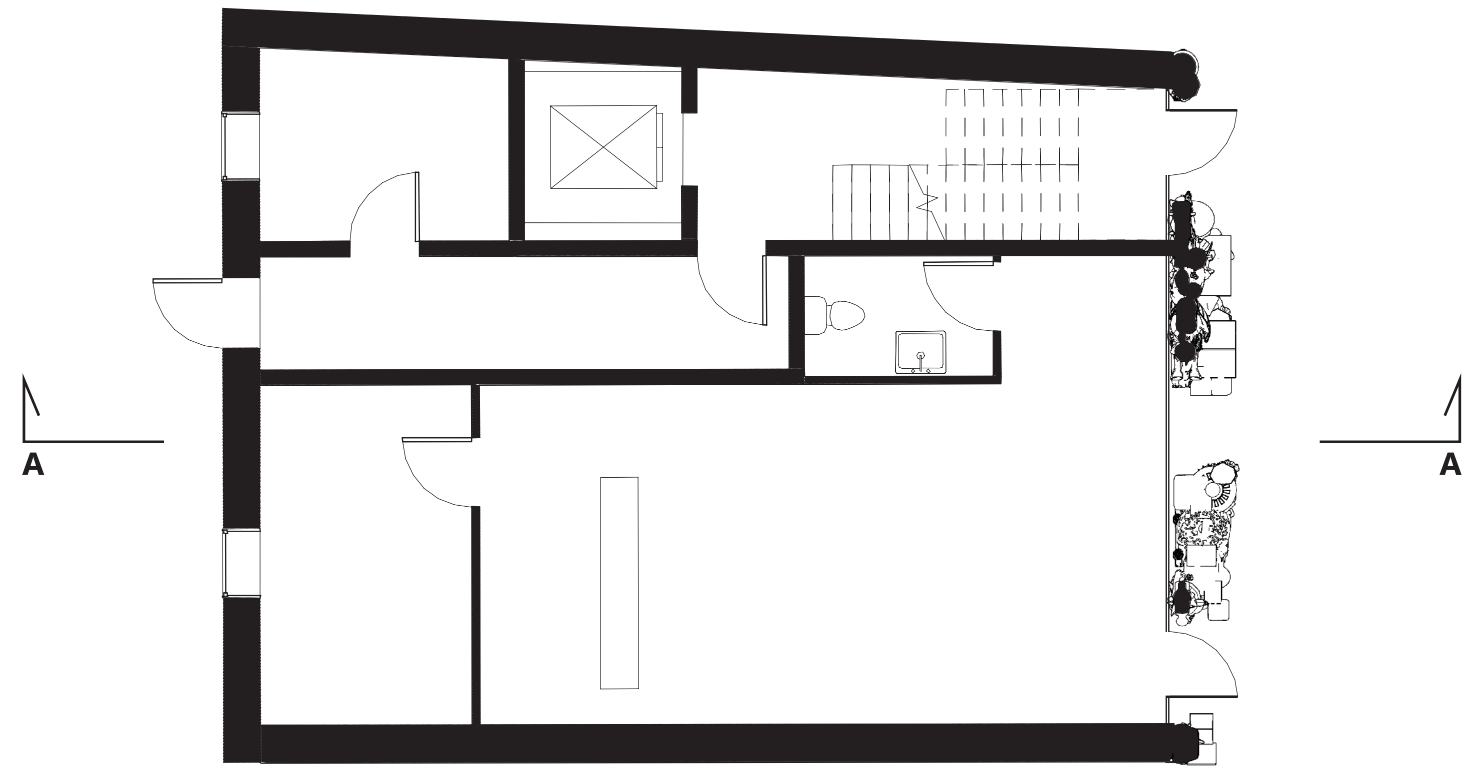


This design has some parallels to Casa Mila, by architect Antoni Gaudi. Its facade is also free-standing, which was very modern for its time. It also has elements of re-use, with the balconies having recycled scrap metal as its material. (Enric 2021)

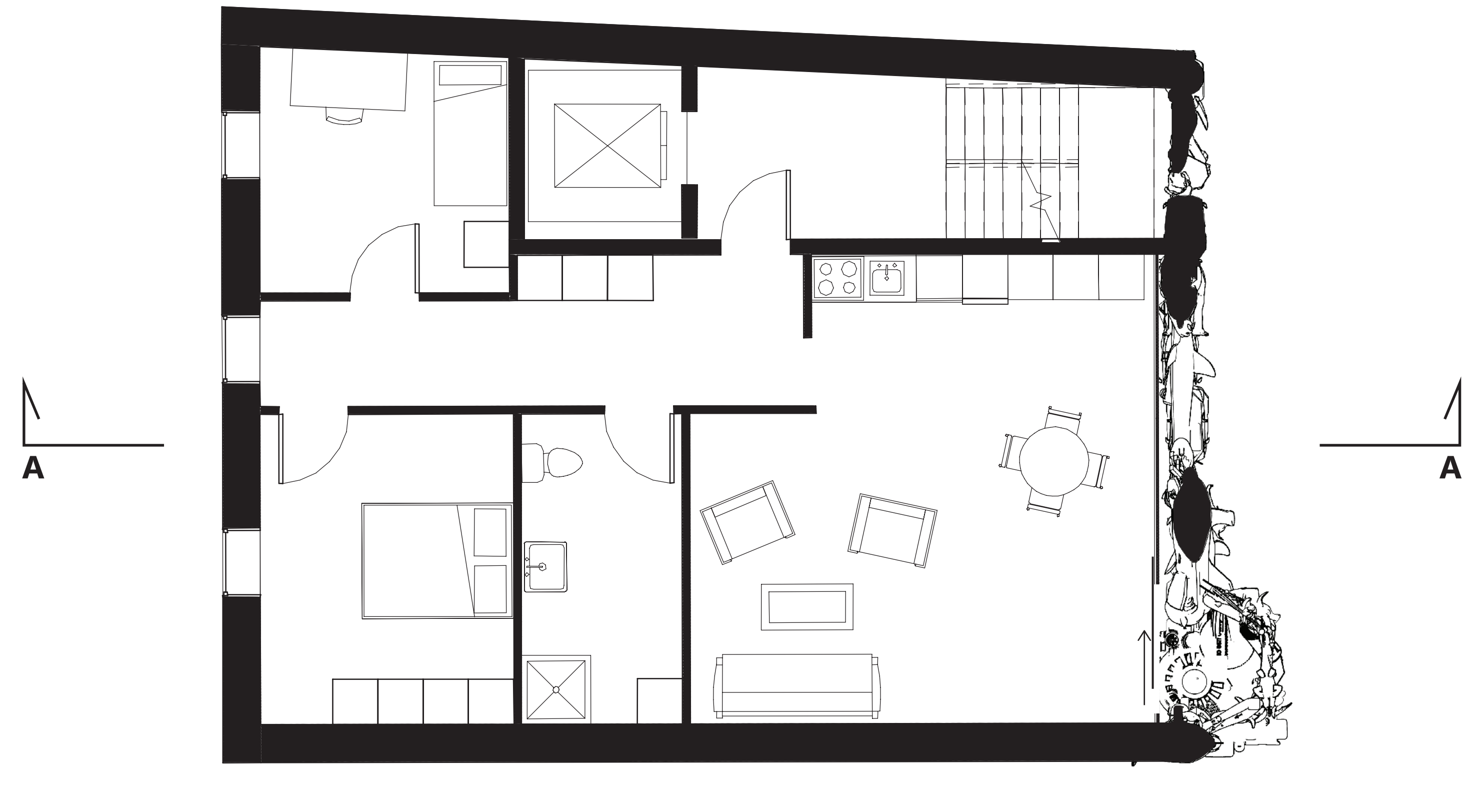
Design Study

Floorplans 1:100

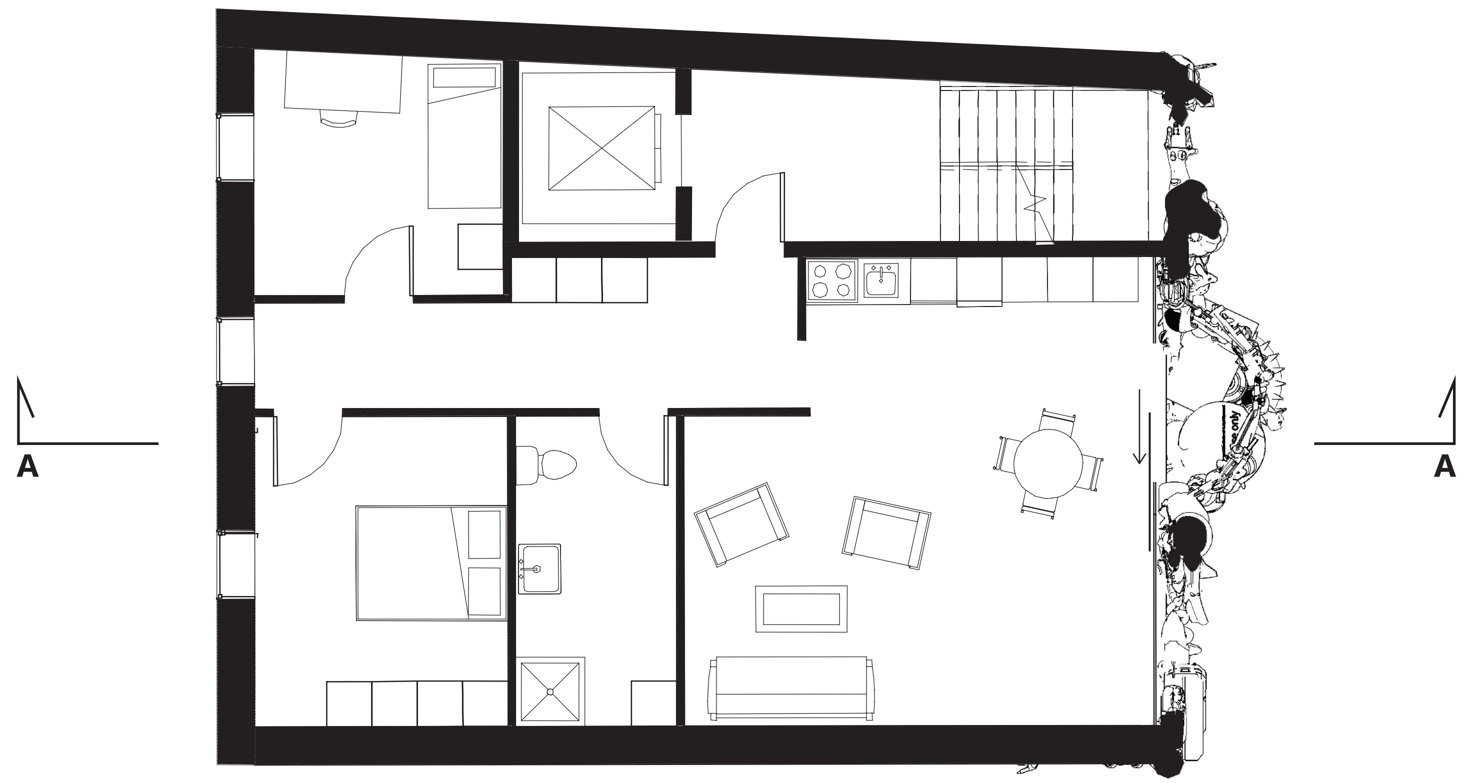
1 5 10 m



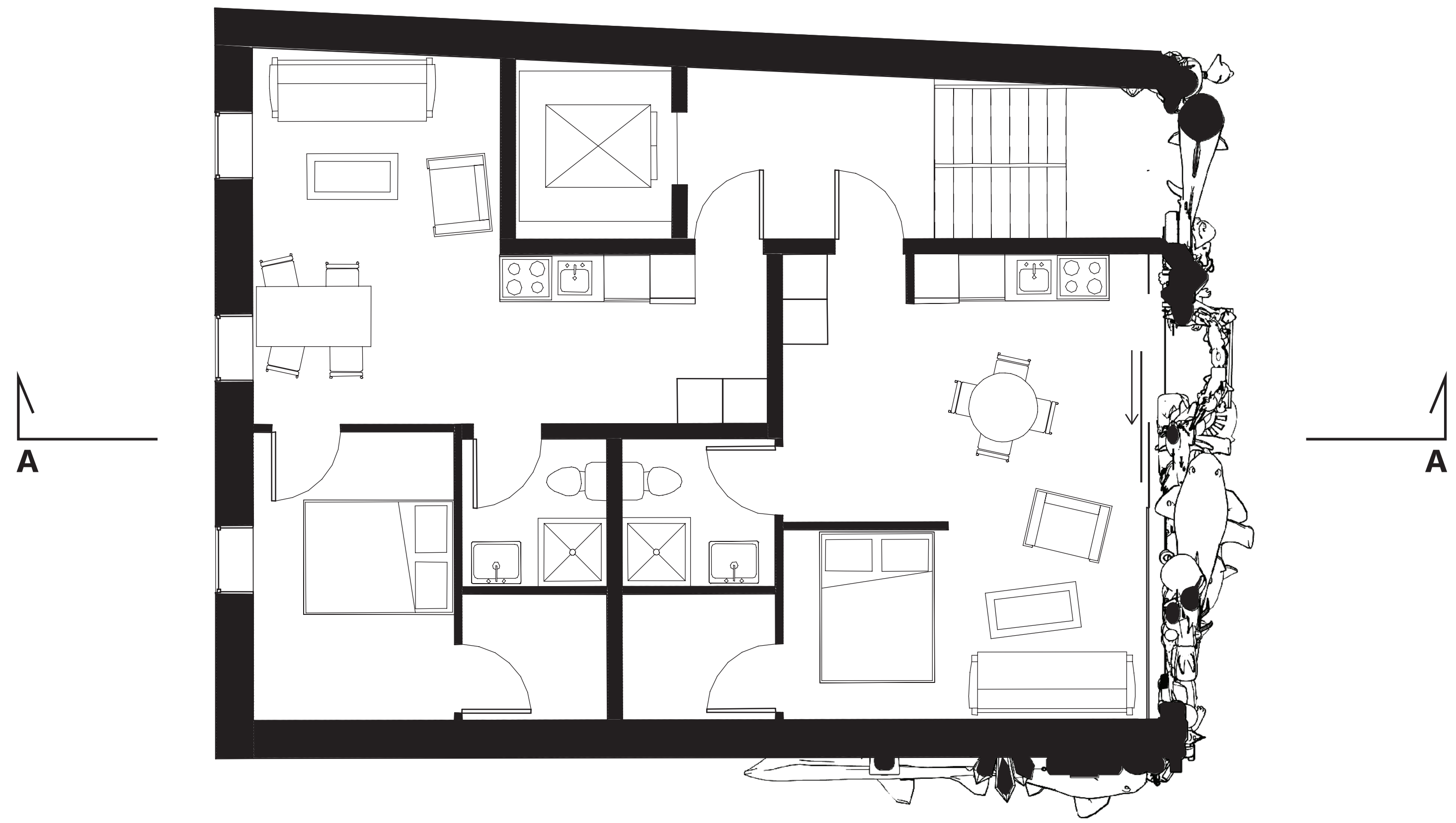
Ground Floor - Commercial Space



Level 2 - Apartment



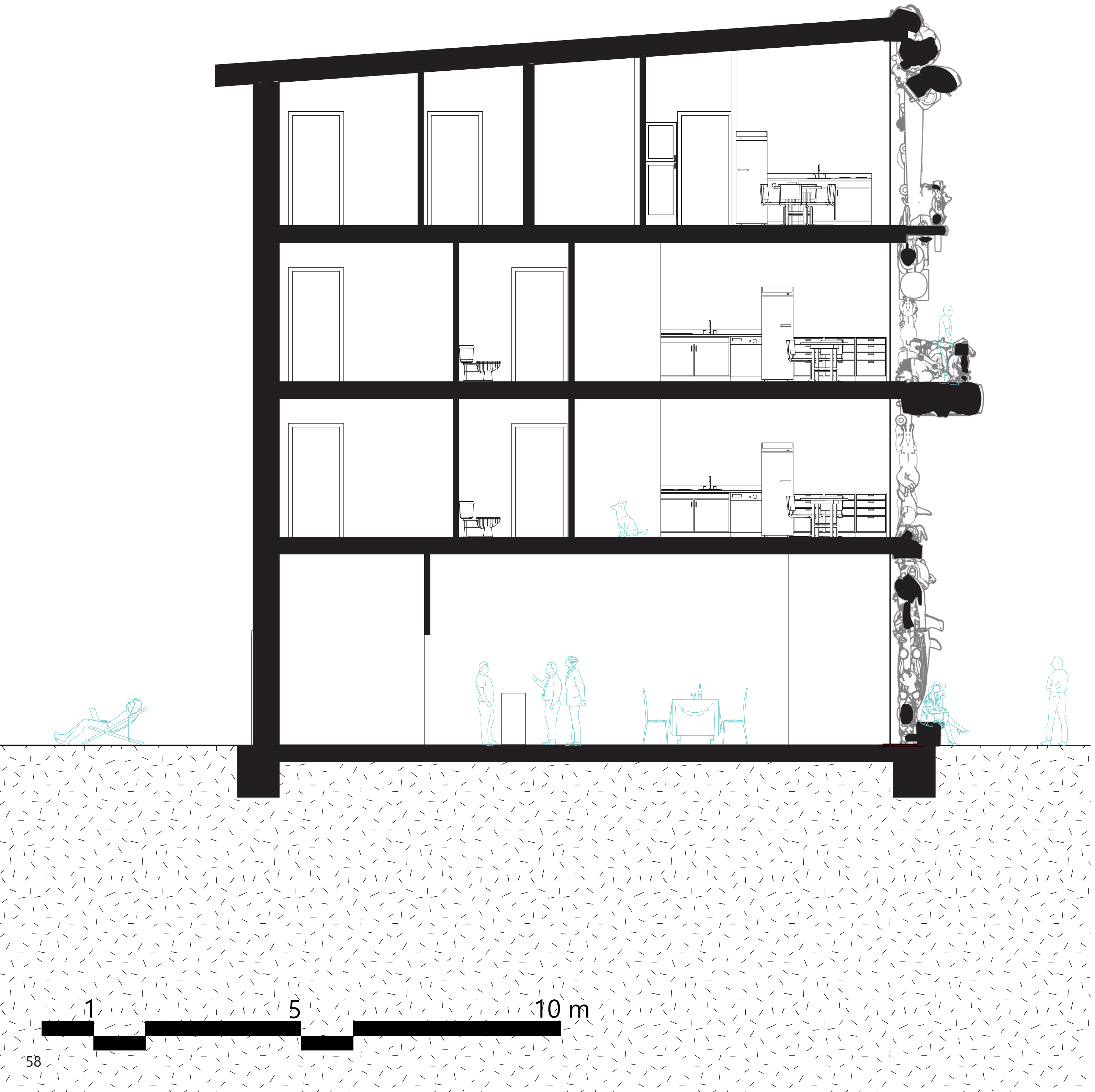
Level 3 - Apartment



Level 4 - Apartments

Design Study

Section 1:100



[...]"Since the inside is different from the outside, the wall - the point of change - becomes an architectural event. Architecture occurs at the meeting of interior and exterior forces of use and space [...]"

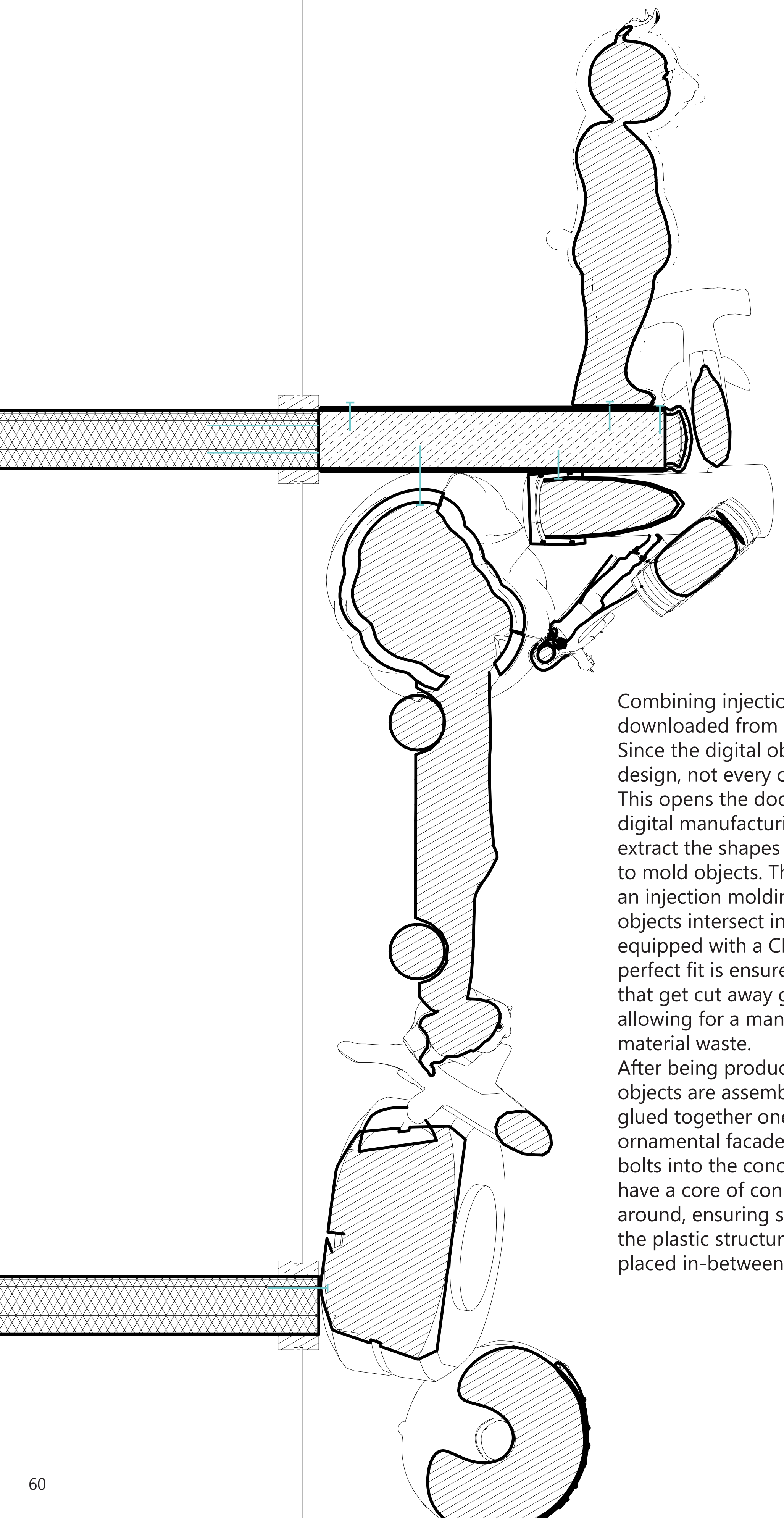
Robert Venturi (1977)

The building is designed all according to municipality regulations and plans for the site, such as having a storefront ground floor and 4 apartments in 4 levels. The facade has a role to play in the use of the building by the people inhabiting it as well as walking past it in its urban context. Since the facade structure makes up the balconies, they are directly usable by the residents. They also get to enjoy the sculptural quality from the inside as windows cover the whole openings between the walls, and the kitbashed facade is placed in front of it. The digital objects have now become physical in plastic, and together they make up a facade including benches at ground level. The facade is ornamental and complex akin to the work of craftsmen, yet it is a facade that is modernistic in that it is a free standing non-structural element, not crucial for the building's load-bearing construction.

Sunny Hills by Kengo Kuma served as a reference for being essentiallly a glass box surrounded by a structure (Kengo Kuma and Associates 2018)

Design Study

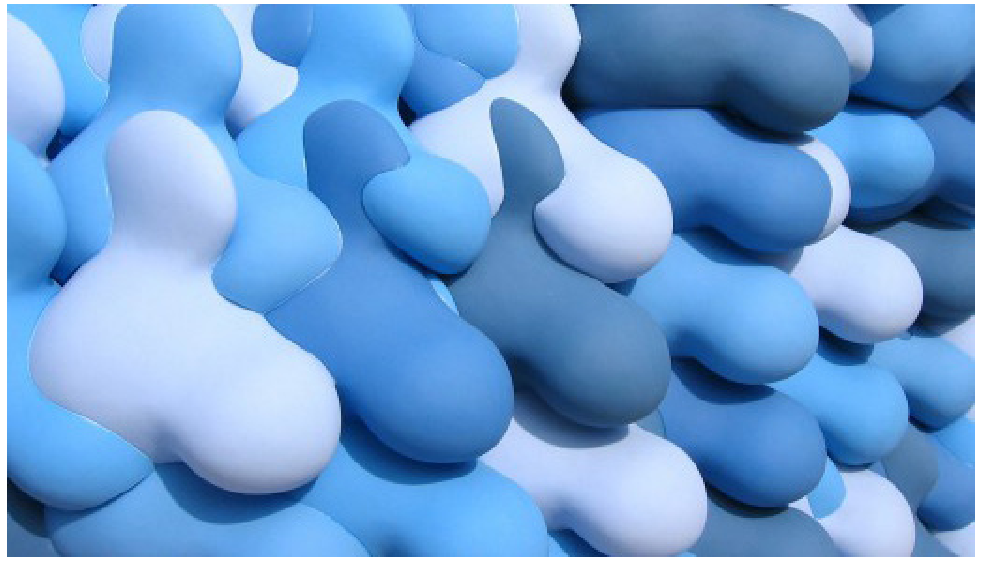
Detail 1:20



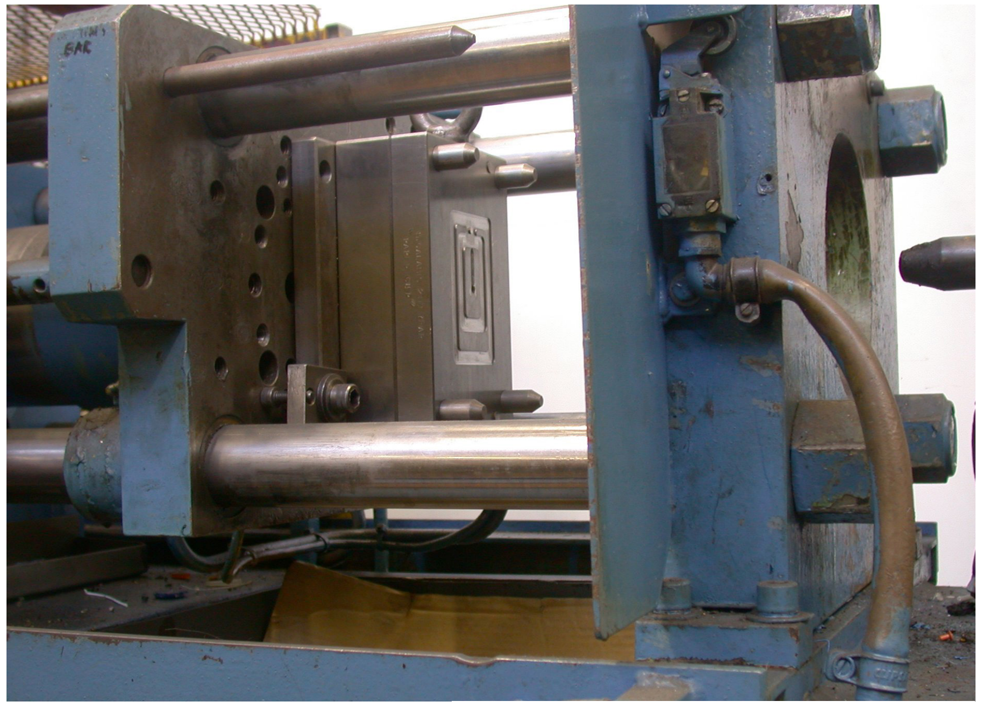
Combining injection molding with CNC cutting, the objects downloaded from the internet can now take physical form. Since the digital objects are used many times in the facade design, not every object needs to be uniquely manufactured. This opens the door for a hybrid of mass-production and digital manufacturing. From the digital models, we can extract the shapes of the dyes, the negative forms used to mold objects. Then the plastic object is created with an injection molding press. After finding the seams where objects intersect in the design, we can feed a robotic arm equipped with a CNC cutter this information. That way a perfect fit is ensured for the later assembling. The parts that get cut away get melted and reused for new objects, allowing for a manufacturing process with virtually no material waste.

After being produced in a controlled factory setting, the objects are assembled at the construction site. They are glued together one by one with epoxy glue, building up the ornamental facade. The plastic objects are fastened with bolts into the concrete structure. Balconies and benches have a core of concrete, with plastic objects “wrapped” around, ensuring stability. The windows are placed behind the plastic structure, rather than being many small windows placed in-between the “branches”.

0,5 1 m



Greg Lynns Blobwall served as reference for the design (Lynn 2007)



Injection molding of plastics. (McKechnie 2005)

The many ornaments of function

Kitbashing was the only approach in the study that used representational objects in any way. By trying out the technique I encountered the problem any designer faces when working with recognizable objects or images: what do the motifs selected symbolize?
When designing with parametric patterns, I did not feel the reluctance or doubt in what theme I should use, or what meaning there is to the shapes. Although there are patterns with cultural associations, I felt as if I could mostly focus on an unproblematic aesthetic choice of forms. I experienced this as a somewhat easier approach as a designer, with the goal of creating something decorative and beautiful, not depending on having any deeper meaning to be enjoyed by the viewer and user.
But by avoiding the question of symbology or cultural connection, a designer might miss out on the potentials of representational objects in ornamentation. In using recognizable objects, images or patterns, subtly or explicitly, themes can be embodied, expressing functions, relating to context or connecting to culture and history. In this way, ornamentation can serve as a device giving more value and dimension to architecture.
Kitbashing has the ability to be abstract in its overall shape as well as incorporating recognizable objects. In this, it has the strength to be both enjoyed viscerally as well as intellectually. A similar effect could potentially be achieved with patterns incorporating and deriving images or symbols.
In my design study, I didn't use any conscious reference to traditional ornament such as capitals, but elements such as the pillars in the smocking iteration are on their surface reminiscent of classical columns. By mere geometric complexity, some of the digitally conceived ornaments are akin to the decorations of the pre-modern days, standing in sharp contrast to the expressions of the industrial era and Modernist architecture.

Several of the design approaches in the study use parametric scripts. This allows for the rapid creation of several versions of a design, easily adjustable and adapting circumstances. In this way, parametric design is a form-finding device rather than a tool for drawing. Thus, in its essence, parametric scripts can perform something different from the manual design process. This makes otherwise tedious designs easy to achieve, as drawing each of them manually would have taken a long time. It is also possible to embed parameters such as production constraints into the design early in the process, making the design and manufacturing more closely correlated. As randomness can be introduced as a factor in parametric design, it has the ability to create forms outside of our imagination. Since the process can have fixed parameters as well as randomized ones, it has a capability to provide architecture with novel shapes, yet controllable for the desired complexity or scale level. Thus, digital manufacturing can generate an intricacy akin to handcraft or reminiscent of pre-modern ornamentation, yet without being a pastiche or merely copying. However, not every design used parametric scripts, showing that ornaments can be created through various means, and that digital manufacturing is not limited to parametric processes.

As I did not implement the manufacturing processes in reality, I did not have the experience of physically fabricating the designs. My thesis is therefore closer to design than fabrication, albeit using aspects of fabrication as starting points for the design approaches. This may have led to a simplification of the digital manufacturing process, as I might have encountered more questions of the details regarding the implementation of the different design iterations the closer I got to their physical realization. For example, the calibration of the properties of concrete was quite difficult even in a rough simulation in the computer. I can only imagine how difficult it must be to precisely calibrate to perfectly match physical reality. Yet, in Annie Locke Scherers research, she has shown it to be possible. I used reference projects like hers to provide real life examples for every manufacturing approach. None of the design iterations uses any kind of lush or luxurious material as its source for beauty. It is rather in the way the material is shaped that gives the designs extra aesthetic value. Digital manufacturing can therefore be said to have an ability to transform everyday objects such as pipes or material such as concrete into something extraordinary.

Results

Obviously, kitbashing is not the only way to achieve ornamented balconies, and parametric patterns is not the only way to design sunscreens. These are design choices I made in the study of digital manufacturing methods.
Yet, the act in itself of correlating decoration and function, provides ornament with more substance. By making ornament part of a structure or giving it a specific performative function, ornament receives more roles to play, and maybe more reasons for it to exist. The functions can range from blocking out the sun, to being a structural element, to helping the reading of a space. These functions give ornament something to correlate to and inspire its shapes.
My design of the kitbashed facade is seemingly a structure in itself. Alas, it is "lying" in that it is actually supported by concrete structures for balconies and benches. This was due to me doubting the strength of the structure. This leads to the ornamental structure rather being wrapped around the construction than being one with the construction.
The design iteration using smocking could be said to be an embellishment of the structure, unified by the material concrete. With its columns and pilasters, I think I managed to mix structural and non-structural elements in a believable way, through uniting them by appearance, similarly to the "Bird's Nest'' by Herzog & de Meuron.
The 3D printed design iteration is fully structural, not only self-supporting but also holding up the roof. The scale of this 3D printed design is perhaps making it closer to spatial than ornamental. More sculptural than decorated, it is shaping the space of the exterior and interior, with its curved forms and openings.
This correlation to space is evident in the other design iterations as well, with openings defined in the randomized growth pattern, or sunscreens being layered and adjustable to shape the density of the wall and the interior layout.
Some of the design iterations engage with shadows and light. The patterns for sunscreens does so by filtering it into the interior. The kitbashing and smocking approaches do so in their three-dimensionality, engaging with shadows and lights during the day, resulting in a more varied facade expression. I think this adds one more dimension to the articulation and beauty of the facade, as opposed to flat patterns on facades such as Eberswalde Library.

For the design study, I used one approach at a time, letting me concentrate on aspects of each of them in my design iterations. By combining the techniques or adding additional ones not used in the design study, a richer facade design with stronger articulations could be made.
It is not hard to envision for example the kitbashing technique being implemented on the ground floor only, articulating its commercial space inside and being closer to the viewer walking by.
Similarly, tools like CNC engraving machines could be used to make the metal boxes of the 3D printed facade more ornamental and obtain a wider range of detailing levels.
The ornaments could also be used more strategically, like the randomized growth not being uniform over the facade but articulating certain areas with a higher complexity level.
The function of the building that I used for the design study was already defined by the municipality. Perhaps another function with a more high-profile characteristic would be a more suitable match for some of the design iterations. Especially the kitbashed facade design might in its extravagance be more motivated for a museum or a flagship store looking to obtain attention.

In digital manufacturing, there are potentials for sustainability. Additive processes like 3D printing are virtually without material waste. With material choices such as recycled plastic, a more sustainable production can be achieved. Any element not clearly having a function might be criticized for being wasteful, especially in our days. Making ornament and function converge is one way to give it more credibility. But there are also unfathomable values to architecture.
Ornamentation can contribute to the beauty of a building, lending it character, or expressing something beyond its mere existence. In these immeasurable ways, ornament can give value to architecture. A building loved for its appearance or typical for a time period, is less likely to be torn down. This is especially relevant as ornamentation now can be created with the tools typical of our age: digital ones. Through this, ornament in the digital age expresses its time.

Reflection

In my design study, I experienced a tendency in digital manufacturing that the design and fabrication processes blend, with the characteristics of a material or a production method being present already in the early stages of the design.
I think there are also big opportunities for hybrids between conventional and digital manufacturing, as several of the examples in the design study showed, the digital can be either fully integrated throughout a building process, or partly, in its design or its fabrication.
I hope to see more physical implementations of ornamentation through digital means in the future. It would be very interesting to see examples of randomness to introduce new geometric complexity, or representational images and objects in more ways than shown in this thesis. I hope to see an architecture in the future that is celebrating new technology through expressions not emulating the past, whether a hand-crafted or a standardized mass produced one. And especially one that dares to be decoratif.

I personally think that I mainly appreciate old forms of ornament because of their complexity in form and intricate detailing level, rather than any symbology or tectonic expressions involved. Whether inspiration comes from nature or from the classical orders, I think it is the will to ornate in itself that makes these buildings special. Ornament acts as a bringer of complexity, and as an agent of widening the range of scales, from the big shapes of a whole building, to the fine details articulating elements and facades. Digital manufacturing can offer this complexity and variation of the architecture of pre-modern days.
Yet, any kind of symbology could add an extra dimension to the direct visual sensation of architecture. Ornament can serve as a sign of the times, in an ambition to express aspects of society at the time of its creation. The inclusion of themes from the present day ensures the legibility of the ornament as one of the digital age and not of the handcraft era. As does material choices, with recycled plastic being in sharp contrast to the stone and plaster ornaments of the past.

My hope is also that ornament becomes more widely recognized for its use as a strategy for articulating features of architecture or helping the legibility of the built environment. Ornamentation is the act of making utility beautiful through decorative expression, and can perform in many ways simultaneously. However, an element being a mediocre sunscreen and a mediocre decoration at the same time is not enough, It needs to be at least sufficiently functional in both roles.
It shouldn't claim to be the optimal solution for just one of the problems and neglecting the other, but a convergent element, correlating to several aspects. Such is the nature of architecture, at the crossroads of function, space and beauty. Architecture cannot validate itself in purely technical terms.
When the structure is ornamental in itself, ornamentation comes to signify the act of shaping utility in a beautiful way, rather than decorative objects added to a structure. Ornamentation, then, is central to the practice of architecture, as the act of rendering utility beautiful. This is opposed to the role of an engineer, for whom measurable problems are to be solved.

Aesthetically, digital manufacturing techniques can offer architecture with new expressions. It is especially interesting to me how a high level of complexity can be achieved. In its customization and possible geometric complexity it is similar to pre-modern handcraft, but without becoming any kind of pastiche of bygone eras. The computer has the potential to contribute as a co-designer in various ways, giving the design something novel, avoiding formal copying of earlier styles. By having a more seamless connection between design and production, the architect could get more control over the process as well as a much closer relationship to material. I think this provides confidence as well as an authority to realize ideas that might have met struggles in conventional construction. There is also a strong cultural connection between these new digital fabrication methods and society today as a whole, characterized by the digital and physical blending in every aspect of life. In that way an architecture who is aspiring to reflect its times, cannot avoid the digital as a theme for expression.
Digital manufacturing is not only working as the tools for physically producing variation or ornaments, but also as the theoretical tool to challenge the current paradigm. Just as machine logic of mass-production justified modernist aesthetics, digital tools can provide with the production logic that allows an aesthetic of irregularities and higher complexity.

To me, ornaments add beauty to the utility of a building and make an urban setting more interesting. I am inclined to believe, like Semper and Jones, that the will to decorate is universal and timeless. Today, through digital means, we can direct this primal instinct into envisioning new forms for architecture.

(Jones, 1868)

Bibliography

Balık, D. & Allmer, A. (2017) Simulating Craftwork in Contemporary Architecture. The Journal of Modern Craft, 10(1), pp. 37-57.
doi: 10.1080/17496772.2017.1294324

Baltus, R, (n. d.) The return of ornamentation in architecture: for what purpose? To express
What? https://www.vmzinc.lt/news/10000010-the-return-of-ornamentation-in-architecture-for-what-purpose-to-express-what.html [2022-05-26]

Blanchi, Y., Lequay, H.& Marin, P. M. (2011). Thinking With Computers and Fabricating With Machines. In
Proceedings of the International Symposium on Algorithmic Design for Architecture and Urban Design. Tokyo, Japan, March 14-16, 2011.

Carpo, M (2014). Breaking the curve: Big data and design. Artforum, 52(6)

Christiansen, K. (2016). Digital Fabrication – Back To The Future! Digital Fabrication in Tomorrow's Architecture. OPEN ROOM publication series, 3. Aarhus, pp. 48-53.
ISBN: 978-87-90979-59-1

Sedrez, M & Celani, G. (2017). The new ornament in architecture. Generation of complexity and fractals. Arquitextos, 204(1)
ISSN 1809-6298

Domiesen, O. (2008a) Beyond White Walls. Architectural Design, 78(6).
https://doi.org/10.1002/ad.786

Domiesen, O. (2008b). Communicating Content. Archis, 17(3).

Domiesen, O. (2008c). Ornament and redemption. In Ornament Neu Aufgelegt/Re-Sampling Ornament. Pp 6-10. Basel: Switzerland, June 1 - September 21, 2008.
ISBN 978-3-85616-371-6

Domiesen, O. (2018) Ornament - Architecture's second nature. In (eds.) Colletti, M & Peter Massin, P. Meeting nature halfway. Architecture interfaced between technology and environment. Innsbruck: Innsbruck University Press

Domiesen, O. (2013). Back to the future: The rewriting of history. Archithese, (4).
ISBN: 978-3-7212-0883-2

Ferguson, F (2008). Dance of the Veils. In Ornament Neu Aufgelegt/Re-Sampling Ornament. Pp 59-60. Basel: Switzerland, June 1 - September 21, 2008.
ISBN 978-3-85616-371-6

Hearn, F. (2003). Ideas That Shaped Buildings. Cambridge, Massachusetts: The MIT Press
ISBN 0-262-58227-9

Heath, T., Smith, S. & Lim, B. (2000) The Complexity Of Tall Building Façades. Journal of Architectural and Planning Research, 17(3), pp. 206-220.

Heathcote, E. (2015). Ornament is the language through which architecture communicates with a broader public. https://www.architectural-review.com/essays/ornament/ornament-is-the-language-through-which-architecture-communicates-with-a-broader-public [2022-05-26]

Humphrey, C & Vitebsky, P. (1997). Sacred Architecture. London: Duncan Baird Publishers
ISBN: 1-900131-70-6

Jensen, S (2016). Digital Fabrication. Digital Fabrication in Tomorrow's Architecture. OPEN ROOM publication series, 3. Aarhus, Pp. 38-47.
ISBN: 978-87-90979-59-1

Jones, O. (1868). Grammar of Ornament. Piccadilly, London: Bernard Quaritch.

Larsen, N. M. (2014) To Generate Architecture. Platform Digital Tectonics. Aarhus: Arkitektskolens Forlag.
ISBN: 978-87-909-7937-9

Leatherbarrow, D & Mostafavi, M. (2002) Surfaces Architecture. Cambridge, Massachusetts: The Mit Press
ISBN 0-262-13407-1

Locke Scherer, A. (2019). Concrete Form[ing]work: Designing and Simulating Parametrically-Patterned Fabric Formwork for Cast Concrete. In Architecture in the Age of the 4th Industrial Revolution, Proceedings of the The 37th Conference on Education and Research in Computer Aided Architectural Design in Europe / The 23rd Conference of the Iberoamerican Society Digital Graphics. Porto, Portugal, 11-13 September, 2019, pp. 759-768.

Loos, A (2002) Ornament and Crime. In (eds.) Miller, b & War, M. Crime and Ornament, The Arts and Popular Culture in the Shadow of Adolf Loos.

Maak, N. (2008). Ornament's New Promise. In Ornament Neu Aufgelegt/Re-Sampling Ornament. Pp 94-96. Basel: Switzerland, June 1 - September 21, 2008.
ISBN 978-3-85616-371-6

Malé-Alemany, M. & Sousa, J.P. (2005). On Ornamentation: A Digital Perspective. In 93rd ACSA Annual Meeting, The Art of Architecture/The Science of Architecture. Pp. 451-457.
DOI: 10.13140/RG.2.1.3231.7281

Marcos, C. L. (2011) New materiality: ideation, representation and digital Fabrication.
In eCAADe Conference Proceedings, Ljubljana: Slovenia, September, 2011, pp. 351-360.
ISBN 978-9-4912070-1-3
doi:10.52842/conf.ecaade.2011.351

Moussavi, F. (2008). The Function of Ornament. Harvard: ACTAR
SBN-10 8496540502
ISBN-13 978-8496540507

Naboni, R. S. & Paoletti, I (2015) From Component to Process Customization in the Construction Industry. Milano: Politecnico di Milano, Building Environment Science & Technology, [Evo]cative Research Lab.

Oxford Languages (n. d.) Ornamentation.
https://www.google.com/search?q=ornamentation [2022-05-26]

Pell, B. (2010). The articulate surface. Ornament and Technology in Contemporary Architecture. Basel: Birkhäuser GmbH.
ISBN: 978-3--0346-0221-1

Picon, A (2013). Ornament: The Politics of Architecture and Subjectivity. Chichester: Wiley.
ISBN: 978-1-118-58824-6

Picon, A (2016). Ornament and its Users: From Vitruvian Tradition to the Digital Age. In Necipoglu, G. & Payne, A. (eds.) Histories of Ornament: From Local to Global, pp. 10-19.
Princeton: Princeton University Press.

Schumacher, P (2009) Parametric Patterns. Architectural Design, 79(6), pp. 28-41.

Stadsbyggnadskontoret Malmö Stad. (2021). Underlag Till Begäran Om Planuppdrag
Detaljplan för fastigheten Liljan 26 i Innerstaden i Malmö.
SBN-2016-656

Steele, B. (2008). Cutting, bending and stacking by code: Machines and ornament in architecture. In Ornament Neu Aufgelegt/Re-Sampling Ornament. Pp 26-28. Basel: Switzerland, June 1 - September 21, 2008.
ISBN 978-3-85616-371-6

Strehlke, K. & Loveridge, R. (2005). The Redefinition of Ornament. Using Programming and CNC Manufacturing. Switzerland: Department of Architecture, Swiss Federal School of Technology

Sullivan, L. (1892). Ornament in architecture. The Engineering Magazine.

Søndergaard, A. & Borup, R. (2014). Teaching Digital Experimentation. In Larsen, N. M. (ed.) Digital Tectonics. Aarhus: Arkitektskolens Forlag, pp 6-15.
ISBN: 978-87-909-7937-9

Twemlow, A (2005). The decriminalisation of ornament. EYE Magazine, 58(15).

Venturi, R (1977) Complexity and Contradiction in Architecture. Second Edition. New York: The Museum of Modern Art.
ISBN 0-87070-282-3

Österlund, T. (2016). Digital Timber Fabrication – Digital Craftsmanship. In Larsen, N. M. (ed.) Digital Fabrication in Tomorrow's Architecture. Pp. 16-27.
Aarhus: Arkitektskolens Forlag
ISBN: 978-87-90979-59-1

Photos and illustrations

Ahsmann, M (2014). File:20140723 Postmodern apartment buildings in Helmond 06.jpg [Photo]
https://commons.wikimedia.org/wiki/File:20140723_Postmodern_apartment_buildings_in_Helmond_06.jpg [2022-05-26]

AMOB Group (2016). Cnc Tube Bending Machine To The Scandinavian Piping Industry [Photo]
https://www.amobgroup.com/en/cnc-tube-bending-machine-to-the-scandinavian-piping-industry/ [2022-05-26]

AsVL3 (2008). File:John Lewis pattened facade.jpg [Photo]
File:John Lewis pattened facade.jpg - Wikimedia Commons [2022-05-26]

Beyond My Ken (2011). File:40 Bond Street entrance.jpg [Photo]
https://commons.wikimedia.org/wiki/File:40_Bond_Street_entrance.jpg [2022-05-26]

Chakraborty. P (2017). File:Linderhof Palace (front view) - Bavaria.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Linderhof_Palace_(front_view)_-_Bavaria.jpg [2022-05-26]

Crocker, J (2010). File:2010-07-04 1880x2820 stlouis wainwright building.jpg [Photo]
https://commons.wikimedia.org/wiki/File:2010-07-04_1880x2820_stlouis_wainwright_building.jpg [2022-05-26]

Dalbéra J. P. (2018). File:Le magasin Louis Vuitton Matsuya Ginza (Tokyo) (28834352748).jpg [Photo]
https://commons.wikimedia.org/wiki/File:Le_magasin_Louis_Vuitton_Matsuya_Ginza_(Tokyo)_(28834352748).jpg. [2022-05-26]

Delcam Plc (n.d.). File:PowerMILL robot interface.jpg [Photo]
https://commons.wikimedia.org/wiki/File:PowerMILL_robot_interface.jpg [2022-05-26]

Enric. (2021). File:169 Casa Milà (la Pedrera), pg. de Gràcia 92 - c. Provença (Barcelona).jpg [Photo]
https://commons.wikimedia.org/wiki/File:169_Casa_Mil%C3%A0_(la_Pedrera),_pg._de_Gr%C3%A0cia_92_-_c._Proven%C3%A7a_(Barcelona).jpg [2022-05-26]

Fernandes, G. (2015). File:Edifício seagram (16323245586).jpg [Photo]
https://commons.wikimedia.org/wiki/File:Edif%C3%ADcio_seagram_(16323245586).jpg [2022-05-26]

Giel, I (2005). File:FH-Eberswalde Bibliothek Fassade.jpg [Photo]
https://commons.wikimedia.org/wiki/File:FH-Eberswalde_Bibliothek_Fassade.jpg [2022-05-26]

Hansmeyer, M (2008) Platonic Solids [Photo]
https://www.michael-hansmeyer.com/platonic-solids [2022-05-28]

Hansmeyer, M (2010) Subdivided Columns [Photo]
https://www.michael-hansmeyer.com/subdivided-columns [2022-05-28]

Heidelberg Cement (n.d.) Sweden's first 3D-printed house [Photo]
https://blog.heidelbergcement.com/en/swedens-first-3d-printed-house [2022-05-26]

Holmstad, Øyvind (2017). File:Monoton modernist windows.jpg [Photo]
File:Monoton modernist windows.jpg - Wikimedia Commons [2022-05-26]

Juursema, J (2014). File:Felix 3D Printer - Printing Head.JPG [Photo]
https://commons.wikimedia.org/wiki/File:Felix_3D_Printer_-_Printing_Head.JPG [2022-05-26]

Kengo Kuma and Associates (2018). Sunnyhills' Apple [Photo]
https://kkaa.co.jp/en/project/sunnyhills-apple/ [2022-05-26]

Kumar, A (2014) File:Prime Tower skyscraper at Zurich Hardbrucke 03.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Prime_Tower_skyscraper_at_Zurich_Hardbrucke_03.jpg [2022-05-26]

Lascar. J (2008) File:Lascar Beijing National Stadium (Bird's nest) (4497567401).jpg [Photo]
https://commons.wikimedia.org/wiki/File:Lascar_Beijing_National_Stadium_(Bird%27s_nest)_(4497567401).jpg [2022-05-26]

Lascar, J (2014). File:Lascar The Beijing National Aquatics Center (Water Cube) (4475631690).jpg [Photo]
https://commons.wikimedia.org/wiki/File:Lascar_The_Beijing_National_Aquatics_Center_(Water_Cube)_(4475631690).jpg [2022-05-26]

Laurenatclemson (2008) File:Utrecht University library.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Utrecht_University_library.jpg [2022-05-31]

Locke Scherer, A (2021) CONCRETE FORM[ing]WORK: Design, Fabrication, Simulation and Correlation of Parametrically Patterned Flexible Formwork and Concrete.
ISBN 978-91-7873-962-2

Lynn, G (2007) Blobwall [Photo]
http://glform.com/environments/blobwall/ [2022-05-28]

Mark Foster Gage Architects (2014). Minion - Yale Seminar Research [Photo]
https://www.mfga.com/copy-of-fluid-point-processing [2022-05-26]

MartinD (2008). File:Van der Rohe Pavillion overview.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Van_der_Rohe_Pavillion_overview.jpg [2022-05-26]

McKechnie, G (2005) File:PlasticsInjectionMoulder-die.jpg [Photo]
https://commons.wikimedia.org/wiki/File:PlasticsInjectionMoulder-die.jpg [2022-05-30]

Michelpost (2005-2008) File:Villa Verbruggen1.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Villa_Verbruggen1.jpg [2022-05-30]

Milano, A. (2021). File:3D-printer arm for semi-automated construction of sustainable houses.jpg [Photo]
https://commons.wikimedia.org/wiki/File:3D-printer_arm_for_semi-automated_construction_of_sustainable_houses.jpg [2022-05-26]

Murray-Rust, A (2010) File:Nottingham Contemporary - geograph.org.uk - 1771481.jpg [Photo]
Alan Murray-Rust / Nottingham Contemporary / CC BY-SA 2.0
https://commons.wikimedia.org/wiki/File:Nottingham_Contemporary_-_geograph.org.uk_-_1771481.jpg [2022-05-31]

Paste (2007). File:30 St Mary Axe, 'Gherkin'.JPG [Photo]
https://commons.wikimedia.org/wiki/File:30_St_Mary_Axe,_%27Gherkin%27.JPG [2022-05-26]

Perez, D (2011). File:Astorga Catedral 04 by-dpc.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Astorga_Catedral_04_by-dpc.jpg [2022-05-26]

Praefcke. A (2007). File:Weissenhof Corbusier 03.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Weissenhof_Corbusier_03.jpg [2022-05-26]

Rhode Island School of Design Museum of Art (2016). File:1884 reception dress, silk satin and brocade with chenille fringe 08.jpg [Photo]
https://commons.wikimedia.org/wiki/File:1884_reception_dress,_silk_satin_and_brocade_with_chenille_fringe_08.jpg [2022-05-26]

Romero, F. (2017). File:Stuttgart - Neue Staatsgalerie (35736920402).jpg [Photo]
https://commons.wikimedia.org/wiki/File:Stuttgart_-_Neue_Staatsgalerie_(35736920402).jpg [2022-05-26]

Sarin, S (2015). File:Kumiko.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Kumiko.jpg [2022-05-26]

Schneider, M & Aistleitner, C (2008) File:Graz Kunsthaus.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Graz_Kunsthaus.jpg [2022-05-30]

Spiluttini, M (n.d.). Ricola-Europe SA, Production and Storage Building, Mulhouse-Brunstatt [Photo]
https://arquitecturaviva.com/works/nave-y-almacen-para-ricola-europe-sa-mulhouse-brunstatt [2022-05-26]

Taylor, K (2009). File:Barcelona Part Deux - 21 (3466071039).jpg [Photo]
https://commons.wikimedia.org/wiki/File:Barcelona_Part_Deux_-_21_(3466071039).jpg [2022-05-26]

Tomascastelazo (2011). File:Teatro juarez columns guanajuato.jpg [Photo]
https://commons.wikimedia.org/wiki/File:Teatro_juarez_columns_guanajuato.jpg [2022-05-26]

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