3

Typology and Search

In the second half of the past century a theoretical discussion on types and typology began to take shape and became an important part of architectural theory ever since. It is worthwhile to revisit some of these texts with a new point of view, thinking about digital tools and parametrical modeling. Giulio Carlo Argan in his 1963 essay "On the typology of Architecture" citing Quatremère de Quincy gives us a clear idea of the type and the Model:

> "Quatremère de Quincy gives a precise definition of an architectural "type" in his historical dictionary. the word "type", he says, does not present so much an image of something to be copied or imitated exactly as the idea of an element which should itself serve as a rule for the model:
>
> > . . . the model understood as a part of the practical execution of art is an object which should be imitated from what it is, the "type" on the other hand is something in relation to which different people may conceive works of art having no obvious resemblance to each other. All is exact and defined in the model; in the "type" everything is more or less vague. The imitation of "types" therefore has nothing about it which defies the operation of sentiment and intelligence."

(Argan 1963)

We can draw parallels between the type and the parametric model, as both being containers of a series of models or versions that have common characteristics but are all indeed different from each other. Each type has invariant characteristics that all of the instances contained in it share, in the same way as parametric models have invariants. All objects of a given type are different, they contain differentiating features in the same way parametric models do. In the case of parametric models these features are called parameters. Quatremère de Quincy also alludes to the use of types in relation to the "conception" of new works of art. Types are not just meant for abstract theoretical conceptions, but they are a part of the creative process as well.

This parallelism between types and parametric models has been mentioned by architects and critics in the past*, but what is important for this PhD research is how this parallelism can help us understand the role that parametric modeling and search algorithms can have in architectural design. We will try to trace a link between typology and design thinking.

Very important to our discussion on Search and Typology is the way Argan describes how a type is created or "formed". Argan illustrates this process in the following way:

> "The notion of the vagueness or generality of the "type" which cannot therefore directly affect the design of buildings or their formal quality, also explains its generation, the way in which a "type" is formed. It is never formulated a priori but always deduced from a series of instances. So the "type" of a circular temple is never identifiable with this or that circular temple (even if one definite building, in this case the Pantheon, may have had and continues to have a particular importance) but is always the result of the confrontation and fusion of a series of buildings having between them an obvious formal and functional analogy. In other words, when a "type" is determined in the practice or theory of architecture, it already has an existence as an answer to a complex of ideological, religious, or practical demands which arise in a given historical condition of whatever culture."

(Argan 1963)

Types are *deduced* not formulated a priori, we create them while looking into past buildings, the information we use to trace types resides in past

*see for example the conversation between Antoine Picon, Mario Carpo, Ingeborg Rocker and Michael Meredith at the end of their lecture entitled The Eclipse of Beauty: Parametric Beauty (Rocker et al. 2011).

experience. Argan talks about "formal and functional" analogies between these buildings, alluding that types do not only refer to formal characteristics, but they also are formed for functional or performance reasons. The final phrase in the previous paragraph is also key. By saying that when a type is determined, there is already an answer to complex demand, Argan is telling us that types become types because what we see in them is important information. We do not create types randomly, we create them to guide us in future experiences, to learn from the past. Commonly, the invariant characteristic that defines the type is embedded with "answers", with a virtue of some sort, in some cases this can be measured by some performance evaluation. This virtue might even be the reason why the type was formed in the first place. Successful building features are repeated, and soon enough types are formed.

In his essay "Typology and Design Method" Alan Colquhoun also alludes to the knowledge present in architectural types, and the designers ability to adapt it to the present:

> "In mentioning typology, Maldonado is suggesting something quite new and something that has been rejected again and again by modern theorists. He is suggesting that the area of pure intuition must be based on a knowledge of past solutions applied to related problems, and that creation is a process of adapting forms derived either from past needs or from past aesthetic ideologies to the needs of the present".

(Colquhoun 1969)

Alan Colquhoun is talking about intuition, the design knowledge present in the architect, and how it must be based on something else, past knowledge and its adaptation to present problems. Both Argan and Colquhoun present us with a dual outcome from the study of types: (i) an abstract knowledge of the types, their definition and relevance in architecture theory, and (ii) a more practical or operative use of the types, as containers of architectural forms and function. Aldo Rossi wrote about typology in many and varied forms, assigning types all kinds of values and ideals. In this small passage he talks about the function of types:

> "In all of these definitions it seems that the function of types is that of warning us in advance of what will be the future experience; in other words they enable us to anticipate the course

of the design process."[†]

(Rossi 1975)

Again in this passage we see the idea of anticipation, of advice from the past that is useful on foreseeing something in our project, the implication that the study of types has a function in the design process.

3.1 Typology and performance based Search

The two most important characteristics of types that we can take form the previous discussion is their outcome into (i) design knowledge and (ii) practical operative use. An analogy between types and parametric models was outlined above, as they both define the forms in invariant and variable elements. A more interesting analogy can be traced between the study of types and Search processes as proposed in this PhD thesis. Types are not only defined by their forms, but as Argan writes, by their formal and functional aspects. Parametric models on to themselves contain only geometry, but search processes give us performance based information on a large series of solutions. Functional descriptions of entire sets of solutions are the outcome of the search process, and from this outcome we can derive both (i) design knowledge on the set and (ii) practical operative information pertaining to a current and specific architectural project. From this point of view we can see a clear parallel between types and search processes.

Performance evaluations on their own, with no exploration involved, give us only knowledge on one particular aspect of a design solution, they do not give us much design knowledge or paractical information. Optimization processes, as opposed to search processes, give us very practical information on very detailed, specific and limited aspects of a present project, more generalizable design knowledge is not given.

The knowledge present in architectural types is quite varied in its nature. If we think back at Andrew Witt's studies on Design and Instrumental knowledge[‡], we can surely say that Types allude to both design and instrumental knowledge. Some Types allude to spatial values, some to technical

[†]Translated from: "In tutte queste definizioni sembra che (esprimendo i concetti in forma sintetica) la funzione dei tipi sia quella di avvertirci in anticipo di quale sarà l'esperienza futura; in altri termini essa ci mette in grado di anticipare il corso della progettazione."(Rossi 1975)

[‡]see section 1.6.3 in page 26 of this thesis, and his article "A Machine Epistemology in Architecture. Encapsulated Knowledge and the Instrumentation of Design"(Witt 2010)

performance values such as structure or circulation distribution. Argan gives us his classification of types:

> "Although an infinite number of classes and sub-classes of "types" may be formulated, formal architectural typologies will always fall into three main categories; the first concerned with a complete configuration of buildings, the second with major structural elements and the third with decorative elements."

(Argan 1963)

Other authors have completely different classifications of types, and they certainly vary in the different disciplines associated with architecture. In his masters thesis, Myron Goldsmith talks about the effects of scale in structures, most relevant to our discussion he talks about the limitations of each Type of structure, in particular he makes the example of railroad bridge structures (Goldsmith 1953).

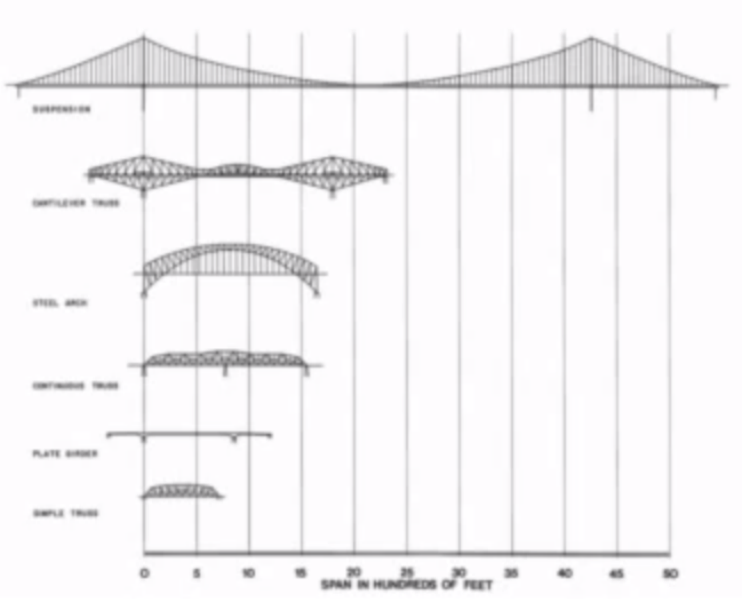

Figure 3.1: Myron Goldsmith: Bridge Structure Types (Goldsmith 1953)

Figure 3.1 shows us a diagram of several bridge Types and how they compare to each other in terms of their span. The diagram of course only shows us one bridge for each type, one suspension bridge, one steel arch bridge, one simple truss bride, etc. But we know that for each type there are a great number of existing bridges, many instantiations of the type. Yet all bridges of the same type share roughly the same performance metric, the same limit in span. More accurately, we can say that each type has one particular instance that has the longest span, a single solution can represent the maximum performance of each type.

As it was discussed above, types are discerned after a good number of instances of the type have been built. The common invariant feature among these instances is very often the cause of the repetition of the type, its virtue. The study of types can therefore be a good starting point in the definition of parametric models for the purposes of performance based search processes. Of we expect to find high performing solutions, for either explicit or implicit goals of our search process, then the invariant feature in our parametric models has to be well thought out. We can stand to learn from types as to how to formulate search processes.

Architects often explore types in all three of Argan's categories (and many others [§] very early in the design process, one of the very purposes of the conceptual design phase is the decision of a large scale geometrical shapes and for example the principal structural elements. Performance based search processes should not be different. The discovery of strong performing building features by means of search processes is analogous to the process of the creation of a type. In other words, if we can "anticipate" what the design process will be from the study of types, if we can translate past experiences into design knowledge, the same is true of performance based search processes. Knowledge on the behavior of a large set of solutions can be achieved by means of search.

While traditional types are formed by looking back at a series of buildings, they are deduced, performance based search, by means of simulations done at the moment of design can help us discover new and high performing building features. Design knowledge can be generated not only by deduction, but by performance evaluations of large sets.

The study of typology can help us better formulate questions for our search processes. If we consider Rittle's warning about dealing with "wicked" problems trough automation,[¶] we can say that we can better formulate

[§] An example considering Concert hall types is discussed in the section 3.2.

[¶] See Rittel's quote on page 29.

search processes and ask the right questions if we take a look at types, their performances, variables, constrains and most importantly the commonalities between types. Innovative and never before seen high performing solutions however are less likely to come from the study of types. Search processes based on performance simulations can give us information on solutions that do not yet exist. Therefore, search processes are capable of generating knowledge on future solutions, regardless on the question asked, be it an old problem or a new one.

Search processes give us performance values for entire sets of possibilities, allowing us to group high performing solutions and study their features. When it is the case that high performing solutions share common formal characteristics we can begin to learn why some solutions are better than others, we can extract important knowledge that is useful both in present and future problems, both design knowledge and practical operative information. We can then generate parametric models containing those high performing features as invariants, meaning that at most of the instances contained in the model are also high performing. Arguably, if these instances were to be built and studied, they could eventually become architectural types.

3.2 The Origin of a new Type: The case of the Berlin Philharmonie

Architectural Types are not created but rather deduced from studying a series of past buildings. Following this logic we will look at the "Vineyard" type of concert hall. We can see a series of built examples all over the world, and recognize in them many common characteristics. The vineyard concert hall however did not exist before the design and construction of the Berlin Philharmonie (figure 3.2) in 1963. We can therefore say that architect Hans Scharoun and acoustician Lothar Cremer designed a concert hall that would later become a Type.

Before the design of the Berlin Philharmonie most concert halls belonged to either the "shoebox", Fan shaped or Hexagonal type. But after Berlin, a large number of concert halls were built following many of the characteristics of this important hall. This makes for an interesting case in the study of types, since it is very recent and we know a lot about the architectural and acoustical design of this room, as well as how the room type has since been applied in many other concert spaces. We know what remains constant in these rooms, and what makes these rooms architecturally and acoustically interesting.

Figure 3.2: The Berlin Philharmonie - photo credit: Alfredo Sánchez Romero.

“Music in the center” was the main requirement Architect Hans Scharoun made to Acoustic consultant Lothar Cremer. he wanted the audience to completely surround the orchestra, giving them the chance to sit behind the musicians and face the conductor, or sit beside them and look at their performance from up close. The architect argued that traditional rooms, where the orchestra performs at one end and the audience sits strictly in front of them, have a limitation when it comes to orchestra and audience communication (Beranek 2004). Under Scharoun’s model, the audience (all 2215 of them) would sit no farther than 30 meters from the stage. This spatial relationship between the orchestra and the audience that the architect desired presented Cremer with important challenges:

> “The original concept of Scharoun was to have a completely circular hall with a shape close to an amphitheater where the orchestra director would be standing exactly at the centre of the

> circle, under a dome shaped ceiling an acoustically very dangerous concept as this geometry is prone to serious acoustic focusing. The principle behind Scharouns concept was to position the orchestra as close as possible to the centre and thus create the most "democratic" hall. To respect the fundamental rules of acoustics, Cremer suggested a ceiling with a tent shape rather than a dome and to break up the symmetry of the hall by using convex curves. He replaced the concave curves, which tend to focus sound, with convex curves, which diffuse sound. The idea of a central orchestra was kept. Also, the fact that the audience is located behind and to the sides of the stage, combined with the absence of a balcony has resulted in a room width that is much bigger than that of shoebox halls, and clearly wider than what is acoustically acceptable without having to introduce compensating elements. The latter elements, consisting of large wall sections, or partial walls creating "vineyard terraces", helped to reduce the apparent width of the hall and create acoustic reflections, leading to the concept of the vineyard concert hall."

(Kahle-Acoustics & Altia-Acoustique 2006)

The Berlin Philharmonie concert hall was a big success both with musicians and audiences. They both appreciated the new found intimate contact between each other, and the acoustics of the room were also praised. Since the opening of the Berlin Philharmonie and other vineyard halls, several studies have been done on their acoustics and been compared with other types[‖]. Several strengths and weaknesses have been revealed and the importance of its features been detailed. The type has been of course refined and developed in different ways.

The four most important concert hall types are the Shoebox halls, the Fan-Shaped hall, the Hexagonal hall and the Vineyard hall. Historically and still today the most popular of them has been the Shoebox, but from the construction of the Berlin Philharmonie on, the hexagon and fan-shaped halls have been built much less frequently and the vineyard hall has seen a big development worldwide (Meyer 2013). Other recent examples of concert halls built under this type are the Danish Radio Concert Hall by Jean Nouvel (Figure 3.3), the Disney concert Hall by Frank Gehry or the Elbe Philharmonie by Herzog & de Meuron.

[‖] see for example (Hidaka et al. 2008)

Figure 3.3: The Danish Radio Concert Hall - photo credit: Frans Swarte.

Of course not all novel buildings translate into new Types. Not all innovative building features are high performing and appreciated by architects and the public. It is therefore interesting to investigate why did the Berlin Philharmonie became a type. Why did architects and acousticians repeat its distinguishing features? Why didn't they attempt other ways to improve the intimacy without the use of the vineyards terraces?

The reason for the repetition of the vineyard concept was the combination of the effective architectural idea with the high performance acoustical solution. Scharoun's idea "Music in the center" was proven very successful in the architectural realm and the experience of the concert was enhanced by it, but without Cremer's terraces and reflecting walls, this concept would not have been acoustically satisfying. The terraces and their walls achieved the desired early reflections that would be otherwise missing, and this is why *both* the stage in the center and the vineyards were repeated, and not just one or the other.

In the first part of the twentieth century fan-shaped halls were very popular among modern architects, and many of them were built. Quite a few

Figure 3.4: The Aula Magna of the Unversidad Central de Venezuela by Carlos Raúl Villanueva.

examples can be mentioned, from Le Corbusier's unbuilt Palace of the Soviets, to Alvar Aalto's Auditorium of the Helsinki University of Technology, to Carlos Raul Villanueva's Aula Magna in Caracas. All of these rooms have angled walls opening up away from the stage, a concave curved back wall, and the seats are arranged in concentric circles of increasing radii, much like the greek amphitheater. This arrangement of the seats guarantees that seats in the same row are all at the same distance from the stage, making it an efficient seating arrangement and enhancing the intimacy of the room. Architects repeated this type because they liked the arrangement and they associated its shape with the greek acoustical quality. While the greek amphitheater was an outdoor environment, these spaces were enclosed, and the room shape was not optimal. The big distances of most listeners in the center of the room to the nearest wall and the opening angle of these walls, causes a big problem in receiving early sound reflections. The concave back wall also causes problems.

The fan shaped rooms were very successful from an architectural point of view, they were repeated all over the world. But they are being increasingly phased out for acoustical reasons.

The main lesson to learn from the Berlin Philharmonie is that Types are created for a reason, they are there because of some performance, spatial or economical reason that makes them desirable, repeatable and/or interesting to designers and users in general. The vineyard was repeated for both architectural and acoustical reasons. This is why when we look back into a particular type we can distinguish spatial and architectural characteristics as well as many technical advantages or problems related to the type. This is why Aldo Rossi confers types the ability to put us in the condition of foreseeing the design process ahead of us.

There is much to learn from the study of types, and this is especially true when using parametric models in combination with automated search methods. The questions asked when types are created should be a guiding example when we formulate search goals. The differences and variations the geometry of the single type should also be of example when we parametrize geometry for a performance search algorithm.

3.3 Cognition and search: Clustered search spaces

Search is a very broad term that describes many activities in the human (and animal) world. Human cognitive search mechanisms can be divided into two important categories, external search and internal search. External search is related to external goals, such as food and water, but also to external information. Internal search refers to Memory search, search for information we have obtained in the past and hopefully stored in our brains.

The interest in this distinction lies in the fact that when we design we mainly look for information that is external to us, we employ external search mechanisms, but we also rely on memory to access information we already found and might help us solve the problem. For example, when we use typological knowledge present in our memory, we employ an internal search mechanism. Parametric search processes are more related with external search mechanisms since it implies new goals that cannot be associated with memory.

From the beginning of the human species, we have always used our brains to search. The first and perhaps most primitive search problems for humans (as for all other animals) is the search for food or water, it is an external search process. Food and water resources are not homogeneously distributed in the human habitat, food sources are distributed in patches of land heterogeneously present. For reasons related to landscape, climate and soil conditions, food and water resources vary in quality and quantity in different regions, but not in a random way. This primordial search problem had an heterogeneous, patched, clustered and non-random search space. The search space for this primitive problem seems to have shaped our brains and cognitive abilities thereafter (Hills & Dukas 2012).

Studies on human cognition have found a deep relationship between the search space in problems such as finding food or water (a spatial search process), and our search mechanisms. We seem to have adopted a spatial-like search mechanism for all kinds of search, internal, external, spatial or non-spatial.

Like in the search for food or water, external search spaces are engaged by humans in a local search first, global search second pattern. Humans tend to search for resources first in a local space, typically a space where they recently had success in finding resources. If they are unsuccessful in finding resources (or information) in that local environment, then they move on to a global search with a wider search space, and seldom return to local spaces where they have previously been unsuccessful. This local search first and global search second pattern is present both in external and internal search.

> "Human subjects tend to focus their visual attention on the vicinity of a recently detected target but switch their attention to other spatial locations if no target is found at this area within a short giving-up time. This behavior, which is reminiscent of area-restricted search is called *inhibition of return*"

(Hills & Dukas 2012)

We look for information first where we think we are most likely to find it, and if unsuccessful we expand the scope of the search into a more global space. This mechanism is ver similar in internal search. Internal memory search is directly related to the way we store information in our brains:

> "Studies in written language - presumably reflecting the internal structure of cognitive information - find evidence for a strongly clustered environment. With nodes representing words and links representing relations within words, these language

> networks often reveal a small-word structure, indicating that words are much more likely to appear together in small clusters of related items that one would expect by chance... Moreover, this structure of language and free association networks is well correlated with the order in which children learn about language. This indicates that the patchy internal structure of memory may be tightly linked with the patchy external structure of information."

(Hills & Dukas 2012)

The following example explained by Hills et al. may help to clarify these ideas about memory search:

> "Research on sequential solutions in problem-solving tasks also demonstrates that people show local preservation in internal search environments. For example, people tend to produce solutions that are more clustered together (i.e. similar) that one would expect by random generation; for example, in math search tasks and anagram search tasks. In one case Hills et al. had participants search within scrambled sets of letters for multiple words. Participants would see a letter set, like BLNTAO, and they could find "BOAT","BOLT", etc. An analysis of the string similarity (e.g. bigram similarity comparing the number of shared letter pairs: "BO", "OA", etc.) between subsequent solutions determined that participants tended to produce solutions that were most similar to their last solution. This was true even though previous solutions were not visible. Results indicate that participants were searching locally around previous solutions, before transitioning to a global search strategy."

(Hills & Dukas 2012)

Humans tend to store items in they memory in a clustered environments similar to the one where they got the information in the first place. Clusters in memory however are not organized according to repeatable categories. This is one important difference between internal and external search mechanisms:

> "An item in memory can belong to different representations simultaneously: the word "cat" can belong to the category "pets"

> as well as to the category of “predators”. The representation need not be based solely on semantic similarity but also, for instance, on phonological similarity (“cat” and “bat”). Thus could potentially belong to more that one patch.”

(Hutchinson et al. 2012)

Clusters in memory may categorize information in ways that are not consciously decided by the person, and therefore internal memory search is less conscious. This might not mean that is less efficient, but external search processes can surely be more planned and systematic.

It seems that we are naturally pre-disposed to classifying information into clusters, so we should not be surprised at the presence of types and typology in architecture theory and practice. Types become clusters of information about the built environment, and these clusters are ready for us to investigate building potential for future projects.

The search space in performance driven search for architectural design is often unknown and unexplored. We do not know beforehand how the search space is populated with high performing solutions. We might be looking in a space that does not have what we are looking for, or we might we looking in a space where all solutions are high performing, either way we have little information from which make decisions. Also, we cannot be sure if we are dealing with homogenous or a patched environments, are the best solutions all similar and close to each other in the search space? or are they very different and far from each other? We need to employ tools that are able to give us relevant information regardless of the type of environment we have. It seems logical to use local first and global second patterns when we search for design information. We can use parametric models as clusters of information about design goals, especially when innovative forms and new design goals are in question. These clusters of information are there to be searched computationally, much as types have been studied in the past by the deduction and analysis of the existing built environment.

4

Automation and Authoriality

When automated processes are involved, design control and authoriality are often a point of discussion. A traditional point of view on automated processes would stipulate that the authorship of the resulting object is not clear, that automation somehow robs the designer of his design intent.

Automated processes are surely being more and more employed in todays design process, but they are hardly new. By looking into older examples we can discuss authoriality and design control with a larger context. This issue by going into detail in different scenarios of past and present use of automation.

Planned randomness

A recent trend in architecture, particularly in the design of facade and ornamental elements, is to look for the appearance of randomness, the use of casual and apparently chaotic geometry. In contrast with the standardized element and the repetition of forms, this recent trend intends to give the opposite impression, one of uniqueness, randomness and non repetition. In most cases this is achieved by the use algorithms, and then built with the help of digital fabrication processes. Voronoi diagrams, fractal elements and other algorithms are very present in contemporary architecture, examples are the Beijing water cube by PTW architects, the serpentine gallery pavilion by Toyo Ito and the Grand egyptian museum by Heneghan Peng (under construction). In all of these cases there is no actual randomness behind the generation of the form. The form was generated by an algorithm that was carefully planned by the design team. In this case there are no issues of control, just the appearance of randomness. The end result is the subject of the algorithm, it is always under the control and supervision of the designer.

One example that merits mentioning is the stonework for the Therme Vals building by Peter Zumthor depicted in figure 4.1. In this case the architect wanted to avoid the look of a standardized stone wall, while still maintaining strict control over the geometry. The stones are laid in rows, all stones in the same row have the same height, but not all rows have the same height. In addition, Zumthor specifies another rule to this "natural" pattern, the combined height 2, 3 or sometimes 4 rows has to always add up to 15 centimeters, creating a repeating modulus. This allows him to use these rows as steps in the staircases without interrupting the pattern or breaking a row. Apart from these rules or constraints, the stonework is casual, and the length of each stone is different. We can describe this method as a set of constraints, a constrained* bit random selection of stones. The end result is a very controlled, yet not regular looking pattern.

In all of these examples, architects never relinquish complete control over their designs. In all of the above cases there are some features that are established by the architects as invariants, constraints are always presents. When the architect establishes constraints he is making a strong statement that determines, to a good degree, the final outcome. He establishes what cannot be changed, what makes the design his own.

It is true that in some of these examples there are features of the outcome that are not a direct result of the architects initial intent, he did not draw them with his pencil like in a more traditional process. But when the architect makes the conscious choice to let an automated process generate these random or external features, he is also making an authorial decision. Often he is looking for a particular result that he deems better achieved by means of automation or randomness that by means of his own hand.

The Accident

Perhaps the most representative work in this category lies outside the realm of Architecture, Jackson Pollock's dripping and splashing painting techniques depended on accidental and uncontrollable events to apply the paint to the canvas. Pollock, when talking about his technique, claims to have complete control and denies the use of the accident but then he also talks about the unconscious and the painting having life of its own. But it is clear that he used the splatter, and dripping of the paint as a means of expression.

*Axel Kilian devoted his PhD thesis to the study of constrained algorithms in architectural design (Kilian 2000).

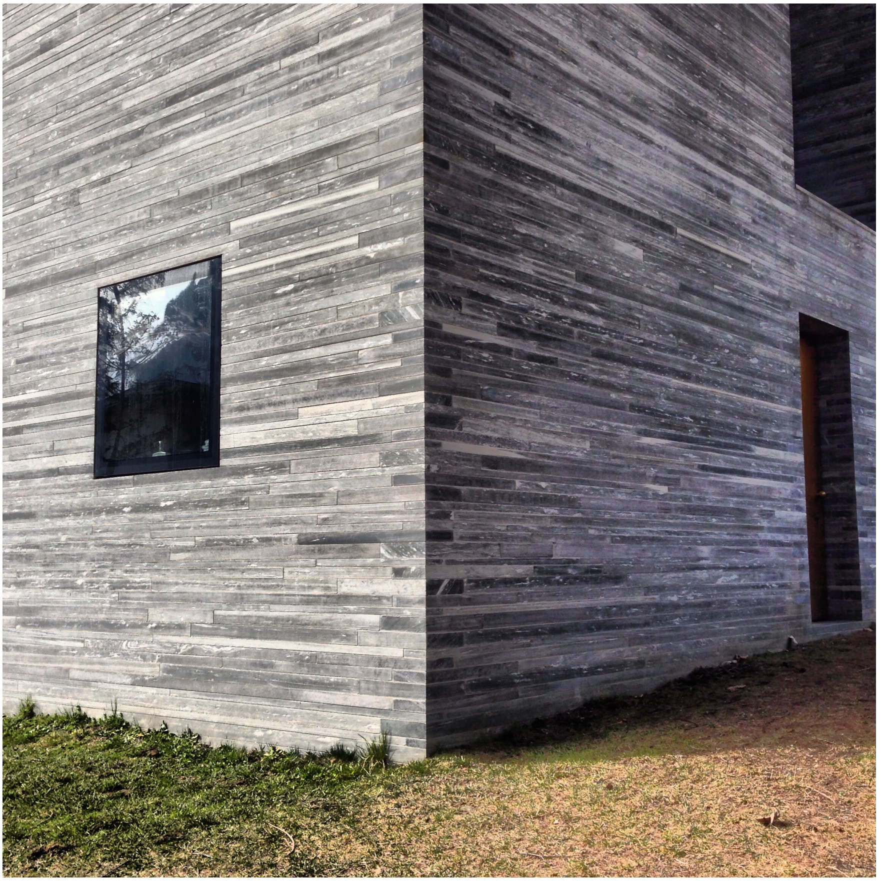

Figure 4.1: Detail of the Stonework in the Therme Vals hotel building by Peter Zumthor - photo credit: Marco Palma.

This technique allowed him to achieve results that were not possible without it, hence this technique is crucial to the artist's intent, not just a means of exploration.

Even in such cases when the accident is deliberately chosen, and there is almost a complete absence of invariants, the artist is making a choice that is reflected in the resulting artwork. Authoriality is therefore not in question.

Since architecture is an allographic discipline, the accident is only employed by the architect in the design process itself, not in the realization of the finished product. The accident is used as an exploration tool during the design process, the accident has to then be interpreted and developed by the architect. In this process the architect takes full control of the design, the accident is an exploratory start. The use of scraped pieces of paper or hand-drawn random scribbles is comparable to Pollock's drippings in the sense that some accidental elements are involved in combination with the architect's intention.

Accidents can also present in the architectural construction process, especially when handmade components or natural materials are involved. A good example of this is seen in masonry buildings. Brick colors for example are all quite similar but never exactly the same. Brickwork patterns are usually pre-defined by architects, but the arrangement of the different tones of brick color are not. This is left up to chance or the will of the artisan laying the brick, yet the authorship of the building is never put into question, the artisans involved in the construction are almost never known or recognized. The same can be said about other construction processes involving artisans and their crafts.

Form-Finding

In 1675 Robert Hooke wrote an anagram containing the phrase "As hangs the flexible line, so but inverted will stand the rigid arch". This statement simply declares that the shape taken by a chain loaded by its own weight (hanging in tension) is the same shape of the arch that will carry the loads in compression (Heyman 1995). Gravity is giving the chain a particular and very specific shape, in a way we can call this process a computational process, the computation being done by nature.

This process became known as a form-finding process. Form-finding implies the computation of a particular shape that satisfies some natural phenomenon following an initial user defined configuration. A simple hanging chain model for example, gives different shapes depending on the length of the chain and the position of the two support points. Not all form-finding

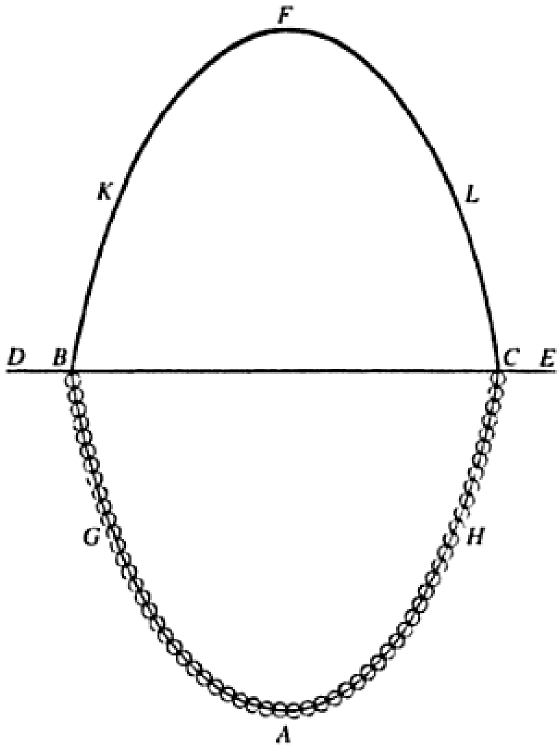

Figure 4.2: Robert Hooke's Hanging Chain

processes are done via natural processes, recently, computer simulations of those processes have been developed and employed for architectural design.

The most prominent example of a form-finding process is Antoni Gaudi's hanging models for the Colonia Guell in which he found the compression only shapes† to the vault structure by hanging chains and weights and reversing the result. Frei Otto used another form-finding process for the purposes of computing minimal surfaces between rigid curved elements (see Figure 4.3). These shapes were then used to design Tensile Structures, for example Otto's olympic stadium for the 1972 Munich Olympics.

†A good example of form finding processes for compression only complex surfaces can be seen in the work of Philippe Block (Block 2009)

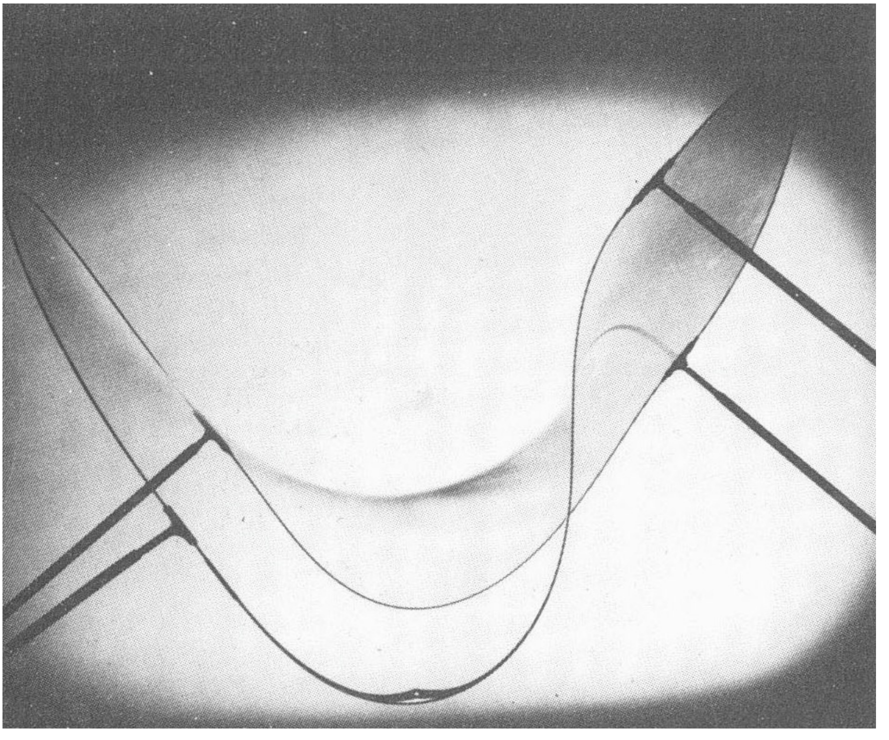

Figure 4.3: Frei Otto - Minimal Surface Studies by use of soap films.

In all of these processes there are instances where the designer leaves aside control over the design. He does not directly trace a shape with his hand, instead he leaves it up to the process to compute the shape, knowing that the end result will have an ulterior benefit that would not be possible to achieve otherwise.

In form-finding processes the interaction between the designer and the model is usually a fundamental part. Most of these processes generate a solution in a very short amount of time, and present it for the designer to consider, discard or modify. The resulting form is usually an input for the designer to make a modification in the model parameters (e.g. weights on the hanging model, shape of the metal elements in the soap film study, or numerical parameters in a digital form-finding tool). So of course the designer regains control over the result immediately after the process.

Computational Search

Computational Search Algorithms like the ones described in this PhD also have elements of control to be discussed. In section 1.7 a discussion is presented on how designers can interact with search algorithms, but in between those interactions, it is the algorithm that is doing most of the work, and depending on the algorithm, there are plenty of random events involved. For example Genetic Algorithms contain various operations that involve the use of stochastic sampling, most notably the selection of the first generation of solutions is made completely and purposely at random[‡]. But randomness in some operators does not mean that the overall purpose of the algorithm is lost, on the contrary. Randomness is employed to increase the exploratory power of the algorithm, and to counteract the exploitative power of the genetic operators.

Architects in the past have dealt with operations in which the resulting design is not a direct result of their hand, many examples of this are shown in this chapter. But this does not mean that the end result is outside of their design intent.

It is easy to see that, with the increased use of computational tools, this kind of event is being used more and more, and the part of design that is left outside of the designers control is always bigger and bigger. However, at the end of the random event, the designer *always* has the choice to take or leave the result. The designer is obliged to decide how the rest of the design process will evolve, if it will be defined by the information found during search or not. If the designer decides not to take the results, he can then re formulate and regenerate new solutions, or simply undertake an entirely different process. If on the other hand, the designer decides to take the results and use them in his final project proposal, he takes the automated results as his own, assumes the responsibility of the choices made for him by the automation, accident or random event. He resumes control of the process.

[‡]see the complete description of the genetic algorithm in chapter 7.