From parametric design to robotic fabrication, challenges and opportunities around architectural design

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Abstract

In this research we go through an analysis about the characteristics of the parametric design, its background, benefits and areas of opportunity. The principles proposed by Luigi Moretti on parametric architecture are contrasted with the different versions that Patrik Schumacher has presented on parametricism in order to equilibrate a more recent posture. Three important challenges are pointed out in the incorporation of the parametric design and its correspondence with the computer-aided manufacturing, when taking into account the automated manufacturing with computerized numerical control machinery and the different robotic tools in existing architecture. The challenges are tackled through the conception of a framework of considerations that allow us to recognize the benefits of parametric design and tools with greater freedom, through a review of the conditions of human labor concomitant with robotic manufacturing processes, while shedding light on technological challenges in favor of greater competitivity.

Introduction

It is necessary to recognize the evolution of the architectural concept by virtue that today it can be reinterpreted as an assembly of ideas, data and specifications free of occurrences. The concept thus conceived has to integrate, among others, technical, normative, statistical, economic and constructive criteria as direct determinants of its geometry. The complexity demanded by these contemporary statements must estimate their approach through advanced design strategies, such as some parametric design strategies, according by what of today is possible, since this type of design allows a substantial, precise, and efficient approach to the incipient complexity expected in the architecture.

It is important to start by decoupling erroneously preconceived attributes in favor or against parametric design as long as it is not the same as 'Parametricism' and in particular when demonstrating that it has evolved from a primary conception of what was the 'Parametric Architecture' framed since the decade that began in 1970 by Luigi Moretti. Thus, by recognizing the freedom that it welcomes and the capabilities it operates, it seeks to expose itself here as a set of tools of greater and more diverse utility to the habitually recognized.

Fundamentals of parametric design

Parametric design is conceived in architecture as an approach to design that exerts an intensive use of parameters. Its development, is based on the use of algorithms with which it is possible to systematically structure interconnected and codependent architectural elements whose characteristics are determined by data. Under this methodology and with the tools available today, it is possible to modify any parameter in the set, causing a corresponding integral reconfiguration of the project system while obtaining a visible and immediate result. The time it takes for a digital environment to process a simple adjustment can be done in a few milliseconds so that it makes it possible for decision making to ponder a greater number of options before taking decisions.

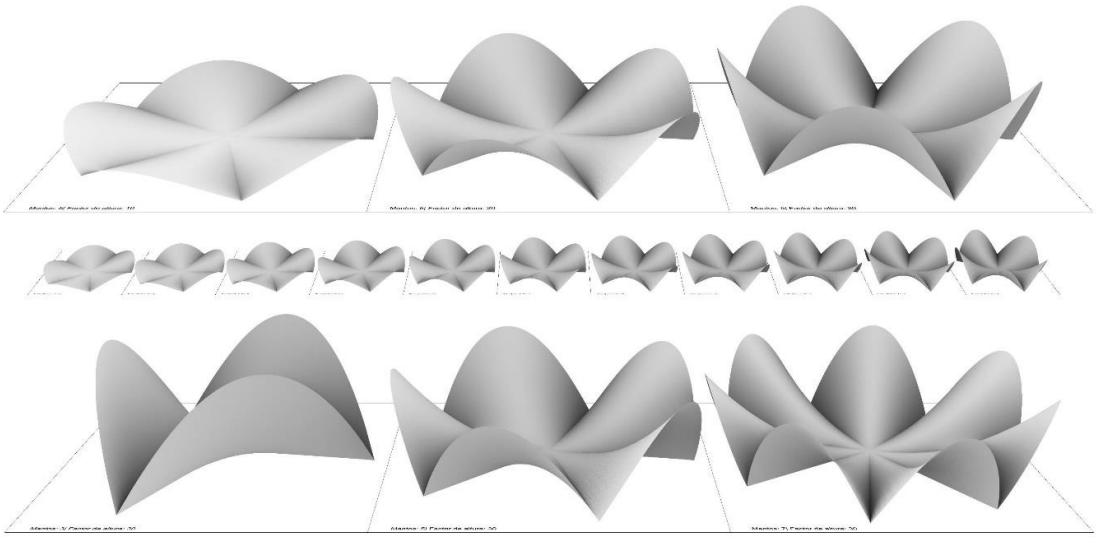

Figure 1. Canopy shell study based on mantles product of hyperbolic paraboloids, top and middle: change of heights with five mantles | Bottom: same height change of number of mantles. Author's investigation

This vision of design is possibly closer to that of a biological metabolism and is far from the representation drawn on plans. Coincidences can be framed since both can be conceived as a set of singular elements, where each operative element with differentiated function exerts alterations that affect in the set.

The generative design, also similar to the metabolic operation, seeks to obtain functional and formal results determined from considering procedures that conceive the different necessary variables, the result is not known until a series of iterations have been developed that will be evaluated according to the combinatory of data and its result is best achieved according an expected objective.

Parametric Design Background

The first parametric reference in graphic schemes was proposed by James Dana in 1837 (Davis 2013), when inviting a parametric plane to be inserted into a cube within a geometric description.

The first mention of parametric architecture is made by Luigi Moretti first, in the decade that began in 1940 with the mention of the use of parameters in architecture and later would reinforce this concept, in the XII triennial of architecture in Milan in 1960, thanks to the use of an IBM 610 computer (Frazer 2016), since it presents a model of the N Stadium as an example of this type of design in the parametric architecture exhibition. Moretti finally formulated two years before his death, in 1971, eight points that define his conception of parametric architecture.

1. Rejection of empirical decision making
2. Evaluation of traditional phenomena as objective facts based on interdependence of expressive, social and technical values
3. Exact and complete definition of architectural themes
4. Objective observation of all the conditioning elements (parameters) related to the architectural theme and the identification of their quantitative values
5. Definition of relationships between parameter values
6. Indispensable adoption of different scientific skills and methodologies according to operational research criteria to define conditioning elements and their respective quantities
7. Affirmation of the freedom of the architect in the decision and expression, only in case of not affecting the characteristics determined by analytical investigations
8. Research of architectural forms towards a maximum, and therefore definitive,

accuracy of the relationships in their general "structure". (Gallo and Pellitteri 2018)

In 2008 Patrik Schumacher proposes five principles with the parametricist manifesto, with the aim of injecting new aspects to what he considers as a parametric paradigm. This is a synthesis:

1. Interaction of systems: So that it is possible to associate multiple subsystems such as: envelope, structure, internal divisions and paths.
2. Parametric accentuation: Enhancing the whole sense of organic integration towards intricate correlations that favor amplifying the deviation can also include the deliberate assignment of thresholds and singularities.
3. Parametric figuration: Integration in a single parametric model of the concatenation of different latent readings, as well as other parameters related to the variability in lighting as well as different observation points.
4. Parametric sensitivity: The environments can be designed with a kinetic capacity that allows them to reconfigure and adapt to the prevailing patterns of use and occupation.
5. Parametric urbanism: It implies that the systematic modulation of building morphologies generates powerful urban effects and facilitates orientation. This urbanism is conceived with influence of the previous concepts. (Schumacher 2008)

In the proposed revision to Parametricism that Schumacher himself does in 2016 with Parametricism 2.0, two highlighted phrases can be considered as the most forceful in the introduction to his review.

1. Parametricism is the architectural response to contemporary civilization, computationally empowered

2. Only Parametricism can properly organize and articulate social constructs at the level of complexity demanded today (Schumacher 2016)

From Moretti's proposal we can read what is initially possible to do under a parametric approach, while with Schumacher we can see how far it is possible to get.

New framework for action

The first challenge is formulated. We need to have an action framework that helps to exercise the benefits of parametric design without the need to join a pre-specified, polarized or pretentious sublime, which, although it allows the production of designs with high complexity, do not dismiss the creation of concept-based designs originals that benefit from the characteristics of the parametric design. This in order to open the operability of the parametric design, without making a tabula rasa to be able to resort to valuable antecedents that may be drawn from some lessons of the modern movement, such as being reasonable with the resources, seeking agility in the materialization of any built environment and accommodate tectonics is contributing directly to aesthetics.

Among the approaches of one and another author, it is possible to gather a list of points were parametric design in architecture particularly allows us to integrate concepts in consideration of:

1. **Make informed decisions** by incorporating data through mechanisms that reduce human interpretation to the point that human awareness can focus on the functional or symbolic nature of what is done, therefore concentrated on the result it is possible to reduce ambiguity.
2. Start from a **preconfigured calculated procedural methodology** that explains geometric results. There is now a greater ease of incorporating a scientific approach that leads to a better informed and universal decision making, far from being empirical.
3. Configure in the architectural object the different parts that integrate it in an **interconnected and codependent** way, allowing each part to act in correspondence, so that any adjustments in a project can then be limited to be exercised exclusively where they are desired, with full confidence that the rest of the project can be reset accordingly and automatically.
4. Contrast the constructive, functional and plastic nature with the previously carried out, in order to proceed with **positive heuristics** from the background in favor of greater, better or innovative ways of doing architecture. The continuity with the architectural background must act in any case in accordance with a critical procedure

and in consideration of a variety of convergent factors.

5. Define an architectural object in its entirety with greater precision and speed so that the **entire object is previously determined technically** and can contribute to synthesize a greater degree of certainty with respect to the constructive process or that may be manufactured by computerized numerical control machinery
6. Analyze, evaluate and simulate patterns of use and operability that can be configured, reshaped or determined as a range of options thanks to the **incorporation of dynamic and reactive elements**
7. Consider **different scales** of action by virtue of the ability to adapt greater accuracy and ability to receive emerging sources of information

In any case, it is necessary to consider that parametric design strategies and methods are not the only applicable criteria, and they do not assume to respond to all social dynamics. It should be recognized that they are applicable in a very different way, and assume that they are only applicable in particular cases, acting in such a way would lead into leaving aside other actions that although they are not complex, spectacular or far from the modern movement, they can be better informed, more affordable, more sustainable , faster to build or more precise due to parametric and generative strategies

Although we do not seek the mere substitution of the drawing by the computational code, we are really interested in that the parametric design stands for free expressions, which contribute to provide an agile and efficient response to an architectural challenge, and that it may correspond to an economic, cultural and social reality in a diversity of contexts. And that it contributes in favor of a more successful decision-making that understands the inhabitant in a central role. Architecture then should be conceived as an improvement of the environment centered on those who inhabit it, centered on the humanity.

It is also necessary to emphasize that when exercising the parametric design it is not

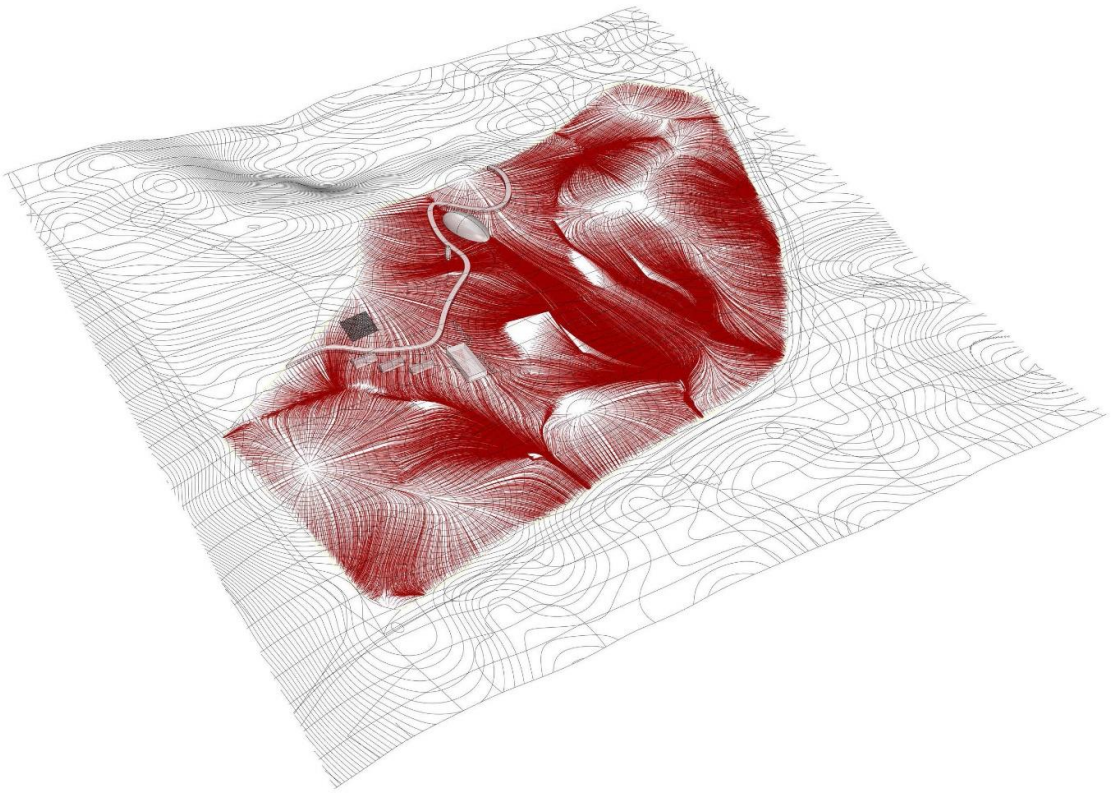

Figure 2 Parametric analysis of land runoff in Santa Fé CDMX. Data from USGS and Open Street Maps. Software used: Rhinoceros 6 + Grasshopper, Elk and Bison. Author investigation.

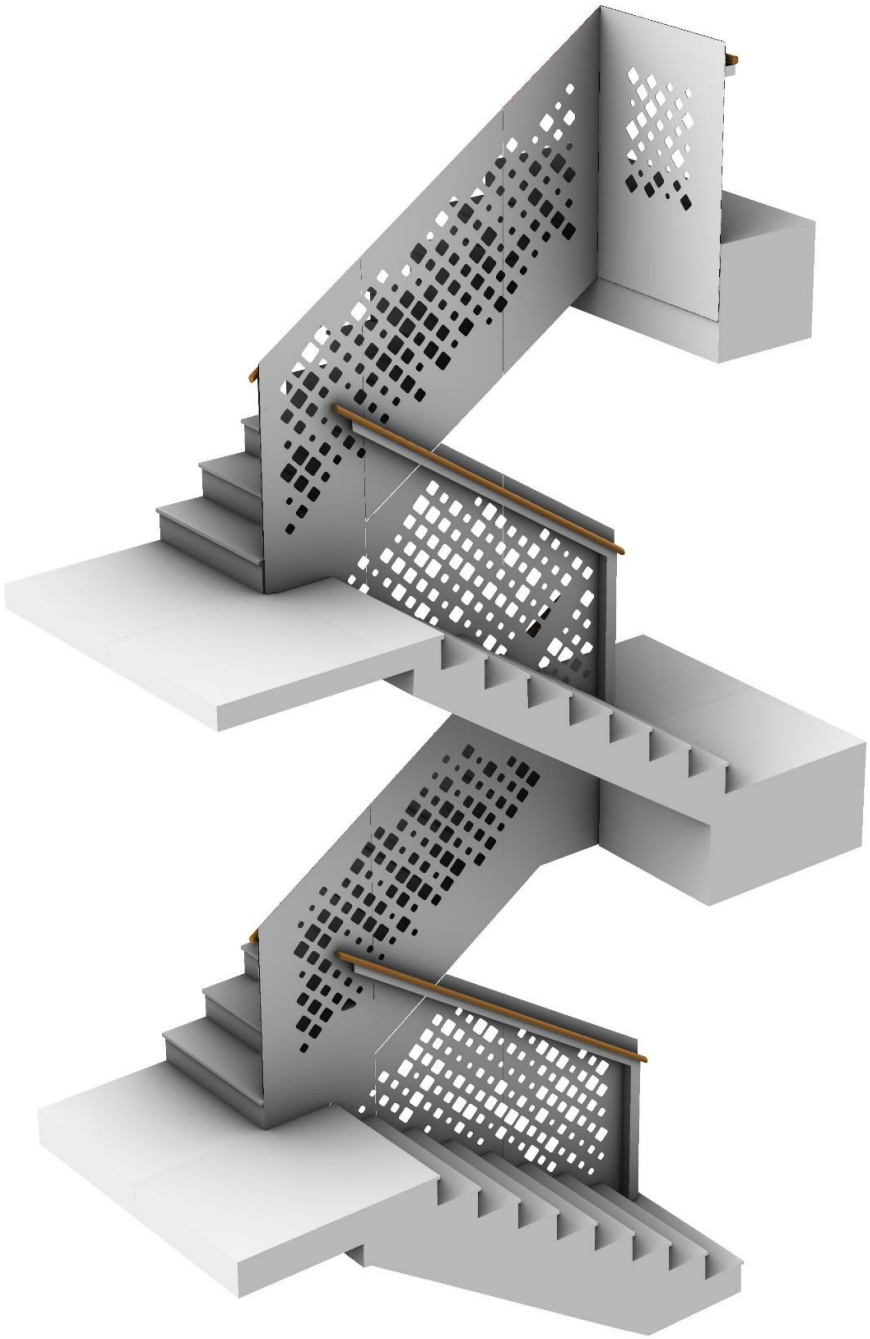

Figure 3 · Study of stair railing with openwork of different sizes in steel sheet. Author's project

necessary to do it with the maximum deployment of resources, with the maximum capacity of geometric processing or with the greatest possible complexity, at least not in all cases. Recognizing alternative criteria in other currents of thought such as critical regionalism allows us to expand responsible acting as architects. The exploration through the qualities of parametric design are open to diversity and invite for original proposals.

Let everyone seek to inspire the human spirit with poetic product of effort and talent, let everyone acquire the most and the best tools to pursue achieving the ideal in the configuration of the architectural object, and let this is be able to pleasantly surprise because of its uniqueness, originality and due to being a strong example that marks its belonging to a particular time.

Qualities of parametric design strategies

Programming interfaces that allow parametric design methodologies, can process automated or semi-automated massive amounts of data, with thousands of data that support a range of design possibilities, the result can also be reflected in a multiplicity of geometries, or in very sober results that can even offer unique and different answers for every part ot the result.

The graphic programming interfaces have had greater acceptance among designers in general thanks to the fact that in addition to operating from a CAD or BIM environment they have reduced the need for the necessary care in the programming syntax, in addition to allowing the objetive to be prioritized over the method, enhancing the visibility of results obtained. This type of environment allows the visual and abstract construction of a logical framework that visually highlights the connectivity between values and processing through graphic elements. It supports increasing the capacity of the platform by developing plugins or pieces of code aimed at specific operations that can be shared, in symmetry with the ability that one has to be able to use what others have done in the same tenor, thus fostering a collaborative community of design, where collective intelligence can be exercised. In addition to the fact that virtually the entire programming environment and plugins are free, in one of the paths that may be selected, you would only have to pay for a license from the Rhinoceros CAD platform.

The ability to operate multiplicity of data and geometries, allows the mass reproduction of elements to be part of a whole or to be configured as a set of separate elements, it is also possible to make these elements to have subtle differences between them to make possible, what Jeff Kipnis and Greg Lynn call continuous differentiation throughout the reading of the set, so that there may be inscribed content, that is to say, a meaning that cannot be reconciled in the isolated reading of each element, but is only possible to make a significant reading under the analysis of the whole set. The possibility of singularization for each element in a mass set, gives rise to think about mass customization, by allowing specific conditions to be incorporated into each element that could proceed even from choices made for each element by different people.

When data from surveys or even data obtained through sensors are incorporated we can talk about the production of informed objects. Among the parameters that give rise to the geometric conception it is possible that some data has been incorporated directly, and it is thus that the architectural objects acquire characteristics product of the information itself. This connection reduces interpretation activities, which in turn reduces the chances of incorporating errors into a process. If it is possible to reduce errors, greater fidelity is maintained between the source of information and the product obtained, and a greater approximation capacity is opened through a scientific approach where the creative process is reduced in arbitrariness, ambiguity and occurrence.

If we consider the ability of the parametric design to be informed with direct data, data captured by sensors and even statistical data, the product obtained can also be conceived as a responsive architecture, that is, it is the product of a more direct response than what has informed it and it is possible to have greater clarity in what has motivated it. Therefore it offers an explicit response.

Although the parametric design considers managing the massive processing of input or output data, the graphical programming interfaces, in addition to the geometric and

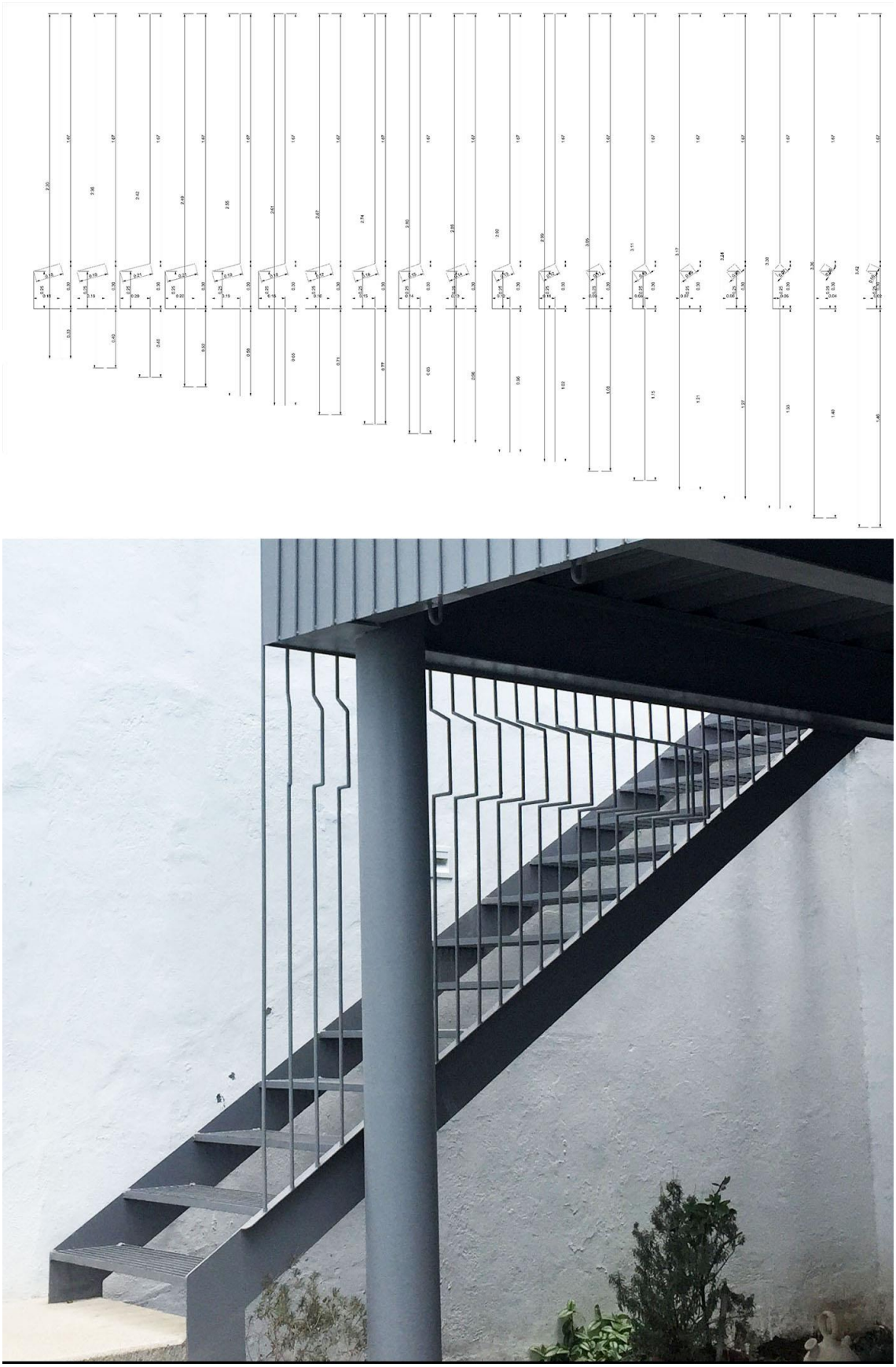

Figure 4 Top: railing exploded with automated dimensioning of each bar | Bottom: finished rail. Author's project

information outputs, have attempted to expand connectivity in terms of hardware, based on increasing communication channels and the areas of instrumental performance, this is done through the intercommunication with databases and peripherals, or with the control of external tools.

Taking into account the progress that the computerized numerical control machinery has had since the decade that began in 1960, as well as the reduction of the cost in its acquisition and operation, and more particularly its accelerated approach to architecture in the last decade, It is then possible to consider computer-aided manufacturing or CAM (for its acronym in English) as a technology to test architectural elements at scale or produce architectural elements capable of being incorporated into the construction of a building today. It is important to consider that each process that connects CAD or BIM with CAM ceases to require plans for its materialization and therefore becomes an incipient change in the course of the profession.

Technical implications in the documentation

The building information models facilitate the documentation of the architectural and executive projects by automating changes in cut-off floors and other sections of a particular model, this with more emphasis from the changes and adjustments made in every project, the product documentation of perpendicular projections, printed as plans, may be required less and less as long as the information models gain ground and more if digital manufacturing manages to chain greater number of tasks with a leading role in construction.

The plans as we know them today, may in the not too distant future be relegated to sample documents that contribute to the geometric understanding of a building, or adopt the 'map' role, orienting a person about their spatial location in a 'you are here' fashion.

BIM technology, which is also a type of parametric design strategy, can be redirected from the documentation to an automated manufacturing scheme to now help determine the elements to be built, which together with other digital strategies determine the supply process, constructive order, the particular methods and procedures of work, the control for the actuators, the process of waste disposal and complementary tasks of calibration, cleaning, maintenance, and verification. The project documentation will thus have evolved to the management of the construction process itself.

Manufacturing Considerations

In the different digital manufacturing processes, whether subtractive, transformative or additive, there are limitations regarding the material to be used, the dimensions of the input, the dimensions of the product, the position and angle of the tool, the speed of manufacturing, and the force or power in the tool.

The supply of inputs, the displacement to its final location and the assembly with another piece require more complex processes that have not yet been developed or have not yet been emancipated.

Following this order of thoughts It has been questioned if architecture should be modified in order to be susceptible for being manufactured by CNC machinery, rather it is considered that the machinery should adapt, or the process could evolve concomitantly. In any case the objective pursued, the ability of a context to integrate and to evolve a technology are decisive in the evolution of where the coding and determination of the envelope should be directed.

Although we consider it important to influence automation processes, human labor should not be underestimated, tools should be rather considered as instruments for improving human productivity.

Therefore, a second challenge provided here has to do with the incorporation of automation in pre-existing processes, the reallocation of tasks among workers, together with the training to be able to assume new technological activities, so that the result doesn't end in impersonation of men by machines, but into a closer collaboration that admits more tasks co-carried out by each person-machine assemble in less time, with more economic resources for those responsible for these tasks, with better prices for products as long as we have more efficient processes.

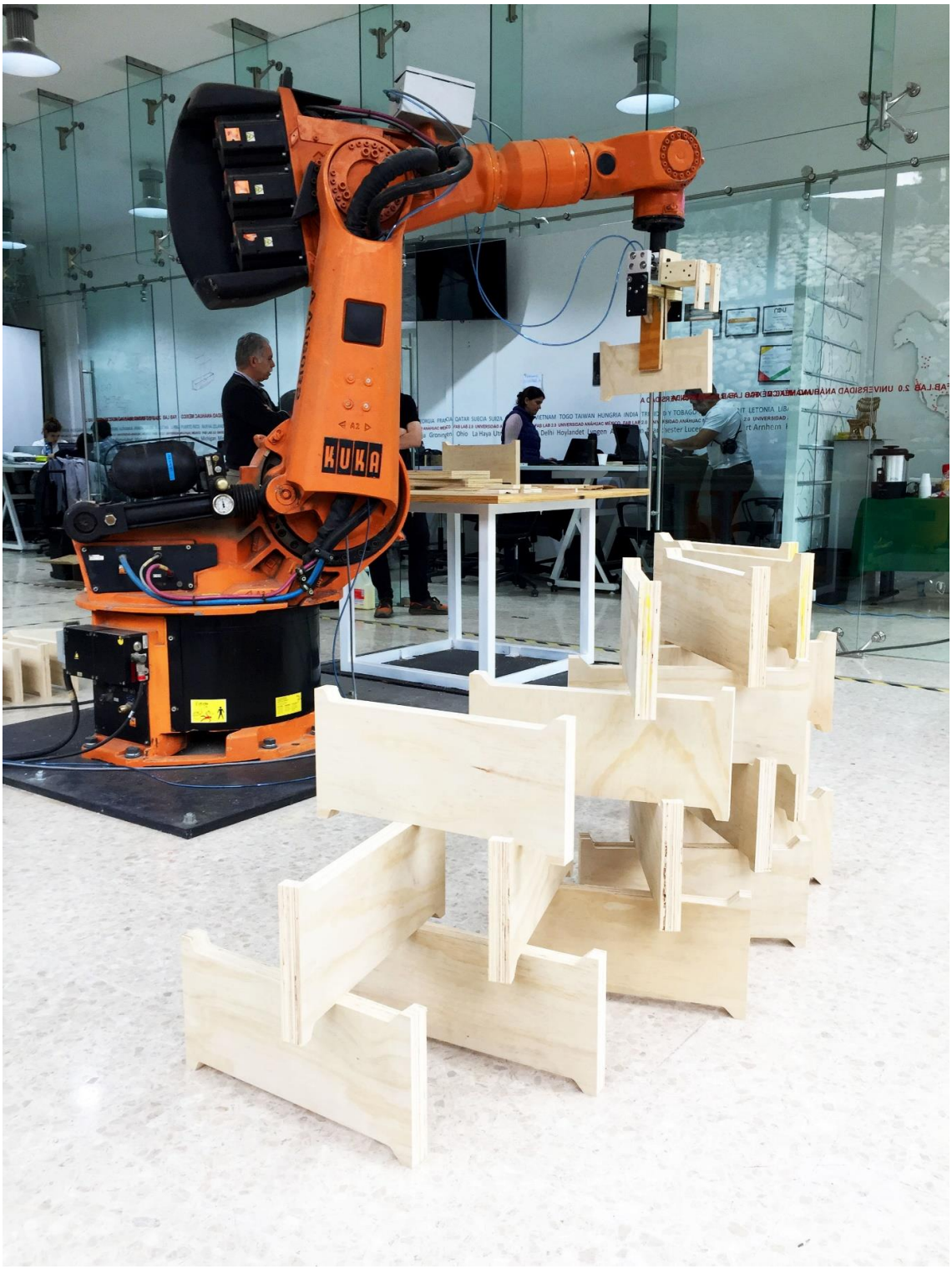

Figure 5. Fabrication of slightly tilted wall section with a KUKA KR150 robotic arm. Workshop Anahuac Collaborative Robotic Timber Assembly. 2019. Project where the author participates together with Julio César Rodríguez, Carlos Ruz and Natalia Boo.

Areas of Opportunity

For as today, the current automated production capabilities for the construction industry mainly include numerical control machinery from the production plants, which contribute to the cutting, milling, bending and drilling of panels that are then transported and installed on site.

Although efforts have been made to add materials on site and transport at different scales, there are still areas of opportunity that allow the integration of different technologies in order to offer a comprehensive solution that contributes to the distribution, supply, monitoring, and review. on site, as well as placement, coupling of elements and adjustment with different materials, cleaning, operation and post occupation evaluation.

Following this argument, finally a third challenge arises that, in addition to calling for the integration of available technology, demands the development of tools, instruments and elements that contribute to the critical technological application in habitat production processes, so that automation cycles can be closed, and start contributing to the reduction of the housing deficit by offering affordable and comfortable housing within a sustainable urban scheme.

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