RESEARCH ARTICLE OPEN ACCESS

Implementation of a Simulation Model Using the Systems Dynamics: Case Study from Study of Mass to Digital Manufacturing

Carolina Araújo[1], Fernando Vázquez Ramos[2]
[1,2](Master Program in Architecture, University São Judas Tadeu, São Paulo, Brazil).

ABSTRACT
With computer technology reaching the construction industry, much has changed in the way that these are idealized and designed. Currently, with the increasing availability of tools for the development of the models and parametric models intended for digital manufacturing, the insertion of these characteristics as design tool allows the designer to test solutions on various factors that permeate the design process, especially as regards the constructive points. The experience of the parameterisation dynamics and the dynamics of digital manufacturing from the design of the project allows the development of complex geometries, since the control their properties the analyses of structural variables of environmental comfort and aesthetics. The growth of the complexity of the projects and the capacity of computing resources, has arisen the need to use a more systemic approach, as well as have emerged the simulation programs based on dynamic systems, a digital simulation methodology in order to understand complex forms, which is part of the concept of systemic thought for the resolution of problems. The objective is in this Article is to identify and analyse the aspects of potential simulation based on dynamic systems and demonstrate a practical case drawn up in Dynamo software.

***Keywords*:** Automated Production, Dynamo Software, Manufacturing Process, Parametric Model, System Dynamics.

I. INTRODUCTION

Digital manufacturing, as well as any software that allows the parameterisation has shown innovative results, combining efficiency, speed and precision to the design process. The potential that these new technologies bring to the production and management of projects extends the dimensional processing of forms, collaborating in spatial understanding and in the development of models that can be prototyped. [1]. The dynamics of calibration and the dynamics of digital manufacturing allow projects which are versatile and of different applications, since once the parametric data is set, the shaping change becomes much more agile.

To introduce the concepts of calibration (aspects of design translated into numbers), digital manufacturing (production of elements which can be constructed as a result of digital processes), and systems dynamics (analysis of complex systems and dynamic), the objective is to present the operation of a simulation of a model using the systems dynamics in the Dynamo software, contemplating the study of masses, analyses, and the process of digital manufacturing.

II. METHOD OF APPLICATION

This article presents part of the data of a broader research on design processes whose methodology is sustained by the two fundamental pillars. First in a theoretical discussion about the dynamics of the parameterisation, dynamics of digital manufacturing, and the dynamics of systems, introducing the graphical interface of programming Dynamo, software that allows you to customise certain model in order to facilitate the analysis of conceptual solutions and the behaviour of elements and parametric data.

Concomitantly, an empirical approach that portrays the dynamics of model simulation, the demonstration of a case study since the process of conceptualization of the project up to its finalisation. This process is divided into two steps, the creative process, which covers the conceptualisation and modelling in the Revit software, and the process of digital manufacturing, which extends from the study of masses to finishing in the Dynamo software. The analysis of the experience of systems dynamics, in the developed model, previously enabled a greater understanding of the possibilities in the development of complex geometries.

III. DYNAMIC CALIBRATION

The current stage of parametricism is related with the steady advance of digital programming technologies, sophisticated parametric techniques and parametric modelling. Parametricism emerges from creative exploration of systems for parametric drawing, in order to articulate processes of increasingly complex projects. Works toward complexity organised (governed by rules) that assimilates parametric jobs to natural systems, where all forms are the result of forces that interact by means of rules. As well as the natural systems, the parametric compositions are integrated and cannot easily be broken down into subsystems independent. [2]

The characteristics of parametricism are due to the advance in the systems architecture, scripts, processes, software design, new techniques of parametric modelling, new possibilities of building materials and techniques. In figures 1 and 2 we observe forms guided by parametric data.

The parameters are the aspects of the project translated into numbers which are connected to the geometrical entities of the digital model. Designing with parameters requires the establishment of the series of parametric principles and the creation of a model that includes geometric elements defined by its mutable variables, acting as an interconnected information system. [3]

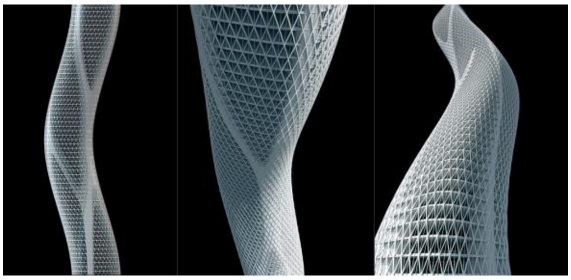

Fig.1 Evolutionary Computation, Jens Mehlan, Christoph Opperer, Jorg Hugo, 2006. Source: Architectural Design, 2009, p. 73. [4].

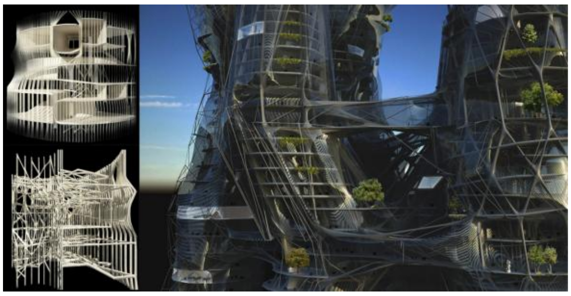

Fig.2 Code [9], Patrik Schumacher Studio, 2014. Available at: <Http://drl.aaschool.ac.uk/portfolio/code-9/>.

The parametric description of forms is an extremely versatile representation of curves and complex surfaces. The values of the parameters can be modified and thus changing the shape of the curve, without their fundamental description expressed by data provided is amended. [5].

The highest value of the parameter is the "ability to define, determine and reconfigure the geometric relationships". [6]. In highly complex forms, the parametricism is paramount for the holistic control and for the dynamic processes of the form.

The dynamic processes intervene in the concept in a dynamic way, where the adjective "dynamic" refers not only to a flexible way that can be modified over time, but also to the creative process, that is, continuous flows are part of programmatic formulation, the phases of the design and its construction. [7].

The shape is generated by the manipulation of commands, within rules established by the user. In this process geometry and parameters dialogue and the shape is edited, transformed, decomposed or fragmented. However, there are different ways to shape in the virtual environment, either free shaping or the one resulting from parameters. There are, therefore, modelling tools for complex shapes and tools that generate shapes from ideas or data sequence translated by the parameters; both define the transformational behaviour of the shape.

In the analysis of these techniques Oxman and Liu in 2004 [8], and also Dennis Dollens in 2002 [9], show that the computer, in some cases, has become a co-protagonist of conception and idealization of the project, almost a co-designer, a collaborator in the definition of the shape. [10].

According to Oxman [7], the combination of interactivity with generated, processed and manipulated variables derived from parameterisation, generate shapes with a large degree of accuracy, in the scope of the project.

Thus, the digital model has parameters for the modelling from surfaces, extrusion, surfaces of revolution, solid modelling, modelling of free-form, among others, which are mathematical representations of three-dimensional geometry, from a simple 2D line, circle, arc or curve, to more complex surface or solid 3D free shapes. Because of their flexibility and accuracy, the models can be used since the design until the manufacture of rapid prototyping processes. [10].

IV. DYNAMICS OF DIGITAL MANUFACTURING

The technological innovation that the areas of design and construction industry have achieved in recent decades is due in large part to the rapid development of the computing industry, which has introduced new techniques, established new challenges and created new tools in the routine of architects. Thus, it has become possible to use digital geometrical models directly for the production of physical artefacts, from scale models and prototypes in actual size until finished parts for civil construction. [11].

In the area of architecture, engineering and construction, the three-dimensional processing has nowadays become the standard process in several procedures, making rapid prototyping and digital manufacturing a major ally in the new challenges of the design process. One of the main benefits of ever greater development of its use is the option to have visualisation as great collaborator of spatial understanding, as well as complementing and path for the confection of rapidly prototyped models. This new possibility has caused a huge impact from the beginning of the design process until its construction, contributing to changes in the form of design and in its production, automating tasks and introducing new technologies. [11].

The technology of digital manufacturing is reconfiguring the relationship between design and the production of shapes, creating an inter-relationship between what can be designed and what can be built. Digital processes are opening new territories in the exploration of concepts, forms and tectonic of these forms, articulating the morphology and topology focused on emergent properties and their adjustments. This enables the designer to produce and run very complex shapes that, not long ago, could not be designed and built using the traditional means. [10].

An example of that in their use in rapid prototyping, which are being gradually incorporated not only to the possibility of building free shapes or seeking ways, but also to the possibility to generate shapes allied with the concepts of dynamic systems and pre-manufacturing.

Thus, interdependencies between elements and the definition of behaviour of these elements during the formal transformations are established. An example of digital manufacturing process can be seen in figures 3 and 4, the Metropol Parasol project (2004-2011), Sevilla - Spain, by Jürgen Mayer H. Architects. The project comprises 3,000 pieces of wood, the largest wooden structure in the world, which conforms six mushroom-shaped parasols.

Fig.3 Metropol Parasol, Jürgen Mayer H. Architects (2004-2011). Available at: <Http://www.vitruvius.com.br/revistas/read/projetos/11.130/4066>. Access in: 08 Apr. 2016.

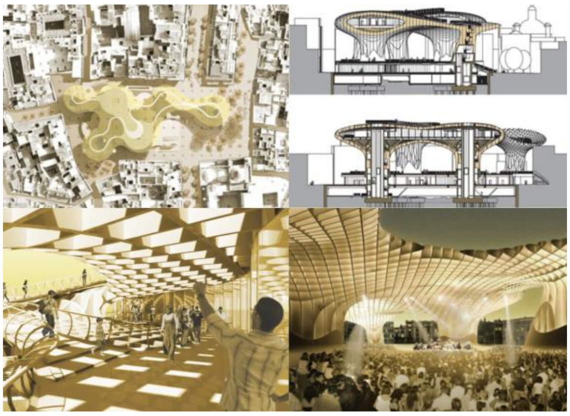

Fig.4 Metropol Parasol, Jürgen Mayer H. Architects (2004-2011). Available at: <Http://estruturasdemadeira.blogspot.com.br/2011/02/metropol-parasols-sevilla-espanha.html>. Access in: 08 Apr. 2016.

The methods for the automated production of digitally tooled parts can be categorized according to their purpose, according to the number of dimensions with which they work, and also according to the way they produce the objects. Regarding its purpose, they can be intended for the production of prototypes, i.e. assessment models, known as prototyping methods (prototyping). The production of final products, such as building elements to be directly employed in the construction, are referred to as fabrication systems or manufacturing. [12].

Professor Regiane Trevisan Pupo [13] describes step by step the digital manufacturing processes of a building element, from its conception until its use in the construction site, from a digital model:

- The design of the architectural form;
- Construction of a building element;
- Preparation of the model to which parametric data shall be set;
- Analyses;
- Finishing;
- The building elements ready to be used in the construction;
- Location of building elements;
- Wrap Up.

Among the techniques and methods used in the design process, three terminologies portray how digital tools of control in shape generation, but with different concepts and characteristics: the parametric model, building information model and the digital manufacturing. The BIM platform presupposes the parametric model in its functionality, but not all parametric models assume the BIM platform. BIM systems comprise a set of programmes and computational applications that include analysis, structure, mechanical, automation and building control and management systems and subsystems, amongst others. After an object and shape oriented programming, the systems could be integrated into a digital 3D model. BIM is a platform for digital manufacturing building, however, that does not always happen. It is possible to manufacture the elements through rapid prototyping without necessarily the object have been designed using BIM. Although they are associated with issues of high performance and productivity during the preparation of the project, it can be said that the project has a parametric strong action in the generation of shape; on the other hand, BIM can be associated with techniques of rapid prototyping, propitiating the digital manufacturing of components. [10].

The difference between the new production methods based on digital models and the old methods of mass production is that the new production methods are not intended to produce identical copies of the same product. On the contrary, they are sufficiently adaptable systems to produce a large spectrum of different shapes, i.e. mass customization, i.e. standardized production. [12].

V. DYNAMIC SYSTEM

The methodology *System Dynamics* is used to analyse complex and dynamic systems. Created in 1961 by Professor Jay W. Forrester, from the Massachusetts Institute of Technology - MIT, it was firstly applied in engineering, but it is currently a tool for the analysis of administrative, social, economic, physical, chemical, biological and ecological systems. [14].

Nowadays, there are several software programmes based on *System Dynamics* in the market. The great advantage of those software, compared to the ones based on other methodologies, is their flexibility and comprehensiveness. The software based on *System Dynamics* allow, for example, to model a process of industrial production, linked to the financial accounting system, and if necessary the market in which the company would be inserted or even the socioeconomic system. All that in a model generally impossible to be solved through mathematical analysis, though possible to be built without requiring advanced knowledge in mathematics from the user. [15].

Modelling is a creative and individual process, fruit of a systemic way of seeing the world in which there are multiple forms of simulating the same model, which depends on the software employed, tools and parametric data supplied.

System Dynamics was the methodology that substantiate the development of software such as Dynamo, Stella, Vensin and Ithing. Such software enable metamorphoses on objects and between objects, dynamic joints between parts of objects and the implementation of forces either external or internal to the object. [10].

The application of a force variable as an initial condition becomes the cause of both the movement and the specific inflections of the shape. The dynamic simulation takes into consideration the effects of forces in the movement of an object or a system of objects, especially the force not originated in the system itself: physical properties of objects, such as mass, elasticity, statics and kinetic friction are defined; gravity or wind forces are applied; collision and detection of obstacles forces and computerized dynamic simulations are specified. Therefore, the shape may be subject to a continuous evolution, by the use of animation and force simulation techniques, which can represent the flows of people or of traffic, weather phenomena or any other type of force. [10].

VI. GRAPHICAL PROGRAMMING INTERFACE OF DYNAMO SOFTWARE

Autodesk's Dynamo software provides a visual programming interface that allows you to customise certain model in order to facilitate the analysis of conceptual solutions and the behaviour of elements and parametric data.

The visual programming software Dynamo is a concept that offers users the means for the construction of programmatic relations using a graphical interface. Instead of typing a given "code" from scratch, the user can combine custom relations by connecting nodes together to produce a specific custom algorithm. This means that the user can obtain shapes from computational concepts, without the need to writing the code. (Fig. 5 and 6). [16].

Dynamo is a plug-in for Autodesk Vasari and Revit that allows the design process, custom automation through a node-based visual programming interface. Once the software is programmed to precisely calculate complex systems, capacities of data manipulation, relational and geometric control structures (that are not possible in a conventional modelling interface) are given. In addition, it is possible to leverage the pre-established shapes and the work flows of computational design within the context of a BIM environment. [16].

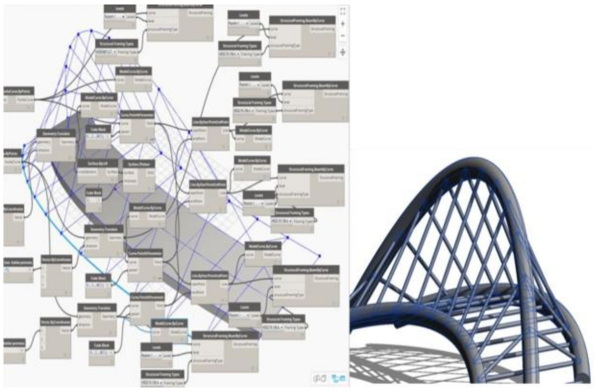

Fig.5 Node-based visual programming interface in Dynamo. Available in: <Https://bim.edu.pl/en/szkolenia/revit-projektowanie-parametryczne-dynamo/>. Access on: 08 Apr. 2016

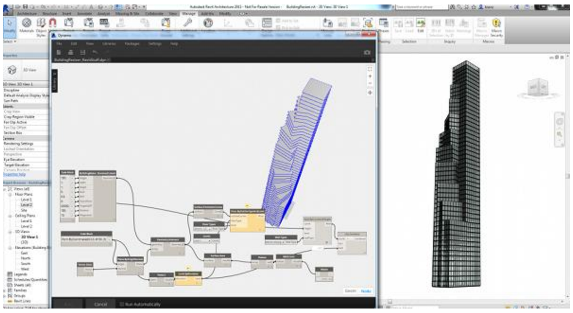

Fig.6 Interactive interface of Dynamo with Revit. Available in: <Https://bim.edu.pl/en/szkolenia/revit-projektowanie-parametryczne-dynamo/>. Access on: 08 Apr. 2016

Some of the characteristics allowed by Dynamo:

- Visual Programming allied to Revit and Vasari software;
- Usage of geometry extracted from the Revit;
- Dynamo geometry: nodes, wires, points, vectors, lines, solids, parameters;
- Management of the parameters of the Revit building model;
- Analysis of constraints, structural analysis;
- Options for conceptual parametric pre-established shapes;
- Parametric flexibility;
- Adaptive component;
- Automating tasks;
- Custom nodes, custom functionality to reuse them;
- Interoperable workflows for documentation, manufacturing, coordination, simulation and analysis;
- Import and export documentation data, analyses and manufacture in Excel spreadsheets;
- Control structures to the creation, positioning and visualization of geometry.

The connections of the scripts that determine the programming sequence (wires) of Dynamo link nodes to create relationships and establish a programme flow, like electrical wires that carry impulses of information from one object to another. The wires connecting the output of a node to the entry of another node, are represented as dashes when dragged, and solid lines when connected successfully. The nodes can represent elements of the Revit in the form of reference points or operations such as math functions with inputs and outputs. Each node gets data, codes, parameters that connect together with the wires to form a visual program. [16]. However, we believe that the visual and interactive interface of the software is graphic as to simplify the operating system software, a visual invention to ease the understanding of the programming system friendly interface.

The ports are rectangular areas, receptors for the wires. The information flows through the ports, which are prone to receive a certain type of data, for example, a node you can connect with XYZ inputs and outputs, which are the coordinate points in space, or connect with the reference points, which are the elements of the Revit. (Fig.7). [16].

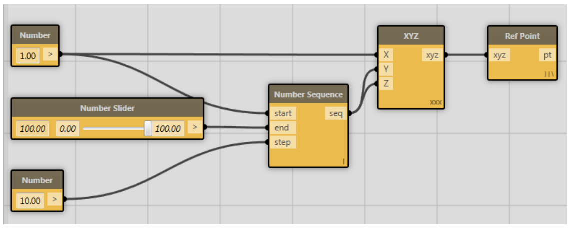

Fig.7 Example of nodes, wires and ports in the Dynamo software.
Source: Dynamo: Visual programming for Design, p. 12. [16].

Figure 8 depicts a metal lattice, being an adaptive component, which was developed from three curves and the XYZ matrix. We determine the spatial position of each curve node, and provide the data of each node, so we obtain the lattice in function of the geometry of the curves.

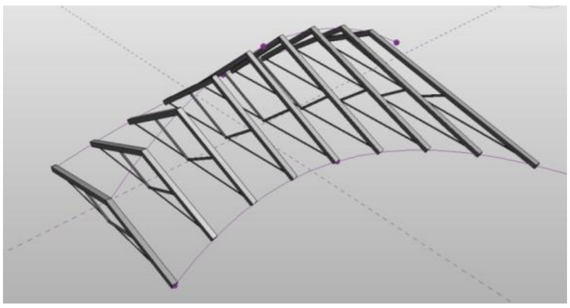

Fig.8 Example of an adaptive lattice in Dynamo software

Source: Dynamo: Visual programming for design, p. 25. [16].

In the manipulations panel of the software it is also possible to obtain data from analyses of constraints, such as the example in Figure 9, the analysis of the model built from data as the position of the sun, date and place. With the solar simulation, we verified that the Dynamo software provides data the size of each amount and panel. The panel sizes vary in order to fit the project and the results of the analyses are extracted as an Excel spreadsheet.

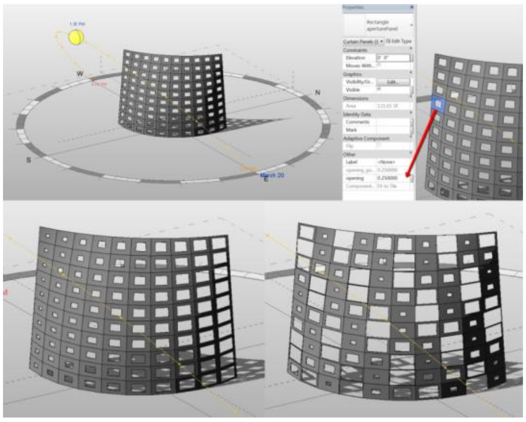

Fig.9 Example of solar analysis in Dynamo software.
Source: Dynamo: Visual programming for design, p. 39. [16].

VII. DYNAMICS OF THE SIMULATION OF A MODEL, PRACTICAL CASE

The case study presented here demonstrates the processes of architectural drawings with the BIM method, the results of a 3D view, the notion of computational tools and their ability to use such tools in a complex and curvaceous geometry in the Revit software.

The model is a multifunctional complex, chosen from exploratory nature and qualitative approach, which aims to understand the perception and the behaviour of a model simulation, combined with the application of digital manufacturing developed in the Dynamo software.

As aforementioned, the methods address since the process of conceptualization of the project up to its finalisation. The process was divided into two steps which were crossed in several moments, making possible the understanding of shape and their more accurate solutions:

- Creative process: conceptualization and modelling in the Revit software;
- Digital manufacturing process: study of masses, finalized in Dynamo;

As demonstrated in Figure 10, during the creative process, in Revit Architecture, it was possible to develop the modelling of the architectural design, modelling of structures in steel deck and steel frame, modelling of hydraulic elements, modelling of components, the representation of views in blueprints, cuts, elevations and perspectives, the documentation of tables, and the possibilities for drawing regarding the formal aspects in an organic language.

Each component modelled on Revit has been added or modified according to the needs of the project. All the components have been defined with parameters, determining its characteristics, restrictions and behaviour in any view on the file. Thus, a floor, for example, can be visualised on different views with every information and characteristic entered therein, such as: coatings, thickness and levels, amongst others.

In the drawing box of the software, in plant, two-dimensional view, various types of shapes and volumes of the model were outlined; for the final result of the towers we explored the mass tool in which we designed the curved perimeter of volume in the basement, copied this same perimeter in the crowning floor and, when copying, supplied parameters and the degree of rotation for all floors, thus allowing twisted volumes.

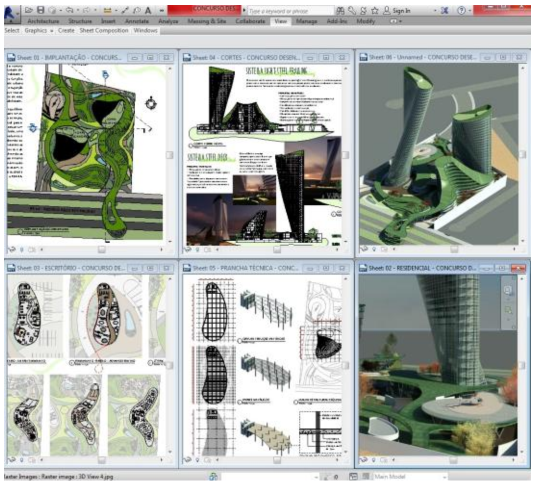

Fig.10 Case Study, creative process in Revit.
Source: The authors.

The way to design with Revit rather facilitated the work, generating details in the application of the modelling. The software allowed that the generation of quantitative in tables and documents were made automatically, as well as the tables of private and common areas, and tables of frames.

Through the experience of the simulation we obtained a virtual reality of space, which is defined by the systems dynamics, creating a 3D interactive environment that can be experienced by those who manipulate it.

The characteristic of storing information and every step of the project defines the relationship between the design of the project and its final result, for the file contains the entire lifespan of the project and the building built in a virtual environment. This not only requires the understanding of the concepts of constructive elements, but also the limitations and possibilities of those elements conducted virtually.

The usage of Dynamo software alongside with Revit for the development of the digital manufacturing process made it possible to organize those processes on the computer, the model for the spatial representations and to the final assembly of the integrated model, in order to allow the manufacturing process contemplating: concept, analyses, structure, floors, panels and finalisation.

In the conceptualization stage, volumetry was developed from a closed curve drawn on the mass environment of Revit. Subsequently the creation of geometry in the Dynamo, specifying the parameters as the height of the top, the displacement of the top in relation to the X or Y axis, rotation of basis in relation to the Z axis and rotation of the top in relation to the Z axis, allowed the automatic creation of mass in the Revit, making it also possible to be manipulated in the Dynamo. (Fig.11).

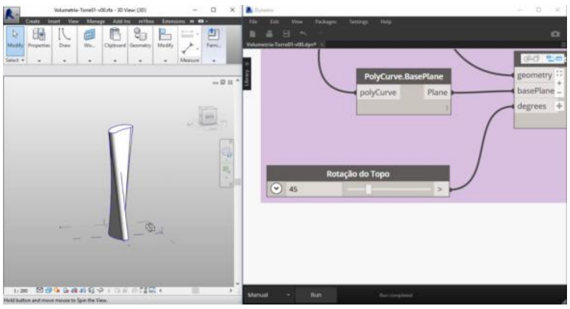

Fig. 11 Step of conceptualization of the case study. Source: The authors.

In the analyses of constraints and geo-referencing stage, we specified information such as date, time and positioning of the sun, which allowed the analysis of sunshine on a given area of the mass, thus extracting every data into Excel. The calculation was done based on direction of the sun and the scalar product of the mass surface normal at various points. (Fig.12).

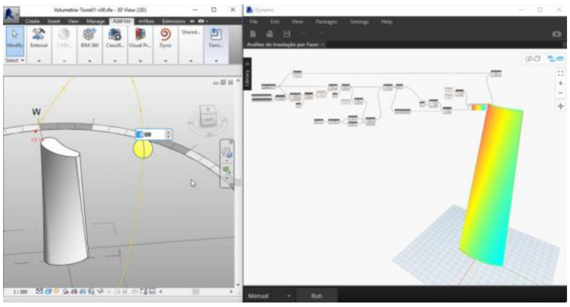

Fig.12 Stage of constraints analyses of the case study. Source: The authors.

In the stage of model structure elaboration, the modelling began in Revit, from the defined structural mesh on steel frame and steel deck and the positioning of the pillars that were used as reference for the positioning of the beams. After inserting the beams, we placed the slabs. All of the wooden beams and the elements that compose the slab were modelled, completing the structural model of the building.

In Dynamo, the mass created was imported to the project, thus enabling the automatic creation of levels using the Dyno Browser solution in order to generate the mass floors. The creation of the mass floors was automatically generated in Revit from the created levels, which served as basic geometry for the determination of the height of the columns. Due to the organic shape of mass we developed a "bridging" method of it in Dynamo for elaboration of the structure. Thus, the columns of circular section were also generated automatically, and finally the adjustment of the columns in Revit. (Fig.13).

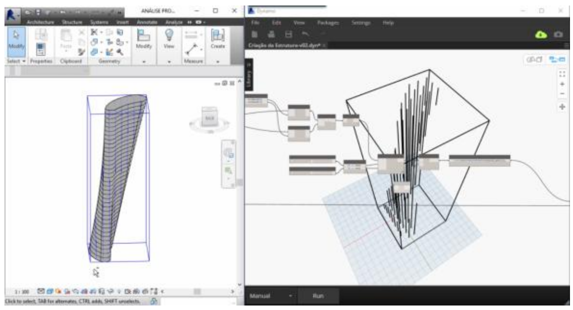

Fig.13 Stage of the structure elaboration of the case study.
Source: The authors.

In the stage of the floors elaboration, they were automatically generated in Revit, taking mass floors as a basis, making it possible to edit them in several aspects, such as finishing, structural materials and total thickness, for instance. This way, it also possible to assess different behaviours of coating materials, manipulating its variables and tolerance. (Fig.14).

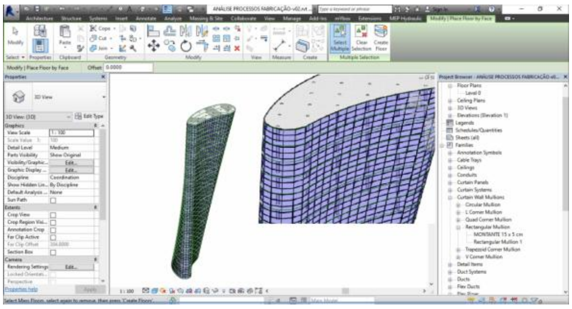

Fig.14 Stage of mass floor elaboration of the case study.
Source: The authors.

In the stage of the panels elaboration, from the selection of the mass faces, the panels were automatically generated in Revit. Once we set the laminated tempered glass for the facades, it also allowed us to study the profiles of the metallic joints that support the windows, which auto fit according to volume and parametric data. (Fig.16).

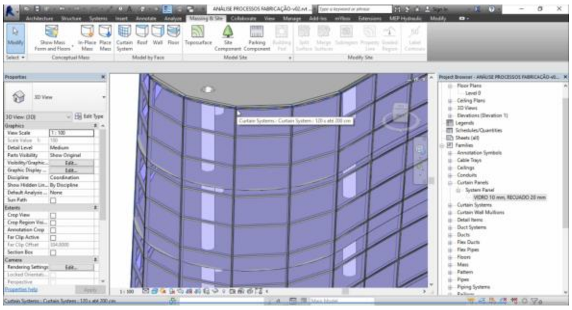

Fig.16 Stage of panels elaboration of the case study.
Source: The authors.

The model is thus composed in its totality, collaborating in understanding spatial and project management, which extends the tri-dimensional processing. The simulation of the model is a system adaptable enough to produce a large spectrum of different shapes and mass customisation, and the digital model is able to develop the production of physical artefacts, from scale models and actual size prototypes until finalised parts for civil construction, due to the documentation, information and data which can be extracted from the template. (Fig.17).

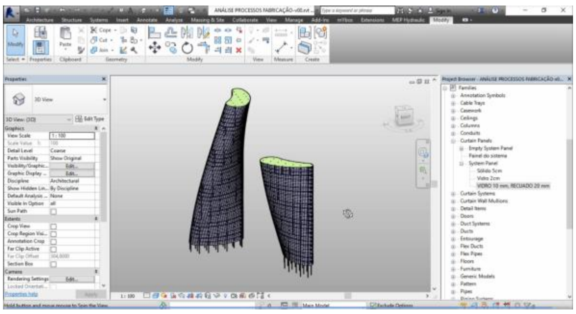

Fig.17 Finalization of the case study. Source: The authors.

VIII. RESULTS AND ANALYSIS

The application of a simulation model using system dynamics allowed more flexibility and scope as an alternative to understand the processes of digital manufacturing.

The virtual environment allowed us to simulate and integrate shapes and aspects of physical space, involve the inter-relations of the proposed project with the capabilities of the software, as well as identify compositional strategy, their programmatic aspects and their structural design.

In seeking this integrity, spatial organization in the software provided exploring dynamic joints; besides, parametric modelling techniques, alongside with the involvement of computational tools, have become essential for the development of the case study.

IX. CONCLUSION

The systemic thought is a valuable instrument for the understanding of the complexity of the shapes and the simulation based on System Dynamics enables the emergence of capabilities as a systemic view, employment of information as a work tool, visualization of strategies and formal compositions, creative capacity and project design.

The experience of system dynamics asks a series of imponderables factors which intervenes to modelling, such as extracting new models, behaviour, parameters, references, a series of elements that contribute to our perception and identify the special features or differences in simulations of space.

REFERENCES

[1] CELANI, G.; VAZ, C.; PUPO, R. Sistemas generativos de projeto: classificação e reflexão sob o ponto de vista da representação e dos meios de produção. *Revista Brasileira de Expressão Gráfica, v. 1, n. 1*, São Paulo, 2013.

[2] SCHUMACHER, Patrik. Parametricism: A New Global Style for Architecture and Urban Design. In: *AD Architectural Design - Digital Cities, London, vol. 79, N. 4*, p. 14-17, Jul/Aug, 2009.

[3] KOLAVERIC, B. Digital Architectures. In: *IV CONGRESSO IBERO AMERICANO DE GRÁFICA DIGITAL*, Rio de Janeiro, 2000.

[4] ARCHITECTURAL DESIGN. *Digital Cities. London, vol. 79, N. 4*, Jul/Aug, 2009.

[5] KOLAVERIC, B. *Architecture in Digital Age*: Design and Manufacturing. Nova Yorque: Spon Press, 2003.

[6] BURRY, Mark; MURRAY, Zolna. Computer Aided Architectural Design Using Parametric Variation And

Associative Geometry. In: *CHALLENGES OF THE FUTURE*. Proceedings. Vienna: Osterreichischer Kunst - Und Kulvurverlag, 1997.

[7] OXMAN, R, 2005. Theory and design in the first digital age. *Design Studies, 27(3)*, p. 229-265.

[8] OXMAN, R.; LIU, T. Cognitive and computational models in digital design: A workshop of DCC04. In: *INTERNATIONAL CONFERENCE ON COGNITION AND COMPUTATION IN DESIGN*, I, Cambridge, 2004. Anais. Cambridge, p. 1-80.

[9] DOLLENS, Dennis. *De lo digital a lo analógico.* Barcelona: Gustavo Gili, 2002.

[10] ROCHA Medero Isabel. Arquiteturas nem boas nem más, arquiteturas possíveis. In: *Arquitetura Revista, 2011, vol. 7, n. 2*, p. 142-160.

[11] MITCHELL, W. J. e MCCULLOUGH M. *Digital Design Media.* N. York: Van Nostrand Reinhold, 1995.

[12] CELANI, Gabriela, PUPO, Regiane Trevisan. Prototipagem Rápida e Fabricação Digital para Arquitetura e Construção: Definições e Estado da Arte no Brasil. In: *Cadernos de Pós-Graduação em Arquitetura e Urbanismo, 2008, v. 8, n.1.*

[13] PUPO, Regiane Trevisan. Ensino da Prototipagem Rápida e Fabricação Digital para Arquitetura e Construção no Brasil: Definições e Estado da arte. In: *Pesquisa em Arquitetura e Construção (PARC), 2008, v.1, n.3.*

[14] OLIVEIRA, L., K., NOVAES, A., G., DECHECHI, E. *Analysis of Agribusiness Systems Utilizing System Dynamics:* A Methodological Contribution. Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto / USP, 2003.

[15] STERMAN, D. *Business Dynamics.* Mc Graw Hill, New York, 2000.

[16] AUTODESK. Dynamo: *Visual Programming for Design.* Disponível em: <http://help.autodesk.com.s3.amazonaws.com/sfdcarticles/kA230000000eAu3CAE/Dynamo%20Visual%20Programming%20for%20Design.pdf>.