Digital fabrication in Brazil
Academic production in the last decade

Elza Luli Miyasaka[1] and Márcio Minto Fabrício[2]

[1] University of São Paulo
[1,2]*Barão de Mauá* University Center
{elzamiyasaka, marcio.m.fabricio}@gmail.com

Abstract. This work aims to review the literature on digital fabrication verifying the Brazilian status on a general view. Concerning the methodology, the research was carried out from 2004 to 2014 analyzing three aspects: 1. the situational context of digital fabrication; 2. digital fabrication in the design process; 3. the Brazilian status. The findings revealed the use of digital fabrication is mainly focused on the design process. Also, the most common objects in the research are the development of models, furniture and pavilions. Moreover, digital fabrication is increasingly being inserted in the syllabus of architecture schools. Brazil strikes in object production both in quantities and interests throughout the country.

Keywords: Digital Fabrication; design production, literature / review; CAD/ CAM architecture.

1. Introduction

One of the main uses of Digital Fabrication refers to the fabrication of curtains and carpet in the beginning of the XIX century. The information was transmitted through little holes on a hard paper which signaled positive or negative commands to the loom machine which would insert different string colors creating various patterns previously set up. According to logical computer matrix, such a codification became electronic data and the principles remained the same along time. In the 70's, Ronald Resch at the University of Utah built an eclipse through CAD system and cut metallic plaques by a computer, a design known as Ukranian Easteregg [1].

In current researches, one of the main examples of digital fabrication was the Disney Concert Hall in Los Angeles of the architect Frank Gehry. In the design, the titanium plaques with carved surfaces which sealed the building were shaped by an aerospace system and the computers controlled the milling machines toward its structuring [1].

In digital fabrication the machines that are controlled numerically can be programmed from the computers as it follows:

[...] the key task in manufacturing and constructions is to convert geometric models (state descriptions of objects) into sequences of machine instructions (process descriptions) [1].

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The process was described according to the diagram as it follows:

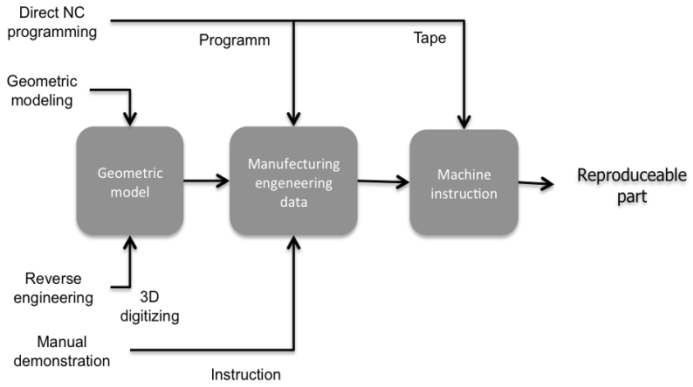

Fig.1 Diagram of fabrication process [1]

A machine receives instructions toward element elaboration which can come directly from a numerical programming or data previously set up by the factory. Such data from a design can be a geometrical model or reversed engineering; the process demonstrates a flow of information which is either organized for production or brought through the production machinery.

The digital fabrication process has been through an improvement since the middle of the XX century in the development of spaceships and submarine capsules. Among differentiated possibilities there are the use of the programs CAD, CATIA[1] and CAM[2] in programming the studies for object building [2].It is a process from design to construction in which it is necessary the translation of designing graphical representations into data, which will be translated to the production machinery. Some translation aspects are related to the connection between the architect and the machinery capacity. That raises the need of architects understand how those tools run, what types of material are applicable, also where the opportunities are toward new possibilities [3].Find below a diagram for model production that uses machinery for fast prototyping [4].

[1] Computer Aided Three-Dimensional Interactive Application
[2] Architecture Manufacturing Design

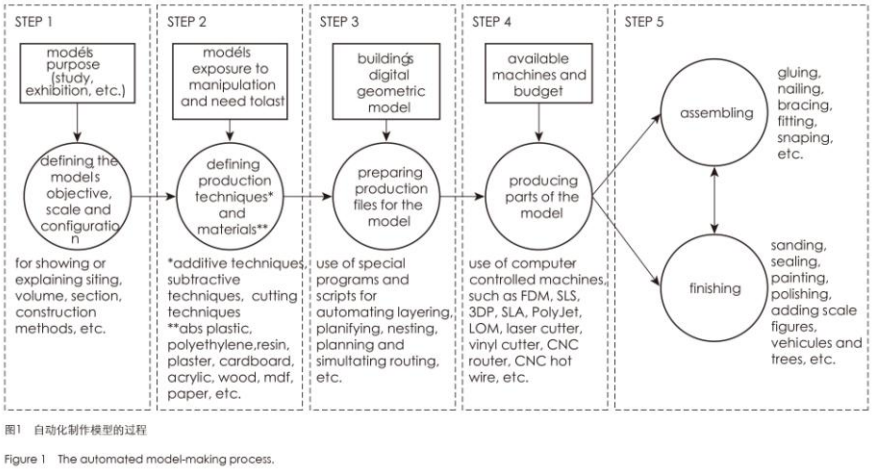

图1 自动化制作模型的过程

Figure 1 The automated model-making process.

Fig. 2 Automatized process for model construction [4]

In the diagram above, there are subsequent steps; in the first one the concern is toward the main characteristics of the physical model such as scale, object, etc. The author mentions that in digital data models, different from traditional ones, it is possible to reach higher accuracy and sharpness having better details of the building. In the second step, when techniques and materials are established, there is the importance of assertive and integrated choices within techniques, machines and geometry which will be applied in the model, as some types of geometry can only be produced under specific techniques. In the third step, it is the moment to produce the files to be addressed to the machines. Those data are generated in drawing, similar to the traditional models, instead in the digital format. In the fourth step, the pieces are produced generated by the machines, which in turn, receive digital data and will transform them in pieces assembled and finalized in the fifth step.

In both commented diagrams, the authors did not mention the increasing information with more complex surfaces; in those cases, the generated data are also more complex in addition to being generally associated with designs to specified piece production through algorithms.

In 1995, it was already discussed ways for the development and production of architecture. It was mentioned the needs for architectural codification, moreover the use of modelling and evolutionary forms in machinery applying it to design development [5].

A more significant requirement is that of materialization into a buildable medium. This could be achieved by making part of the code simply representing a material and a precise construction technique […] final transformation should be process-driven, and that one should code not the form but rather the precise instructions for the formative process [5].

For the production of buildings with elements produced digitally, the challenge has been to interpret data appropriately by designers applying parametric relations. This transformation involves the surface elaboration of various parts as the machines would perform cuttings, forms and component drilling. For example, on performing a decreasing spiral cover carried out in 1990 by the CAD system, it was elaborated over 300 individual panels. Nowadays, it could be performed faster and probably under lower cost. The algorithm production would produce defined panels for the machine, according to the specification of the architectonic design as well as the edge details necessary to avoid water infiltration [6].Production can be characterized by the target, number of working axes, also object production means which can be studied, that is, models and prototypes are named under fabrication or digital manufacturing [9].

Digital fabrication is a posterior phase to the concept process and a fabrication method under digital data; however the designer needs to verify and analyze the fabrication process longer before the object concept phase [7]. The production strategy can be: 1. 2D fabrication generally using CNC cutting, works with shaping, triangulating or polygon, reproducing deformable surfaces or unfolding. They are related to the creation of flat components for structures and surfaces. 2. Subtractions are related to the material removal from a solid surface, the CNC Milling is a kind of computer-driven equipment with a cutter for sculpting. 3. The addictive system, opposite to the last one, places the layers for an object formation. 4. The building system performs the material through force, heat or steam toward either remodeling or malformation, mainly using axial or surface movement [8].

In 2008, the applying of digital fabrication in Brazil was still restricted and probably there were little technical uses due to high equipment cost as well as inputs. Another important aspect was the working force qualification into the handling of such equipment, besides higher education made little use of those machines for the design development [9]. Currently, the digital fabrication process seems to have great building potential thanks to equipment and available technology. A professor at the University of Brasília [10] mentions the existence of complex building production equipment in Brazil, also that some of them can be found in some products; the use of that technology is starting to impact little pieces such as art pieces with scales and structures.

In the mentioned scenario where we described briefly some aspects of the current digital fabrication context taking into account the Brazilian status, this work aims to analyze and review the literature concerning the proposed issue within the last 10 years.

2. Method

The research was carried out in the second semester of 2014 through the registered article WebWilson system at the library of USP - University of São Paulo, furthermore the databank of Cumincad which gathers articles related to Computer Aided Architectural Design and works of main events of the theme such as ACADIA, ASCAAD, CAADRIA, eCAADe, SiGraDi and CAAD futures. The keywords were

Digital Fabrication, Design for Production and CAD/CAM for architecture. The search has looked for articles published from 2004 to 2014. After that, it was analyzed the title, keywords and abstracts verifying the link with the research. After this selection, the articles were read, tabulated and categorized according to the following criteria; 275 works comprised the sample:

_ Data of author identification: name, university, country and hemisphere;
_ Publishing data: journals, magazines, book and thesis, title and year;
_ Debating area: teaching, design, buildings and research;
_ Scale: object / body, furniture / pavilion, building / construction and urban;
_Type: theoretical / critical, parametric, geometry, biological, historical patrimony;
Equipment: Robo (3D), Laser Cutting (2D), CNC miling (3D).

The analysis was divided in three topics:

Topic 1 refers to the general literature context with the approach on digital fabrication identifying the quantity data, the working types in which the scale objects and others are produced. Topic 2 debates the architectural design process, also digital fabrication dividing it in 4 blocks for analysis under the tendencies of the contemporary debates. Topic 3 reflects the Brazilian situation in the broad view showing peculiar characteristics of the country. Finally, the works were read and analyzed targeting the current context; besides the ways through which digital fabrication runs.

3. Results and Discussions

After presenting how the articles were organized and divided, we show the analysis and discussions below:

3.1. Topic 1 - Identification of Data

This item refers to the identification and contextualization of general literature. From 275 articles which dealt with digital fabrication, 82 (30%) were from North America, 79 (29%) from Europe, 77 (28%) from South America, 29 (11%) from Asia, 4 (1%) from Middle East, 3 (1%) from Africa and 1 (0%) from Central America. 65 South America published articles (84%) were Brazilian productions, 6 (8%) from Chile, 3 (4%) from Argentina, 2 (3%) from Peru and 1 (1%) from Uruguay. This distribution of publications seems to be related to their national events what promoted researchers to write on a daily basis. The highest publishing number was on events summing 197 (71%) works, 64 (23%) of published articles on magazines, and 17 (6%) on books and thesis. The magazines represent the highest publishing on the proposed issue revealing the magazine *International Journal of Architectural Computing* followed by *Automation in Construction* and *PARC_fec.unicamp.br*.

In the articles produced between 2004 and 2014 (Fig.3), we observe the issue has increased in the last 10 years. The highest peak was in 2009 probably referring to the event *Sigradi* which took place in the city of São Paulo making it easier for the Brazilians to take part in the Congress. In addition to that, the necessary machinery

for digital fabrication research was more available; this fact enabled its acquisition by the architectural schools justifying the increase in the published work.

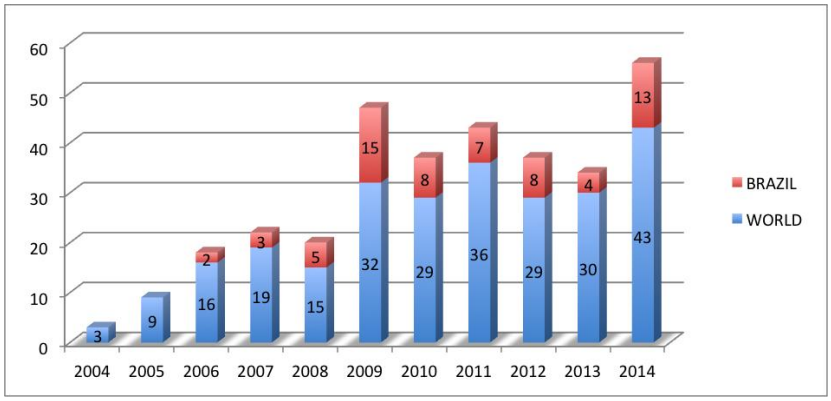

Fig.3 Publications per year

We notice that in Brazil (65) and the United States (80) there have been remarks in researches on digital fabrication in the last 10 years, followed by Switzerland (13), Great Britain (13), Australia (12) and Austria (11). In Brazil, UNICAMP takes part in the total number of 29 (44, 6%) of 65 works, almost half of all published works in the country. In the USA, it is remarkable the work at the MIT with 21 (26%).The works present a main debate on digital fabrication and architectural design in 144 (55%); digital fabrication issue is present in 57 (22%) and 17 (7%) which debate digital fabrication and model; 13 (5%) analyze digital fabrication and teaching. These data will be debated in Topic 2.

Concerning the general approach of works, we verified 60% of them were parametric design, 39% were theoretical or critical, 23% debated geometry for architecture, 9% used biological aspects and 2% debated cultural patrimony. From those articles, 15 debated architecture teaching mainly reflecting the needs of digital fabrication inclusion in the syllabuses of the architecture universities. The Brazilian participation flows through the same tendency, such as on parametric designs, teaching, theoretical one and critical works. It is key element to mention the interest on historical patrimony, although less the technologies are broadly used for cataloging, studying of patterns and documentation in architecture.

On the scales of the developed objects, they were categorized by object, furniture and pavilion scale both in buildings and in the urban areas. The most frequent working scales are the two lowest ones; object (32%) and furniture / pavilion (43%). Most works invest on those scales because they are related to the object process what enable it for dimensions and runtime. Another aspect can be due to the size of production machines which probably have a suitable size for a laboratory and not for a building, in fact, laboratories are organized environment at universities. Brazil also

presents similar characteristics with 46% in object scale and 43% in furniture / pavilion.

The most widely used production equipment are Laser Cutting (2D) and NC (3D) with 123 cases for each; followed by 37 which used 3D Printing and 32 Robo. Laser Cutting use seems to reveal a better ability toward time, also different materials into architectural model construction, and a cheaper equipment cost as mentioned previously.

As aforementioned, Brazil is the country that publishes more articles as far as digital fabrication is concerned, taking part into events it presents an increasingly distribution showing two peaks: in 2009 and in 2014. The main researchers' concern is toward the design process, having several investigative works of parametric design as well as exploration on digital fabrication. The most common work scales are of body, furniture and pavilion in which laser cutters and CNC cutters were used.

3.2 Architectural Design and Digital Fabrication

The debate on the second thematic topic is on the reading of four tendencies related to the architectural design process which are present in the researched articles, as revealed in the diagram below. For such an analysis, the design process is comprised as it follows: the steps are from the need analysis to the program elaboration, execution and evaluations by users and technicians [11].

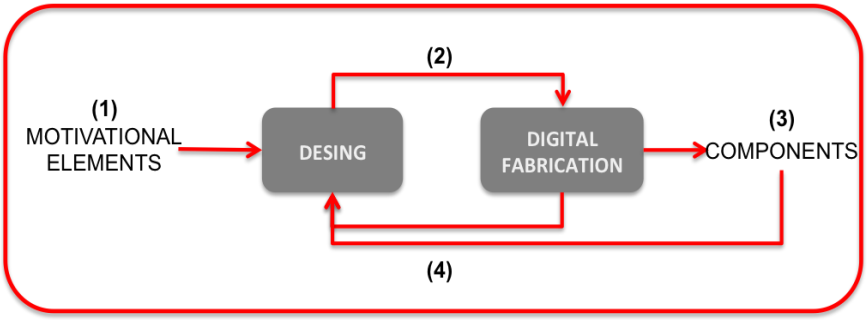

Fig.2 Diagram of analysis

Analysis of block (1): The motivational elements for design elaboration allows us to observe various and several themes: the most common one is the parametric design generally applying the Rhinoceros_Grasshopper program, since this tool can be used when associated with subjects like digital fabrication, simulation, modelling, etc.

The articles present works with shape and their parametric possibilities associated with design development and digital fabrication. They describe constructive experiences, workshops, furniture and pavilion making; they also reflect digital

fabrication as a tool for the design process; they produce comparative analysis with non-visual programming models and those authors in [12], [13], [14], [15], [16], [17], [18], [19], [20], and [21].

Some works show a concern on the material quality in design development and digital fabrication, that is, designs that make use of wood analyzing its behavior or in the search of materials which have similar behavior to other structures, for example cases [22] and [23].Geometry has also found visibility among the analyzed issues in the articles. Generally it deals with the object constructability associated with its complex shapes, for example in [24], [25], [26], [26], [27], [28], and [29]. Some other issues which are less frequent are participation, mapping, historical patrimony, reverse engineering, artificial life and simulations.

Block (2) deals with architectural designs and the planning for digital fabrication. In those cases, the works are focused on the planning for fabrication; this phase is called design for manufacturing, production or automation. It has the focus on the fabrication process from the piece elaboration which will define the proposed shape to the assembling of the site, going through detailing, construction and assembling. In the work for the construction of an exposition basis [30], they describe the work development process as: 1. defining geometry; 2. automated detailing; 3.automated nesting with structure organization, the minimizing of waste, identification; 4. generating NC code for machines that is the final step of the production chain. The works of block 2 have in common the understanding of such phases as a specific production design in which it involves the definition of algorithms for geometry definitions, of detailing that will be translated into the production machine, identification of pieces and assembling. The works in this area are [31], [32], [33], and [34].

The block 3 comprises the set of works addressing customized concepts in mass, production management and manufacturing. Some cases address the Lean concept [35], some others address parametrization toward customized production [36]; computing and automation for industry [37]; technological revising for mass customization [38], among others. In this set of works there are analyses on costs, optimization, and users' participation along with their experiences [39], [40], and [41].

In the block 4, there are articles addressing architectural designs through production and the privileged data are: machine possibilities, material behavior, characteristics on logistics and assembling. These authors analyze how manufacturing parameters can be integrated to the design process enabling communication in the production process [42], also the analyzed production by tolerance tests, structure and assembling [38].Interdisciplinary aspects, cooperation, connectivity, besides creative constructions are fundamental issues to the architects. Before the quantity of data – code, modeling, visualization, analysis, and production – it is paramount to consider the management and exchange of data which are in every design process and production in architecture. Industrial collaboration toward problem solution is about real problems, fabrication, logistics as well as assembling [49].

The Brazilian articles which address the development of architectural designs associated with digital fabrication excel in model uses for architectural design

development (26%), in the production process it is found (26%), theoretical ones in (15%), among other frequent debates correlated there are parametric designs and teaching as it will be debated below.

3.3 Topic 3 - Brazilian Context

In a work published in 2008, it is found that there were a few researching registered groups in fast prototyping and / or digital fabrication; one of them has been in Brasília since 2000, one in São Paulo since 2005 and one in Campinas since 2006 [44]. Nowadays, it is known that the reality has changed due to the published works at several universities. In those, we observe digital fabrication is key debate representing the main discussion on the issue as a tool for the architectural design development. As a tool, they debate the use of parametric design, technology under laser cutting and 3D printers, use in cultural patrimony, representation of drawing according to the model, processes of design creation, model roles, building process of furniture and pavilion, sustainable furniture, design based on biological structures, technological use for the analysis of distinguished architectural designs along with simulations of behaviors in structures.

In all researched Brazilian articles, we observe teaching holds a prominent subject within the addressed issues. The issue is addressed as a helping tool in architectural design, in the use of exciting technologies and their approach toward pedagogical understanding; moreover in workshops they are associated with parametric designs and considerations over the creation process, and laboratory assembling at the Brazilian universities. Regarding the theoretical or conceptual articles, literature addresses definitions in [44], [9], and [45], in the state of art in [44], researches on technological park in some Brazilian regions and clarifying the technological park according to the author, furthermore there is enough equipment for the Brazilian civil construction use [46].

Finally, it is important to note some of the works were carried out at the Fundamental School and social areas that use digital fabrication technology as a pedagogical tool, along with teaching; tools which enlarge the cognitive capacities, manuals and development are present in [47], [48]. Although, they are a few, it is relevant to mention these types of efforts have extensive receptivity in the Brazilian territory taking into account it is a vast field of action given the characteristics of the emerging countries.

4. Final Considerations

About the analyzed articles, we conclude that digital fabrication is mainly addressed in North America, Europe and South America, specifically at conference events. There are two peaks of publishing on the issue probably due to Congresses: one in 2009 and another in 2014. The main debated theme in digital fabrication is linked to architectural design in subjects such as parametric design, geometry and biology.

Generally, the developed objects are in body scale, furniture and pavilion, furthermore the most commonly used equipment is for cutting and subtracting. Regarding the works which discuss architectural designs and digital fabrication, there are four blocks of approach: (1) those that use motivational aspects as parametric design, simulations, geometry, participation; (2) those that discuss the design process for production generally by algorithms for problem solution; (3) articles which address the management issue verifying optimization strategies, cost and feasibility; (4) those that develop architectural design through fabrication parameters. Brazil stands out in articles on digital fabrication; besides addressing digital fabrication, there are also fast prototyping used as tool for the architectural design process. Teaching has also been a concern of authors; moreover technologies should be inserted in academic curricula.

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5. References

1. Mitchell, W.J. and Mccullough: M. Digital Design Media, 2nd. ed., Van Nostrand Reinhold, New York (1995)
2. Smith, R. E.: A Guide to Modular Design and Construction, John Wiley & Sons, New Jersey (2010)
3. Iwamoto, L.: Digital-fabrication_Architectural and Material Techniques, 1st ed., N. Princeton Architectural Press New York (2009)
4. Celani, G.: CAD Integrating CAD Drawings and Model-making: the Computer-controlled Model-shop, Computational Constructs: Architectural Design, Logic and Theory, China Architecture & Building Press, Shanghai, (2009)
5. Frazer, J.: Art Evolutionary Architecture, Architectural Association, London (1995)
6. Zahner, L. W.: Digitally Defined Manufacturing In: Kolarevic, B. & Klinger, K. Manufacturing Material Effects: Rethinking Design and Making in Architecture, Routledge Taylor & Francis Group, New York (2008)
7. Dunn, N.: Digital Fabrication in Architecture, Laurence King Publishing, London (2012)
8. Kolarevic, B.: Digital Fabrication: Manufacturing Architecture in the Information Age, ACADIA, (2001)
9. Celani, G. and Pupo, R. T.: Prototipagem Rápida e Fabricação Digital para Arquitetura e Construção: Definições e Estado da Arte no Brasil Cadernos de Pós-Graduação em Arquitetura e Urbanismo**,** São Paulo (2008)

10. Silva, N. F. et al.: A indústria da Construção Civil está Pronta para a Fabricação Digital e a Customização em Massa? Uma Pesquisa Sobre um Caso Brasileiro, Sigradi _ Congresso da Sociedade Iberoamericana de Gráfica Digital, São Paulo, (2009)
11. Fabricio, M. M., Baía, J. L. and Melhado, S. B.: Estudo da sequência de etapas do projeto na construção de edifícios: cenário e perspectivas, Anais_Encontro Nacional de Engenharia de Produção, São Paulo (1998)
12. Figueiredo, B., Duarte, J. P.: Making customized tree-like structures Integrating algorithmic design with digital fabrication, Sigradi (2009)
13. Goldberg, S. A.: Computational Design of Parametric Scripts for Digital Fabrication of Curved Structures, International Journal of Architectural Computing, IJAC, v. 4, n. 3, 99-117 (2006)
14. Biloria, N., Oosterhuis, K. and Aalbers, C.: Design informatics: a case based investigation into parametric design, scripting and CNC based manufacturing tecnics, Computing in Architecture / Re-Thinking the Discourse: The Second International Conference of the Arab Society for Computer Aided Architectural Design ASCAAD, 25-27 (2006)
15. Schindler, C., Braach, M. and Scheurer, F.: "Inventioneering Architecture" – building a doubly curved section through Switzerland, ACADIA (2006)
16. Oxman, N.: Digital Craft Fabrication-Based Design in the Age of Digital Production, International conference on Ubiquitous Computing, 534-538 (2007)
17. Anzalone, P., Vidich, J. and Draper, J.: Non-Uniform Assemblage : Mass Customization in Digital Fabrication, Without a hitch: new directions in prefabricated architecture 298 – 306 (2008)
18. Florio, W.: O uso de cortadora a laser na fabricação digital de maquetes físicas, Sigradi (2008)
19. Hudson, R.: Aviva Stadium : A case study in integrated parametric design Aviva Stadium: A case study in integrated parametric design, International Journal of Architectural Computing, v. 9, n. 2 187 – 204 (2009)
20. Celani, G. and Vaz, C. E. V.: CAD scripting and visual programming languages for implementing computational design concepts: a comparison from a pedagogical point of view, International Journal of Architectural Computing, v.1, n.10, 1-20 (2012)
21. Vrouwe, I. and Pak, B.: Framing Parametric and Generative Structures ANovel Framework forAnalysis and Education, ecaade 32, (2014)
22. Richards, D. and Amos, M.: Bio-inspired computation for digital fabrication, ACADIA, 101-110 (2014)
23. Oxman, N.: Material Computation, Manufacturing Bespoke, 256-265 (2012)
24. Shadkhou, S. and Bignon, J.: Proposition of a Parametric Model for Non Standard Timber Construction, eCAADe 28, 395-402 (2004)
25. Sheurer, F.: Turning the design process downside-up Self-organization in real-world architecture, Generative Art, Proceedings of the 6th International Conference (2005)
26. Pottmann, H.: Architectural Geometry and Fabrication-Aware Design, Nexus Network Journal, v.15, n.2, 196-208 (2013)

27. Mun, K.: Vitalized geometry ACADIA, 67-70 (2014)
28. Wallner, J. and Pottmann, H.: Geometric Computing for Freeform Architecture, Journal of Mathematics in Industry, v.1, n.1, 1-19 (2011)
29. Hladik, P. and Lewis, C.: Singapore National Stadium Roof, International Journal of Architectural Computing, v.8, n.03, 257- 277 (2008)
30. Schindler, C., Braach, M. and Scheurer, F.: " Inventioneering Architecture " – building a doubly curved section through Switzerland, Acadia (2006)
31. Lyon, E.: Digital Fabrication and Component Optimization Using DFM Integrating Two-Dimensional Cutting and Three-Dimensional Milling in Wood Panel Fabrication, Istambul, Computation: The New Realm of Architectural Design [27th eCAADe Conference Proceedings, (2009)
32. Scheurer, F.: Materializing Complexity. Architectural Design, 2010, 79(4), 86–93, (2009)
33. Scheurer, F., Christoph S. and Markus B.: "From Design to Production: Three Complex Structures Materialized in Wood." In 6th International Conference Generative Art 2005. , ed. Celestino Soddu. Milan, 2005.
34. Brell-Çokcan S.: Digital Design to Digital Production Flank Milling with a 7-Axis CNC-Milling Robot and Parametric Design, Modes of Production - eCAADe 27 (2009)
35. Tsigkas, A. and Chatzoupoulos, C.: From design to manufacturing for mass customization, Advances in Production Engineering & Management, v.4, 19-24 (2009)
36. Anzalone, P., Vidich, J. and Draper, D.: Non-Uniform Assemblage : Mass Customization in Digital Fabrication, Without a hitch: new directions in prefabricated architecture, 298-306 (2008)
37. Silva, N., Santos, D. and Lima, E.: Computing and Automation in the AEC Industry: Early Steps towards a Mass Customized Architecture, Innovations and Advances in Computer, Information, Systems Sciences, and Engineering, 1-4 (2011)
38. Ramani, K., Cunningham, R., Devanathan, S., Subramaniam, J., & Patwardhan, H.: Technology review of mass customization. Precise; Purdue Research Education Center for Information Systems in Engineering (2011)
39. El, K. Mohammad, S., Hanafi, M. A., Nasr and Mohammad, A.: Closer Perspective on Fabrication Realities, ecaad 30 2008
40. Bernardo, M. V. and Cabral, J. S.: Fabricação digital e variedade fora do contexto industrial, Montevidéu, Sigradi (2014)
41. Lara, A. H., Canella, E. G., and Giacaglia, M. E.: Brinquedos , modelos : uma atividade lúdica se transforma em curricular com apoio das novas tecnologias de fabricação digital. Sigradi (2010)
42. Guzik, A.: Digital Fabrication Inspired Design Influence of fabrication parameters on a design process, eCAADe 28 (2010)
43. Klinger, K.: Digital Design through Production Pedagogy: Cases Involving Student / Industry Collaboration, Sigradi (2009)

44. Pupo, R.: Ensino da prototipagem rápida e fabricação digital para arquitetura e construção no Brasil: definições e estado da arte Campinas: parc fec.unicamp (2008)
45. Pupo, R. and Celani, G.: Técnicas de prototipagem digital para arquitetura, Anais Grafica (2009)
46. Silva, N.; Santos, D. and Lima, E.: Computing and Automation in the AEC Industry: Early Steps towards a Mass Customized Architecture, *Innovations and Advances in Computer, Information, Systems Sciences, and Engineering, chapter 93, v*olume 152, New York, (2011)
47. Lara, A.H.; Canella, E. G. and Giacaglia, M. E.: Brinquedos, modelos : uma atividade lúdica se transforma em curricular com apoio das novas tecnologias de fabricação digital, Sigradi, (2010)
48. Angelo, A., Neves, H. M. D. and Campos, P. E. F. de: Fab Lab Kids : Oficina de projetos socioambientais para crianças de escolas públicas fazendo uso da eletrônica e da fabricação digital, Sigradi, (2012)