# USE OF DESIGN FOR ASSEMBLY FOR THE PRODUCTION OF SINGLE FAMILY HOUSES IN LIGHT STEEL FRAMING

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## ABSTRACT

The Design for Assembly (DFA) is a specific type of design, focused on production systems that use prefabricated parts, which includes information about how a certain product should be assembled, reducing costs and production time. Thus, the DFA is highly developed and widely used by serial products industry. In the brazilian construction industry, the DFA is practically unknown and unused, because in Brazil it's not so common to use building systems with prefabricated parts for the production of single family homes. Thus, this paper proposes the development of guidelines for use and development of the DFA focusing on single-family homes that use the building system Light Steel Framing (LSF). This is a work developed from structured interviews, which focused on both the design process as the production process, from the collaboration of companies and professionals who work and develop the LSF, and the literature review of the issues in question as the DFA and the LSF and related topics. The contribution of this paper is represented by the proposed of implementation of the DFA, unprecedented in brazilian civil construction, from a prefabricated building system.

Keywords: Civil Construction; Design for Assembly; Light Steel Framing

## 1. INTRODUCTION

In construction, the design process is an activity very challenging, given that, to design a building there is a need of multidisciplinary teams that usually not exist within companies. This fact makes difficult the interaction between the various disciplines of design given that the process becomes dependent, generally, the experience of professionals, who develop in isolation in the sense of exchange of information between different designs, in addition there isn't an effective planning of the work in construction, which generates wastes and unforeseen.

From the point of view of current practices about design, traditional methods of designing in construction are still grounded in practices that separate this process from production activities. Thus, in order to modernize the sector, the construction industry starts to give more importance to the process of integration between design and construction activities (SONG; MOHAMED; ABOURIZK, 2009).

In this sense, Blacud *et al*. (2009) suggest that the activities of design and production can be overlapped under the terms of exchange of information between such activities, which allow better integration between the processes. The authors show that such overlap and exchange of information can be reached by the concepts of Concurrent Engineering (CE) associated with specific types of design.

In the case of use of the LSF, as a prefabricated building system, the design becomes the key step for the success of the enterprise, both from the point of view of engineering and for the consumer. Thus, for the design of buildings in LSF is necessary the design of all its features aligned to the various subsystem and, specially, prediction of the production. However, as described previously, the traditional practices of design are totally incompatible with prefabricated systems as the LSF.

Regarding the ideal and necessary projectual development, which support the LSF design, Prins and Kruijne (2008) claim that the design can be understood as a process of generating information and specifications that begins on product conception and extends to production through information and subsidies. In this sense, considering the application of CE between processes of buildings in LSF, comes out a specific type of design, called Design for Manufacture. Specifically in the use of LSF, the Design for Manufacture can be particularized for the concept and application of Design for Assembly (DFA). In summary, the DFA is a type of design that aims the simplification of the production process by reducing the number of product components, guiding and facilitating assembly activities that uses such parts.

Thus, this paper proposes the use of DFA in the context in which inserts the process of design and the production of single-family homes of up to two floors in LSF. To that, were developed guidelines that include several steps to construct the DFA for LSF buildings. The guidelines will show information about the structuration of the drawings and the textual information that must go along with the graphics representations.

## 2. RESEARCH METHOD

The reasoning and the final product presented in this paper are based on information for the design and production of buildings in LSF in Brazil, for which were used as a technique for data collection, interviews. According to Beck, Gonzales and Leopardi (2002) in researches with qualitative approach, as the present study, the interview is an important resource for the researcher and configures itself as a technique in which the researcher is present with the informant and establishes relevant issues to your research.

In this sense, a script was developed, divided in two parts that approach both the design process of buildings in LSF as the process of production of these buildings. The approach of the production process along with design was chosen for to note possible consequences that the current design practices relating to LSF cause to the construction sites and, thus, suggest some techniques applicable to design that help to enhance the rationalization provided by LSF. It should be noted that the interviews were recorded by means of electronic devices with proper authorization from the pros. Moreover, it is necessary to emphasize that this work demands a solid conceptual basis, since the theories used here are not commonly used in construction. Thus, it was used a consistent literature review with major authors who research the issues discussed here.

# 3. RELATIONS BETWEEN FOUNDATIONS

## 3.1 Basic Considerations with Respect to Light Steel Frame

Arguably the LSF present major advantages justified by the production of prefabricated components. In a global analysis of an enterprise in LSF, this may represent an enormous gain from a technical point of view, but, commercially, still faces cultural barriers in Brazil. Economically, the LSF is not much more expensive than traditional systems, so that the initial cost of a unit is diluted by their speed of execution compared to the conventional systems.

Gorgolewski (2006) lists some of the advantages of using LSF, such as: high strength, low weight (both structure and other components), high dimensional accuracy, resistance to insects and the materials used are almost entirely recyclable, contributing for sustainable buildings, and contribute to increase the level of expertise and quality of workmanship and establish high standards of construction.

In general, the LSF system uses prefabricated components (the entire structure is prefabricated and can be designed to show solidarity with the modulation of the fence) and thus can be that the buildings in LSF are, obviously if the design provide subsidies for this, produced from the assembly of components, excluding the foundation, which still must use concrete as the main material. Veljkovic and Johansson (2006) point out that the LSF system can be designed to attend all functional requirements, typical of residential buildings and it's suitable for industrial production, can being a part of the process of an industrialized construction.

In a theoretical analysis on LSF construction sites, Vivan and Paliari (2011) ensures that the process of production is based, in essence, for conversion activities defined by assembling the components. In the context in which insert the LSF construction sites, an assembly activity differs from the conversion of inputs, for be understood as the act of uniting, trough connections and fixing devices such as screws, two or more prefabricated components, with specific geometries that will originate the systems elements of the building. In this sense, the ideal characteristics for the design process should be guided by certain principles that allow the effectiveness in production from the integration with the design process.

Thus, from the perspective of prefabrication of components in LSF, is coherent demonstrate the relationship of the process of design with the CE, having principal focus, the reasoning in development of designs that look on the assembly of the elements.

## 3.2 The Concurrent Engineering and the Design of Light Steel Framing

As explained previously, in construction, the processes, intellectuals and executives, are traditionally sequential. For this, much contributes the technological delay of the procedures for the administration and the high incidence of expertise of the professionals, which will hinder the interaction between teams and the dynamics of information flow.

Such problems are related, among other factors, with the decoupling of design, product engineering and production, resulting from the great difficulty encountered by construction professionals, responsible for such steps, to communicate and interact effectively (TOOKEY *et al*., 2005). Thus, to solve these problems, industry professionals have introduced new working methods and organizational structures to enable integration between the design, its development and production. According to Tookey *et al*. (2005) these methods resulted in infinity of tools, and the most remarkable of all is the CE.

In understanding of Antaki, Schiffauerova and Thomson (2010), the CE is a strategy where a number of tasks are developed in parallel, in other words, in a non-linear way, by members and leaders of different departments and locations. According to the authors, the consideration of the flow of information, provided by the CE, ensures higher and better level of communication between departments and, consequently, between processes which reduce costs and design changes during production.

In respect to the design process of LSF, the use of CE, such as actuation strategy, it's especially important, seeing that all activities necessary for the construction of building should be studied, designed and coordinated during the design process because this building system is incompatible with unforeseen in construction sites. The use of CE consent that the assembly activities, inherent in LSF, are properly detailed, revealing to the worker the right mode of execution, the assembly sequences, as well as interference between subsystems, and reducing, or even, eliminating unforeseen (VIVAN; PALIARI; NOVAES, 2010). Thus, considering essentially a project's engineering in LSF, it's necessary to have a special dedication between two of the most important processes that make up the building: design and production.

Thus, CE provides the ideal and necessary conditions for the development of a specific type of design that includes the sequences of elements assembling that use prefabricated parts, as occur with LSF. Koskela (2007), addressing the concepts behind the CE, states that in order to use some innovating tools and the change of the traditional practices, characteristics of traditional design process, some solutions emerged like the Design for Assembly (DFA).

### 3.3 Design for Assembly

The serial products industry has developed in a competent and integrated manner both the technology used in the products and design strategies related to them. Today, in these industries, the design process is fully integrated with production and to others aspects of the product life cycle like marketing, maintenance, sustainability, etc.. In academy, the first studies to approach the design as a process capable of interpreting the specific activities of assembly are by Boothroyd and Dewhurst during the late '70s and early '80s, specially the article entitled Design for Assembly, of these authors (KUO; HUANG and ZHANG, 2001; MOTTONEN *et al*., 2009).

According to Wu and O'Grady (1999), the DFA is an effective approach in relation to the design process for the use of CE, because the main objective is to involve the assembly operations and related support activities, being thus an important aspect of the CE, because to do so, the process of design demand for the exchange of information between teams and processes.

Boothroyd, Dewhurst and Knight (2002), considers that DFA is a design tool that aims to analyze the effectiveness of the ease of assembly of the products through the design, delivering quick and simple results. The authors also claim that the DFA should be easy to understand, to ensure consistency and completeness of the parts during assembly, prevent and even eliminate subjective evaluations with respect to assembly activities, identify problem areas in production and suggest alternative solutions aimed the simplification of the activities of production, reducing costs. A striking feature of the DFA, in view of all its attributes, is its graphical representation. In it, usually, the component or element is represented in exploded perspective showing the components and their locations of fit or fixation.

Thus, analyzing the concepts presented can be said that the DFA is a design method, which aims to predict what the activities and tools are necessary for the production of an object that uses prefabricated parts, in other words, an initial analysis in context in which it operates the construction shows that using the DFA during the design process, means designing a product assembly. As a consequence of its use, the process of developing the design creates possibilities of evolution in the form of the product, since one aim of DFA is to simplify and reduce the parts to be used in the product.

Because there is reduced activity of converting raw materials into a construction site of LSF, the DFA can increase productivity and quality in work, among other improvements. In this sense, Fabrício (2008) suggests the development of guidelines that take into account both the characteristics of the production system as the interface with product designs for that the information generated define properly the execution of work. In the case of housing in LSF, the elaboration of guidelines seeing the execution activities, proposed by the author, can be made through the DFA itself, since the building system in question is characterized by being produced by assembly activities, the would justify the use of such design.

## 4. ABOUT THE INTERVIEWS

The interviews were made with five professionals. The first interview was conducted with a professional who works in the *Companhia de Desenvolvimento Habitacional e Urbano* (*CDHU*). The second interview was conducted at the *Instituto de Pesquisas Tecnológicas* (*IPT*) with professional responsible for the quality of materials used for construction in homes built for *CDHU*. The third interview was conducted with professional responsible for managing a construction site of *CDHU* in the city of *Caraguatatuba*, performed by a construction company specialized in LSF, based in the city of *Curitiba*. The fourth interview was conducted with a professional builder, also specialized in LSF, based in *São Paulo*. And finally, the fifth interview was conducted with professional responsible for the design and execution of buildings in LSF, his company is based in the city of *Belo Horizonte*.

Considering the production of buildings in LSF, it was proved that the manpower is specialized and highly dependent on technical expertise and practical experience to perform the services and any decisions that could be taken at the jobsite. With regard to the designs developed for the LSF, these follow the usual practice adopted in the conventional construction, in other words, there is a hierarchical sequence of services that begins with the architecture of the building. According to respondents during this sequence of development, the designers rarely exchange information among professionals and the construction site, so that the compatibility between systems and subsystems of the building is supported by the contractor.

This shows that companies do not currently use CE as a tool for development of its products, whether through ignorance or for convenience in what is traditionally practiced. In this sense, it was also found that businesses and professionals interviewed did not develop any type of design for manufacture or assembly, despite knowing the general concept of this type of design. It could say that the works in LSF, in Brazil today, are produced with basic designs that somehow are a little more detailed than those used for conventional construction.

In a way, these designs contain very important information for the LSF, like the arrangement of panels and its composition as well as the layout and composition of other elements. But they are not sufficient to meet the demand for information of the activities of the production process, so that usually arise many doubts on the part of workers at the construction site. Thus, in an attempt to reduce the demand for executive information, in sequence, are presented guidelines for the preparation of DFA facing the LSF in order to promote changes in the way of designing such a system with constructive, for greater efficiency production.

## 5. GUIDELINES OF DESIGN FOR ASSEMBLY

In view of the theories presented and beyond the results of the interviews, it's considered possible that the DFA can be applied to the design process of buildings in LSF. In fact, this article presents the guidelines that, the current stage of research and understanding of this tool in construction, it is understood as the most plausible of being applied. The guidelines proposed here include what information should be included in the DFA, so that the concepts of this tool are met in the context in which it enters the production process of buildings in LSF. Thus, it is considered that the design for assembly of buildings in LSF should be prepared from the following guidelines:

**a)** for the early development of the DFA, it is imperative that they strictly follow the information generated by each project discipline, according to the types of profiles that will be used, dimensions, materials and arrangement of elements and components;
**b)** with respect to the general physical aspects of the DFA, it is advisable to use paper plates with the A3 (the dimensions of the structure in question so permit) and, if possible, A4 paper, for the professional in the construction sites have ease of consultation and management of designs;
**c)** in order to use boards in A4 and A3 paper, the DFA should be organized in a Book of Assembly organized by an index. The boards and textual information must be printed "landscape";
**d)** in the Book of Assembly, the boards on A3 paper should be folded so as to equalize the size of A4 paper, in order to print "landscape";
**e)** with respect to the index of the Book of Assembly, it is suggested that this be organized from a structured content in:

- the general list of materials needed and their respective amounts;
- general listing of necessary tools;
- personal protective equipment required;
- plant identification of the panels;

- guidelines and graphic details for the assembly of each building system;

**f)** Considering the plant identification panels, it should be structured as follows:

- drawing with the disposal of fixed panels (structural and sealing);
- the design with the final disposition of the panels should be placed quotas that indicate the length of each panel;
- in this plant, each panel shall be identified by a symbol structured by the combination of a rectangle with a triangle;
- in this symbol should be informed on the rectangle, if the panel is structural or sealing, and type of fence that should receive. In the triangle, should be informed the number of the panel;
- the word structural, to suit in the symbol, should be shortened to “St.”, and the word seal, for the same reason, should be abbreviated to “Se.”
- words that identify the seal material will also be abbreviated and should be enclosed in parentheses, as follows: OSB - (OSB), gypsum board - (GB), cement slabs - (CL);
- the external panels, face out of the building shall contain a description of what type of coating will be used, such as painting, vinyl siding, wood, or any other material that meets the requirements of an element or component of the outer coating ;
- the identification numbers should be continuous and increasing clockwise.

**g)** Each graphical representation of the DFA (on each plate) should contain:

- drawings in three dimensions, of manner that will be, necessarily, in exploded perspective, developed at least at 1:50 scale, so that the perspective adopted permits the visualization of all components of the structure and assembly sequence. The drawings must represent as closely as possible the parts that will be used for the composition of the structure in question, to make it clear, to the professional of construction site, the final installation position. These designs should be structured as follows:
- each piece that makes up the structure in question must be represented, these parts must be arranged to indicate the assembly sequence and the correct position of fixation;
- how the drawing is done in exploded view, the correct position of attachment should be shown by a dashed line which will connect the pieces that must be connected;
- the ends of the dashed lines should be placed lower case letters of the alphabet, in order to eliminate any doubts about which parts should be connected to each other, facilitating the fitting;
- along the dashed lines should include what type of screws to be used for this connection and the amount needed for this. It is suggested the adoption of lowercase letters of the Greek alphabet (α, β, etc..) for the identification of each type of screw in the drawing, preceded by the numbers that correspond to the amount used in each setting;
- each piece that makes up the structural element should be named and it is suggested the following code:

**Xy C - n (Z)**, where:

Xy - Abbreviation for the classification of the type of piece (guide, amount etc.);

C - Sequence of use of the parts in their classification;
N - Order of assembly (1,2,3 ,..., n);
(Z) - Type of section or material that makes up the part.

- stamp of information, comprising:

- design title should be on the structure being represented;
- legend for decoding codes to be used for the identification of parts;
- list of unique tools to produce the structure in question;
- list of screws to be used and the total quantity of use of each one, or other material required for fixing parts;
- number of workers needed for the proposed activity and specialty of each;
- time for completion of the production of the structure represented on the board, giving the date and time of commencement and completion of service;
- the place of production of the structure (depending on the layout of the construction site);
- the ways of transport of the element to its assembly location.

**h)** Together with the exploded view, must be represented the drawing of the complete element, if possible, in the same direction from the perspective adopted for the assembly sequences. In this drawing shall contain the distances between major components;
**i)** In addition to the graphical representation of the main element, should also be made an exploded perspective drawing, which shows the correct positioning of the screws that will fasten the components (if this is the case);

- in this drawing must be represented the components (like the screw in question) in their positions of bolting, and the position where the screw should be fixed by a dashed line that extends to the point of fixation;
- the design of the screw should be identified with Greek letters, as proposed previously, as well as the quantity required;
- must be placed at least two dimensions (one horizontal and one vertical) that plotted the position of fixation screws;
- indicate how many times demonstrated the operation will be repeated in the element in question;
- is not necessary to show the sequence of activities, since such information is already in the main draw;

**j)** For items that are repeated identically several times in the construction and assembly activities are exactly the same (like scissors), should be indicated in the drawing the number of times that the assembly should be repeated;
**k)** It may be necessary elements that, under conditions where the scissors are inserted, for example, undergo changes due to the architecture of the coverage. Thus, the seal of the drawing should indicate the type of scissors that are being assembled by assigning capital letters of the alphabet;
**l)** Each board must be preceded or preceded by textual information (specific guidelines) that will interpret the design, providing:

- production sequence through the activities that must be performed;

- necessary tools for each activity;
- how each component should be set so that the structure is formed;

**m)** In the case of assembly of trusses should be indicated on the board, the number of times that this assembly should be repeated and is obviously in line with the structural calculation.

## 6. CONSIDERATIONS

With an enormous potential for production performance, the LSF is beginning to gain attention of the national market, researchers and all those who seek rationalization of construction. Being a system widely accepted and used in developed countries, its core production, features that are practical, requires that the entire construction process is determined during the design process which, in turn, is conditioned by the break with traditional practices in Construction.

Despite of being a necessary practice, it became clear in this study that this is not exercised by professionals. At the current stage of knowledge applied to design of this system in enterprises, it is noted that professionals insist on sequential design practices, and the omission of some information that are essential to the success of the LSF. Thus, important theories have been addressed as the CE. Because it is a system that uses prefabricated components, it was suggested that projects could be particularized to a more specific tool, called Design for Assembly. From this, guidelines have been prepared with respect to structure the presentation of designs like DFA, as well as their content.

The proposed guidelines aim to promote integration among the professionals involved in various stages of the life cycle of the building in LSF, and brokering best practices, both about design and production for this building system in Brazil, and suggests the adoption of design tools (like DFA) little known in Construction.

It should be clear that the main purpose of DFA is the simplification of components aimed at reducing the production cycle and reducing costs. Their use in this paper represents an initial approach applied this tool in the design of single family homes in LSF, enabling progress in the development of this tool in construction in future studies.

## REFERENCES

ANTAKI, M.; SCHIFFAUEROVA, A.; THOMSON, V. The performance of technical information transfer in new product development. **Concurrent Engineering: Research and Applications Journal**.V.18.n.4.2010.SAGE Publications. 2010.

BECK, C. L. C.; GONZALES, R. M. B.; LEOPARDI, M. T. **Detalhamento da metodologia**. In: LEOPARDI, M. T. Metodologia de pesquisa na saúde. 2 Edição. Florianópolis. UFSC – Pós-graduação em enfermagem. 290 p. 2002.

BLACUD, N. A.; BOGUS, S. M.; DIEKMANN, J. E.; MOLENAAR, K. R. Sensivity of construction activities under design uncertainty. **Journal of Construction Engineering and Management.** V.135. n. 3. p. 199-206. 2009.

BOOTHROYD, G.; DEWHURST, P.; KNIGHT, W. **Product design for manufacture and assembly**. New York. USA. Taylor & Francis Group. 2nd. Ed. 2002.

FABRÍCIO, M. M**. Industrialização das construções: uma abordagem contemporânea**. 2008. Texto (Livre-Docência). EESC-USP. São Carlos. 2008.

GORGOLEWSKI, M. **Developing a simplified method of calculating U-values in light steel framing**. Building and Enviroment. Volume 42, Issue 1. p. 230-236. 2006.

KOSKELA, L. **Foundations of concurrent engineering**. In: Concurrent engineering in construction projects – Chimay Anumba; John Kamara e Anne-Françoise Cutting Decelle (Ed.). Taylor and Francis. 2007.

KUO, Tsai-C.; HUANG, S. H.; ZHANG, Hong-C. Design for manufacture and design for “X”: concepts, applications and perspectives. **Computers and industrial engineering**. N.41.p.241-260. 2001.

MOTTONEN, M.; HARKONEN, J.; BELT, P.; HAAPASALO, H. Managerial view on design for manufacturing. **Industrial Management and Data Systems Journal**. V.109. n.6. p.859-872. 2009.

PRINS, M.; KRUIJNE, K. **The management of design process integration and design integration**. In: Proceedings of the joint CIB W096 Architectural Management and CIB TG49 Architectural Engineering Conference held in conjunction with the 8th Brazilian Workshop on Building Design Management. São Paulo. 2008.

SONG, L.; MOHAMED, Y.; ABOURIZK, S. M. Early contractor involvement in design and its impact on construction schedule performance. **Journal of Management in Engineering**. V. 25. n.1. p. 12-20. 2009.

TOOKEY, J.E.; BOWEN, P.A.; HARDCASTLE, C.; MURRAY, M.D. Concurrent engineering: a comparison between the aerospace and construction industries.**Journal of Engineering, Design and Technology.** V3. No.1. p.44-55. CAPE Peninsula University of Technology. 2005.

VELJKOVIC, M.; JOHANSSON, B. Light Steel Framing for residential buildings. **Thin-walled structures**. N.44. p.1272-1279. 2006.

VIVAN, A. L. ; PALIARI, J. C. ; NOVAES, C. C. **Vantagem produtiva do sistema light steel framing: da construção enxuta à racionalização construtiva**. In: ENTAC - Encontro Nacional de Tecnologia do Ambiente Construído, 2010. Canela-RS. ANTAC - Associação Nacional de Tecnologia do Ambiente Construído, 2010.

VIVAN, A. L.; PALIARI, J. C. **Comparação entre aspectos produtivos de edificações em light steel framing e alvenaria estrutural**. ENTECA - Encontro Tecnológico da Engenharia Civil e Arquitetura. Maringá. Brasil, 2011.