PROCESS PLANNING FOR INDUSTRIALIZED HOUSING CONSTRUCTION: LESSONS FROM THE MANUFACTURING INDUSTRY

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Housing production for low-income families in Brazil now represents a large portion of residential constructions. This is due to rising demand, new financing possibilities and government backed housing programs. However, this sector of the construction market will only become a viable business if building contractors are able to keep construction costs low and productivity high, factors which can usually be achieved by large scale production combined with construction industrialization. To help ease the implementation of these competitive strategies, one should consider the application of many concepts and practices already developed and in use by the manufacturing industry. One area in which this experience acquired from manufacturing might be especially applicable is in construction process planning for the simple reason that most tools used in the construction sector do not consider the scale, optimization and level of detail required by industrialized production processes. The aim of this study is to identify elements of the process planning methodology developed within the manufacturing industry which may be applied to construction, thus improving the on-going industrialization process. The study is based on a broad review of literature covering the manufacturing industry and having as its objective an analysis of the entire scope of process planning, including which activities are assigned and how they are organized, the specifics related to this issue, which information is shared, and the tools employed. Analysis revealed that essential elements of manufacturing process planning can be adapted for industrialized construction. Nevertheless, implementing these acquired data from manufacturing industry experience will require some changes in the way traditional construction management operates.
Keywords: Construction Industrialization, Housing, Manufacturing, Process Planning

INTRODUCTION

Low-income housing construction (defined as family income limited to 10 minimum wages) is now one of the most active sectors of the Brazilian real estate industry (Rapoza, 2011). This recent growth can be attributed to a combination of factors:

- increase in the purchasing power of Brazilian population, especially of the low-income sector, due to the country’s economic growth in recent years and the implementation of new social programmes;
- high demand – there is a housing shortage of 5,6 million units according to the Brazilian Ministry of Cities (Ministério das Cidades, 2010);
- easy financing and low-income government housing subsidies (Rapoza, 2011).

Although the low-income housing sector now offers an abundance of business opportunities, there are some additional factors that must be considered. As housing prices need to be kept low and there is a practical limit to reducing construction costs, profit margins are narrow (Lizarralde and Root, 2008). Hence, to achieve acceptable absolute profit, large scale production is required, so that the low margin is multiplied by many units (Ahadzie, Proverbs and Olomolayie, 2008). This issue, combined with the need for high productivity (due to increasing personnel costs) and for precise management (so that profit margins are not consumed by mistakes), leads to industrialization as a main competitive strategy.

The industrialized construction and large scale production of houses is considerably different compared to traditional construction. It comprises standardization of components, modular coordination, prefabrication, mechanization, as well as changes in the way of organizing the production process (Sabbatini, 1989). In traditional construction, due to the uniqueness of buildings and variability of production conditions, planning is less detailed and management is project oriented (Gann, 1996; Kirsch, 2008). Industrialization, though, necessitates (and makes it possible to invest in) detailed building design and precise production planning, compelling management to be process oriented (Roy; Low and Waller, 2005; Kirsch, 2008). Of these differences, process vision deserves to be highlighted, because it is believed to be crucial for the success of any industrialized manufacturing process. Thorough production process planning results in increased precision, waste reduction, economy and optimized production (Niebel; Draper and Wysk, 1989).

Other than the essentiality of an adequate production management approach to industrialized housing construction, no ready-to-use model for production process planning was found in construction literature. Nevertheless, valid concepts and practices for planning industrialized production developed by other industrialized sectors such as the manufacturing industry may be applied. The aim of this study is to identify elements of the production process planning methodology developed by the manufacturing industry and analyze the possibility of using them for industrialized construction process planning.

The research is based on a broad review of literature covering the process planning methodology adopted by the manufacturing industry. The following aspects were analyzed: the way process planning fits into the product development cycle; accountability for process planning; activities that are part of process planning; information required and produced by process planning and tools employed. This review focused on books and manuals about manufacturing engineering in order to characterize the consolidated methodology, which was chosen as a starting point to analyze the implementation of process planning in construction.

After gathering the data, an analysis was carried out to evaluate which elements identified in the manufacturing environment are applicable for industrialized construction.

PROCESS PLANNING IN THE MANUFACTURING INDUSTRY

Process planning is only one of many activities that integrate a typical product development cycle in manufacturing (Fig. 1).

Once the need for a product is recognized, the first activity of the cycle is to completely define what is to be manufactured, this is called product design (Halevi and Weill, 1995). The next step, “manufacturing system design” (Plossl, 1987), is to plan how this product will be manufactured and which production resources will be used. Having the product and the production process established, it is possible to program production, which involves scheduling the use of previously defined resources and arranging the right logistics for an economic manufacturing process

(Groover, 1996). Then, production and control take place simultaneously (Cimorelli and Chandler, 1996). Nowadays, with the increasing appliance of Concurrent Engineering, the activities before production usually take place simultaneously, aiming to shorten the production development cycle and conceive better products (Syan, 1994).

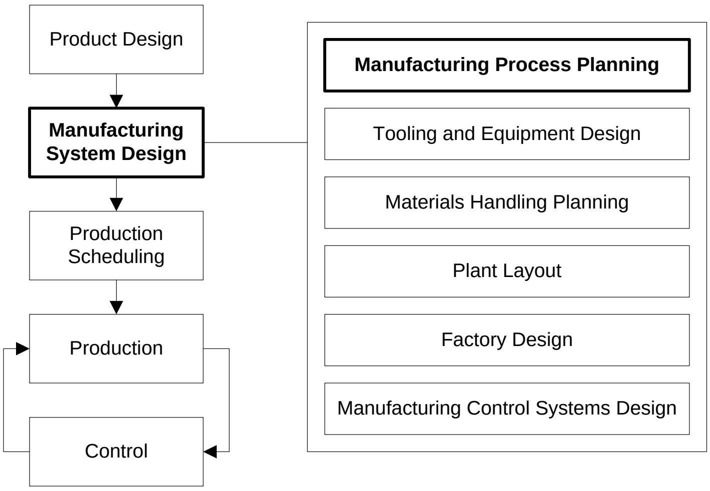

Fig. 1 - Main activities of a product development cycle (adapted from Hitomi, 1979).

Process planning (also known as process design) is an activity within "manufacturing systems design" that consists of defining how a product is to be manufactured, which includes specifying the activities sequence that characterizes the production processes, the resources needed and the parameters employed (Chryssolouris, 2006) . However, additional information is required to fully configure a manufacturing system: the design of tools and equipment employed in the processes (Groover, 1996); materials flow and plant layout (Meyers and Stephens, 2005); factory design, including its entire infrastructure (Plossl, 1987); and control systems design, so that production can be monitored (Nadler, 1992). Nevertheless, according to Chang (1992), process planning can be considered the critical link between design and manufacturing.

Activities of Process Planning

Process planning is usually performed by an area in the industries called Manufacturing Engineering or Process Engineering (Nadler, 1996) and includes the activities presented in Fig. 2. Those in the dashed line box are the process definition itself, but the preliminary activities must be performed to ensure that appropriate decisions are made at this step.

Process planning starts with a comprehensive analysis of the product design in order to fully understand the characteristics that will guide the choices and definitions of the manufacturing process. This analysis is based on documents distributed by the product design team, such as product drawings, assembly drawings and bills of materials (Meyers and Stephens, 2005). The following elements must be observed: dimensions, shapes, materials and components, technical specifications, tolerances and quality requirements (Chryssolouris, 2006). Beyond understanding the design, process engineers also analyze the manufacturability of the product, demanding design changes that they deem essential to make production processes as economic as possible (Walker and Boothroyd, 1996).

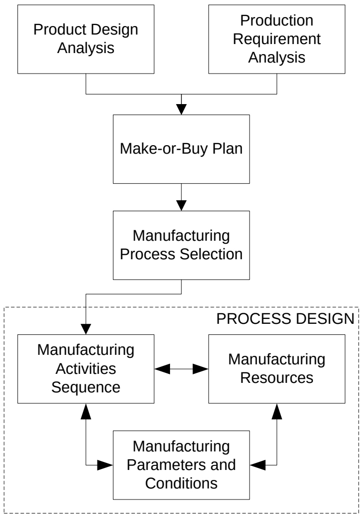

Fig. 2 - Activities of process planning (adapted from Chang (1992)).

Another primary activity for process planning is the analysis of production requirements such as: production volume, lot sizes, production rate, availability of resources (e.g.: equipment shared with other production lines), capacity of resources, target costs, etc. (Kalpakjian and Schmid, 2006). This information will also dictate manufacturing process choices, particularly those concerning the size of machines and degree of automation (Halevi and Weill, 1995).

Once product and production characteristics are known, manufacturing engineers need to decide which parts of the product will be manufactured internally and which will be outsourced, resulting in a “make-or-buy plan” (Chang, 1992). In addition to the available data, this decision requires market information, such as availability of suppliers, component prices, investment required for internal production, etc. (Benhabib, 2003).

The next activity of process planning consists of choosing which manufacturing processes will be employed for the parts produced internally. In some cases, the characteristics analyzed may lead to only one possibility, but the most common is having many processes available, as technology options are increasing due to innovation (Gomes, 2010).

Finally, manufacturing processes are defined. The first step is to specify the sequence of manufacturing activities, and then the resources needed and the parameters used. These three steps take place almost simultaneously and each is influenced by the other. There are usually five categories of manufacturing activities (Chang, 1992):

- operation: object has its characteristics transformed, is assembled or is configured for another activity;
- inspection: object is examined for identification or is verified for quality control;
- transportation: object is moved around inside the production plant, except for situations in which movements are part of an operation;
- storage: object is maintained protected against unauthorized transportation;
- delay: object remains inactive, except for situations in which inactivity corresponds to a technical time required for a process to take place (e.g.: curing).

Areas other than Manufacturing Engineering must be involved to achieve the complete process definition: inspections are defined together with Quality Control Engineering (Lints, 1996) and flow activities (transportation, storage and delay) must be studied with Materials Handling Engineering or Plant Engineering (Sheth, 1996).

As flow activities do not add value to the product, they should be minimized whenever possible (Sheth, 1996).
After the sequence of activities (or a first draft of it) is established, resources for each activity must be identified. Under resources are: equipment, tools, fixtures, jigs, processing materials (e.g.: lubricants) and also, human resources (Halevi and Weill, 1995). In manufacturing most processes are mechanized and specifying the right equipment is decisive for success (Halevi and Weill, 1995). In some cases, specific equipment (not readily available in the market) might be required and the design must be made together with another department called Tool Design (Groover, 1996). It is also important to define instruments for inspection, especially as regards their precision (Halevi and Weill, 1995).
In order to complete process definition, some process parameters and conditions must be established, such as: resources quantity, cycle time, processing speed, tools and equipment setup, etc. (Tanner, 1996). Parameters specification is very important for planning a balanced manufacture, which means the use of resources must be well distributed throughout the entire manufacturing process (Meyers and Stephens, 2005). This activity is within the scope of Manufacturing Engineering together with Plant Engineering (Meyers and Stephens, 2005).

Tools of Process Planning

Many activities and decisions take place during process planning and tools are required to register them. Just as product design drawings register "what" is to be manufactured, process planning documents register "how" this product is to be made. Tools and documents help create a basis for modifying or improving the manufacturing process towards a more economic production (Chang, 1992).
The main tool employed in process planning is the *process sheet*, also known as *route sheet*, *operation routing* and *process plan* (Chang, 1992; Halevi and Weill, 1995) (Fig. 3). It provides the following information: document identification, part identification (usually a manufacturing process is defined for a specific part), operations and inspections sequence, activity description, machine/equipment used, the necessary tools and instruments, and the parameters (cycle times, setups, etc.).

Part No: 031393	Part Name: Housing, valve		Rev. 2	Page 1 of 2		
Matl: 416 Stainless	Size: 2.0 dia × 5. long		Planner: MPG		Date: 3/13/XX	
No.	**Operation**	**Dept.**	**Machine**	**Tooling, gages**	**Setup time**	**Cycle time**
10	Face; rough & finish turn to 1.473 ± 0.003 dia. × 1.250 ± 0.003 length; face shoulder to 0.313 ± 0.002; finish turn to 1.875 ± 0.002 dia.; form 3 grooves at 0.125 width × 0.063 deep.	L	325	G857	1.0 h	8.22 m
20	Reverse; face to 4.750 ± 0.005 length; finish turn to 1.875 ± 0.002 dia.; drill 1.000 + 0.006, −0.002 dia. axial hole.	L	325		0.5 h	3.10 m
30	Drill & ream 3 radial holes at 0.375 ± 0.002 dia.	D	114	F511	0.3 h	2.50 m
40	Mill 0.500 ± 0.004 wide × 0.375 ± 0.003 deep slot.	M	240	F332	0.3 h	1.75 m
50	Mill 0.750 ± 0.004 wide × 0.375 ± 0.003 deep flat.	M	240	F333	0.3 h	1.60 m

Fig. 3 – Process sheet for valve production (Groover, 1996).

Another tool is the *operation process chart*, also called *outline process chart* or *assembly chart* (Kadota and Sakamoto, 1992; Tanner, 1996) (Fig. 4). It is used to represent the sequence of operations and inspections required to assemble the entire product, it being easier to understand than a collection of separate process sheets. The operations sequence begins in the upper left corner and ends in the bottom right corner. Parts input in the process are identified above the horizontal lines of the diagram. Operations are represented in circles and inspection in squares, following the standard set by the American Society of Mechanical Engineers (ASME) (Tanner, 1996).

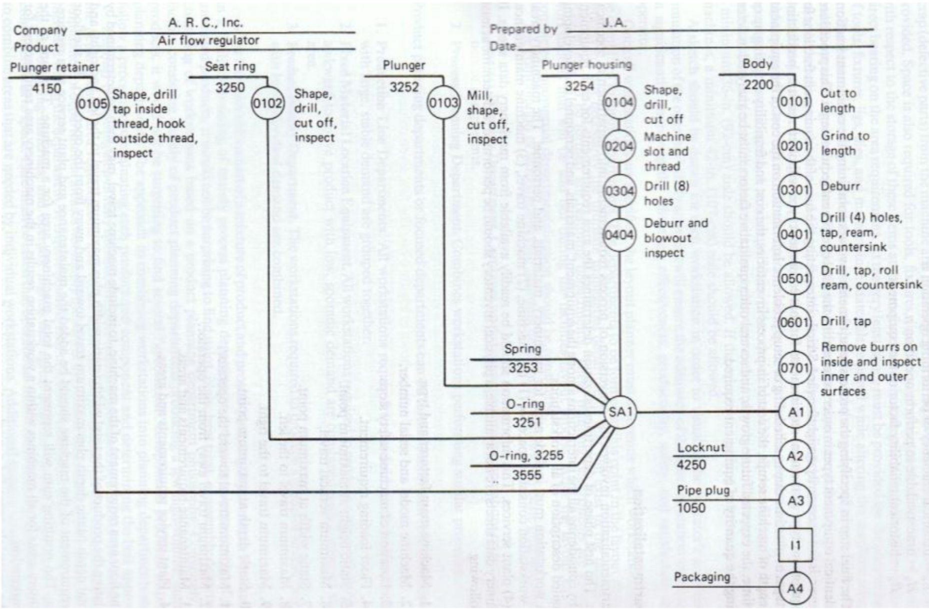

Fig. 4 - Operation process chart for assembly of air flow regulator (Kadota and Sakamoto, 1992).

Neither the process sheet nor the operation process chart represents flow activities (transportation, storage and delays). The tool employed for this application is called *flow process chart* and, like operation process charts, it follows the symbol standard of ASME (Fig. 5).

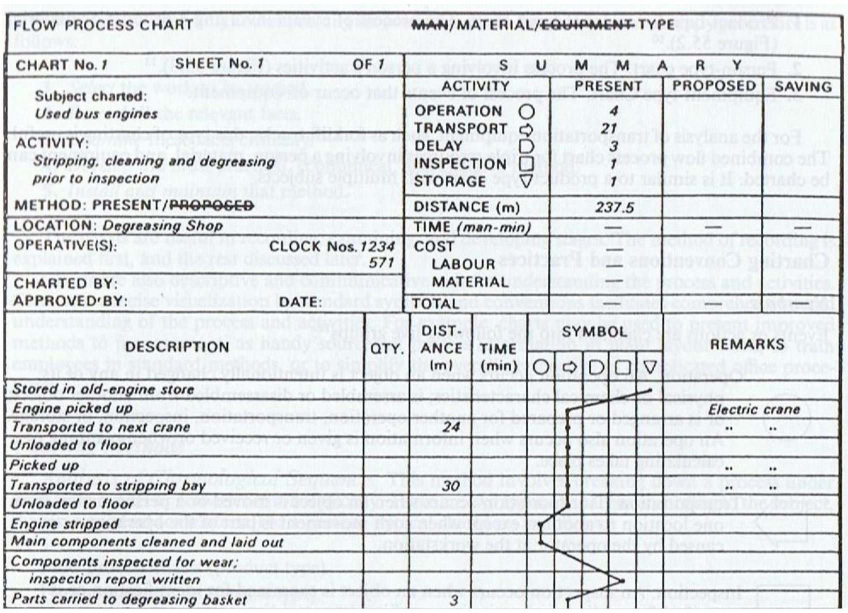

Fig. 5 - Flow process chart for stripping, cleansing and degreasing used bus engines (Kadota; Sakamoto, 1992).

Although flow process charts are useful for optimization of manufacturing processes, they do not describe the process in as much detail as process sheets do, nor do they allow a visualization of the entire assembly process as operation process charts do.

Thus, these three main tools of process planning can be considered complementary. It is also possible to automatically generate the tools and information mentioned above by using Computer-Aided Process Planning (Kalpakjian and Schmid, 2006).

APPLICABILITY FOR INDUSTRIALIZED CONSTRUCTION

The analysis of the process planning model developed by the manufacturing industry, combined with the characteristics of large scale industrialized construction presented in the introduction of this paper, leads to the following considerations:

- One main difference is the separation of "production process planning" and "production scheduling" in the manufacturing industry while in the construction industry these activities are usually merged into only one task called "construction planning" (Kirsch, 2008). The existence of a specific area for process planning, focused on developing economic production processes and working on their continuous improvement is even more important considering large scale production and low profit margins. So, it can be said that creating a specific Construction Process Planning area could be a good practice for industrialized construction in order to achieve optimized construction processes, which are fundamental for competitiveness in the low income housing sector. This separation also enables the area accountable for production scheduling to focus on logistics, thus resulting in a better construction process in general;
- The structure of activities proposed for process planning can also be applied to construction. Actually, this planning rationality is also followed by construction planners, but in a less detailed way, due to the uniqueness of construction projects, that cause detailed planning not to be worthwhile (Gann, 1996). However, a more detailed approach is necessary for industrialized construction, because it enables planners to identify eventual problems and opportunities for improvement, thus resulting in a better construction process. Also, detailed planning prevents making decisions at the construction site, which is mostly not the optimal solution, especially when dealing with large scale production, where mistakes can be multiplied by many units;
- However, not all elements of large scale housing projects have the characteristic of repetition (e.g.: urban infrastructure) and therefore, detailed plans (similar to the manufacturing industry) are only recommended for housing units and its elements. Costa, Schramm and Formoso (2004) developed a production system planning proposal that separates the planning of repeatable units (called "base-units") from the rest of the project (Fig. 6);

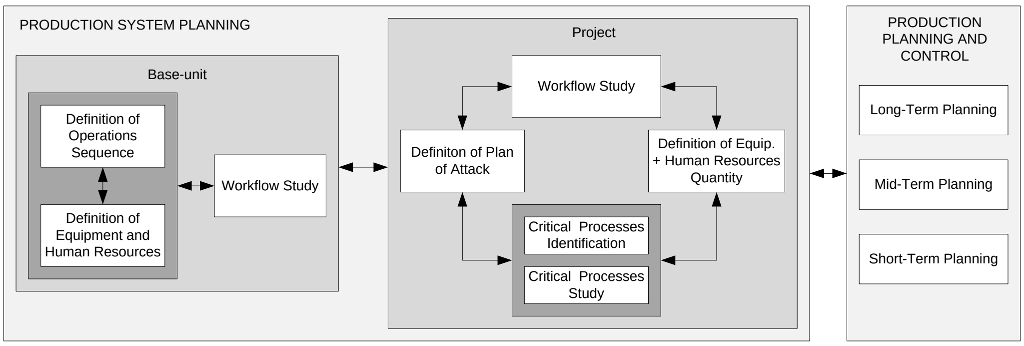

Fig. 6 - Production systems planning methodology (adapted from Costa; Schramm and Formoso, 2004).

- Manufacturing process planning includes defining quality control activities. In construction, these activities are usually specified in procedures that integrate a quality management system (Chalita, 2010), separate from production planning. Including inspections in the process plans for industrialized construction might be useful, though, because situating quality control as a part of construction processes increases the possibility that it will be done. Controlling quality requirements is especially important in this scenario, as process errors can result in correcting measures that are not included in low-cost housing budgets, thus negatively affecting profit margins;

- Flow activities (transportation, storage and delays) are also situated in manufacturing process planning, but not in construction planning (Harris and McCaffer, 2006). However, it is necessary to include these activities in process planning for industrialized construction, because flow activities do not add value to the product and therefore, minimizing them is important for obtaining optimized production processes, one of the main aims of industrialization. Tzortzopoulos, Sexton and Cooper (2005) recommend mapping flow activities in construction to eliminate non-value adding operations. But there is a drawback: unlike factories, construction sites are very dynamic and are constantly reorganizing as construction advances and, thus, planning flow activities can be more difficult in this environment;
- Concerning planning tools, manufacturing process sheets, presented in an easy to understand format, contain sufficient information about construction processes to the extent that they can be considered well defined. Therefore, they can be recommended for documenting construction process planning. Roy, Low and Waller (2005) also suggest the use of process sheets for construction planning, but in a format that does not include resource definition (Fig. 7). Like in the manufacturing industry, where process sheets represent the manufacturing processes for a specific component of the product, these authors also propose to use process sheets for building parts. The whole construction process is then defined by combining different process sheets, which also enables customization, even considering large scale production (Roy, Low and Waller, 2005).

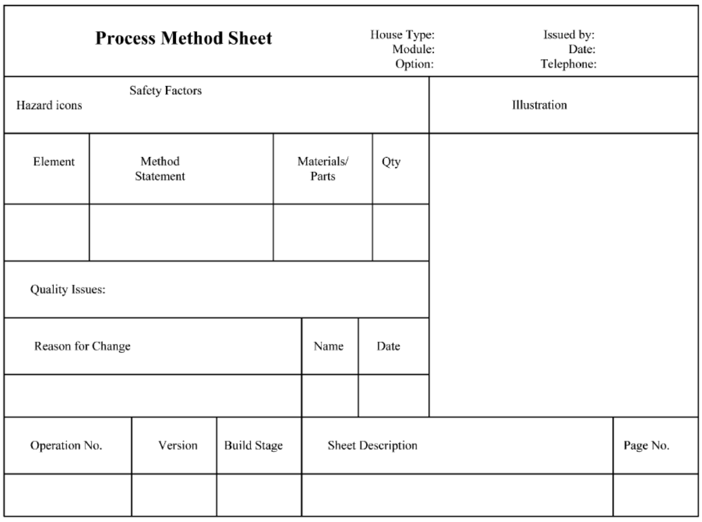

Fig. 7 - Process method sheet proposed by Roy, Low and Waller (2005).

- Operation process charts would have to be adapted in order to be applied in construction, where the product remains static, as opposed to production lines. This consideration is also valid for flow process charts, because in construction flow activities do not happen to the product, but in the product.

CONCLUSION

The analysis of process planning methodology developed by the manufacturing industry shows that many aspects could be applied to industrialized construction: creation of a specific area for process planning; adoption of the process planning scheme proposed in manufacturing process engineering, associated to a higher detailing level for planning repeatable elements of a building; including quality control and flow activities in process planning; and using a simple tool to represent the resulting plans. Based on the experience of the manufacturing industry it is expected that the implementation of these recommendations will lead to more consistent and optimized construction processes, consequently resulting in economic production, which is the main aim for industrializing construction in the low-income housing sector. However, it is necessary to attempt applying these practices, in order to assess their real contribution.

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