IMPROVING THE IMPLEMENTATION OF MODULARIZATION AND STANDARDIZATION OF MEP SYSTEMS IN DESIGN

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ABSTRACT

Modularization and standardization of MEP (Mechanical, Electrical and Plumbing) systems in design is a method to improve predictability and efficiency on the construction site. However, managing information is a challenge to achieve modularization and standardization in alignment with customer values. The aim of this paper is to describe the design development process when applying modularization and standardization, to analyze the workflow, and to identify critical processes to be managed. A process map when applying modularization and standardization of MEP systems is explained, highlighting the challenges that should affect the implementation during design process. Analyzing the design process shows that the challenges to be met through the implementation of the design methodology are 1) aligning the external variety of the building structure to modularized and standardized systems (internal variety), and 2) aligning modularization and standardization to customer values. We propose analyzing work structuring principles to improve the implementation of modularization and standardization. We hypothesize that involving the end customer and construction teams and managing their knowledge will increase the effectiveness and efficiency of modularization and standardization in MEP systems' design beyond the current implementation. The Paper presents a theoretical model that is the basis for further research.

KEYWORDS

MEP systems, modularization, standardization, work structuring, customer value.

INTRODUCTION

MEP (Mechanical, Electrical and Plumbing) systems are complex systems not only because of high interdependencies between the systems themselves but also because of interdependencies with other building systems. Modularization and standardization of MEP Systems have been proved in a previous research to be an effective tool to reduce the complexity of these systems by reducing the variety of components

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through the design process (Mohamad et al 2013). The definition of modularization depends on the goal of it, whether it is in design, production, or use (Baldwin and Clark 2006). Standardization is "an extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability" (Gibb, 2001)

Although the benefits of modularization and standardization in production are high, the cause for limited application on MEP systems is possibly that these systems are highly interdependent. In the current situation, and according to interviews, contractors are accustomed to carry out the work according to their traditional methods and experiences, while modularization and standardization change the way the work is being carried out in design and construction. This causes sometimes changes in design during the construction phase. The production process of modularized and standardized MEP Systems is often not stable. Stabilizing the production process of MEP systems and improving quality of production process, high predictability for time and cost, and prefabrication's opportunities that can be derived from modularization and standardization of MEP systems are not considered effectively in the current assessment. Also, the benefits of modularization and standardization of MEP systems in improving the production process are often not harvested. Furthermore, the construction firms and end customers are either involved inadequately or not involved at all in the design process.

What is needed is increasing the efficiency and effectiveness by engaging the entire stakeholder, and restructuring the work of design and construction to improve the efforts to integrate product and process design when applying modularization and standardization.

We introduce in this paper a theoretical model to improve the implementation of modularization and standardization. First, we distinguish between different types of modularity as recognized in the literature, secondly, we review the concepts of work structuring and customer values, third, a workflow model is proposed, and fourthly, we make suggestions for future case study research.

LITERATURE REVIEW

MODULARITY TYPES

Three types of modularity can be distinguished according to their goal: modularity-in-design, modularity-in-production and modularity-in-use (Baldwin and Clark 2006). Baldwin and Clark (2006) claim that the goal of modularity affects the way the modules are structured.

Modularity in design: Baldwin & Clark (2006) defined modularity in design as "modular-in-design if (and only if) the process of designing it can be split up and distributed across separate modules".

Modularity in production (process modularity): To achieve modularity in production, the specification of the components, for example its dimension, and functionalities are design rules for the manufacturing process (Baldwin and Clark 2006). Modularity in production supports mass customization and can be characterized as process modularity (Sako and Murray 1999). Baldwin and Clark (2006) argue that modularity-in- production of a system does not mean that the design of the system is modular. In modularity in production, making products will be easier by dividing manufacturing process into process modules or cells (Baldwin and Clark 1997). Process modules could be a large production cell or a work station in an assembly (Sako and Murray 1999)). Gershenson et al (1997) define manufacturing modularity as "the development of product modules with minimal dependencies upon other components in the product with regard to manufacturing process". They introduce a methodology for modular product design that depends on three issues: Attribute independence, process independence and process similarity.

Modularity in use is defined as "A system of goods is modular in use if consumers can mix and match elements to come up with a final product that suits their taste and needs" (Baldwin & Clark 2006).

We conclude that modular product design is the best way to achieve product variety while reducing production time (MCutcheon et al 1994). Modularization supports production and manufacturing because of reduced components and common interfaces (Gershenson and Prasad, 1997). Ulrich and Tung (1991) pointed that modularity is a relative property, and this depends on: 1) Similarity between the physical and functional architecture of the design, and 2) Minimization of incidental interactions between physical components. Also, greater modularization supports and facilitates standardization and interchangeability (Ulrich and Tung 1991).

It is essential to have a common understanding of modularity by all participants to improve the process of information exchange.

DESIGN METHODOLOGY FOR MODULARIZATION AND STANDARDIZATION

The design methodology presented in Mohamad et al (2013) is a design method to achieve modularized and standardized MEP systems. In this method, modularization aims to structure the building or parts of it into chunks, called modules, which sparsely interact, and standardization aims to group similar modules in one type of module, and tries to minimize the different types of modules. Modularization and minimization of module's types lead to changes in design. Changing the design includes reconfiguration and redesign of sub- systems or components.

Applying modularization and standardization to the design process of MEP systems involves many challenges that must be considered. One major challenge is finding repeatable sub-systems in the structure and aligning the external variety of the building structure with modularized and standardized systems (internal variety). This balance between the external and internal variety, between maximum standardization and flexibility (Gibb 2001) is responsible for the difficulty of applying modularization and standardization in the design process. Another challenge is the alignment of modularization and standardization to customer values. This alignment includes considering the quality of the end product and the requirement of the production process.

CUSTOMER VALUES

Modularization and standardization of MEP systems affect customer values, especially, end customer value and production process. The value for each end customer/user/owner is different (Mossman 2009). In addition, the end customer defines his precise requirements gradually during the development process of design. On the other side, modularization and standardization process is a continuous process through design. Applying modularization and standardization causes changing the configurations of MEP Systems, geometry, or dimensions. This affects the quality that must be evaluated and approved by the owner and/or user. It is expected to increase the value of the end customer through modularization and standardization. Thus, it is very necessary to involve the end customer/user/owner when applying modularization and standardization to achieve his value.

In the continuous improvement process by increasing modularization and standardization, the production process could be greatly affected. Thus, it will be more effective to evaluate the production process during the design process. The construction team can play an important role in developing solutions to increase modularization and standardization. “A considerable amount of detail design and engineering is implemented by specialty contractors and fabricators simply because the cutting edge of technology has progressively shifted in their hands” (Pietroforte 1995). Olson (1982) emphasizes that "We need more involvement of job-site managers, especially foremen, in the planning process".

The process of modularization and standardization emphasizes the need to analyze work structuring to integrate product and process design effectively.

WORK STRUCTURING

Work structuring in lean construction is defined as “the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts” with the goal of making “work flow more reliable and quick while delivering value to the customer” (Ballard 2000). The work structure is the "description of how work on a project will create a product that meets customer needs” (Tsao and Tommelein 2004). Tsao and Tommelein (2004) introduce a methodology to manage the relationships between design decisions and production process, and show the importance of work structuring as a way to manage bottlenecks that could appear in the production process.

LAST PLANER SYSTEM IN DESIGN

Hamzeh et al (2009) show that Last Planner System (LPS) can be used in design to manage workflow, and they present the following practices of applying LPS in design according to Ballard (2000a), Ballard et al. (2007), and Ballard et al. (2009): "(1) plan in greater detail as you get closer to performing the work , (2) develop the work plan with those who are going to perform the work, (3) identify and remove work constraints ahead of time as a team to make work ready and increase reliability of work plans (4) make reliable promises and drive work execution based on coordination and active negotiation with trade partners and project participants, and (5) learn from planning failures by finding the root causes and taking preventive actions".

RESEARCH HYPOTHESES AND RESEARCH METHOD

Applying work structuring principles can improve the efficiency and effectiveness of modularization and standardization of MEP Systems in design to harvest the benefits of them. Our hypothesis is: Integrating and managing the knowledge of contractors and users increases the effectiveness and efficiency of modularization and standardization of MEP systems.

The research method is based on analyzing the design process to identify the challenges and potentials to increase the efficiency of modularization and standardization. The proposed theoretical model is built upon a previous case study, literature review and analysis on "MEP systems", "Modularization and standardization", and "Lean construction". It must be validated through further case studies.

DESIGN METHOD-WORKFLOW MODEL

Applying modularization and standardization to the design process of MEP systems requires using new criteria in evaluating the design options. The implementation must begin early in design. The geometry of the design concept plays an important role, and it is a basis to develop MEP systems with high modularization and standardization. This early process increases the flexibility to develop modularized and standardized MEP systems later greatly.

In a previous paper (Mohamad et al 2013), a design methodology was introduced through a case study. The design methodology defines the building "product" in a three-level hierarchy as follows: 1) Building geometry, 2) Space utilization, 3) Configurations and components. This classification into three-level hierarchy is based on their effects on modularization and standardization of MEP systems, and on the developing process in design. The generality of the design methodology remains to be tested by future research. A workflow model depending on the three-level hierarchy is explained in the following sections as basis to investigate the hypothesis:

Level 1: Building geometry

Building geometry has reference points to MEP Systems (Khanzode 2011). Therefore, building geometry must be analyzed as a basis for designing and structuring the MEP systems. The work in this phase includes:

- Developing building geometry, and defining a grid system: Defining the grid system helps developing modules later and facilitates standardization process within and between the modules. The modules are spatial chunks of the building where any geometrical element (some typical elements like share walls, columns and facade elements) is only contained within the boundaries of one chunk. The boundaries of the chunks are identified through the grid system. A standardized grid system is a grid system with possibly identical grid fields. The size of the grid fields must be made in a way that allows for maximum modularized and standardized geometrical model. Many design alternatives could be generated. It is important to note that it is difficult to standardize the grid system completely, but it will be tried in a continuous improvement process to increase standardization of the grid system. An initial grid system and initial positions of the geometrical elements must be developed.
- Modularization process: The position of every element of the building must be checked, whether it is located completely in one field, or on the gridline, or none of both. This is the basis for a communication process in design to reposition the elements that are not completely in one field or on the gridline. The undesired position of one building element could be according to the

chosen building element itself in this place or to the grid system itself, etc. The task of the communication process is to identify the best option of changing to increase modularization through: 1) Identifying the elements that must be changed to get a modularized grid system. 2) Identifying the causes of non-modularized grid system. 3) Discussing the possibilities to modularize the building structure. 4) Implementing the options of change.

Thus, modularization process is an iteration process, and can be managed through reliable promising cycle of last planer system. The conditions of satisfaction are defined through the effects of performing one option on building quality and constructability. Therefore, integrating the end customer and construction team in this process is very important. Modularization process can be defined as: increasing modularization of geometry while considering the constraints of constructability and building quality.

- Defining module types: A module type contains similar modularized chunks. The task is to define the similarities between the modules, and then to group them in module types. Different similarity degrees and types could be resulted. The process of defining module types causes iterations in design and it is a source for the learning process to improve iterations through modularization process.
- Standardization processes: the standardization process consists of two steps: 1) Eliminating the differences within one type of modules by aligning the structure of chunks that belongs to the same type of modules by making small changes in the geometry. 2) Reducing the types of the modules by reducing the differences between the different types of modules. Standardization process depends greatly on the experience of the designer and it is an iterative process. The task is to identify the differences within and between the module types and to analyze the possibilities to eliminate or reduce these differences from the customers' perspectives. The question is: What types (kinds) of differences could be reduced or eliminated? The cycle of reliable promising of the Last Planner System helps performing and evaluating the options of changing the design in a reliable manner. The conditions of satisfaction are eliminating or reducing the differences within and between module types without reducing quality and constructability. The following flowchart in figure (1) summarizes the work in the first level of the hierarchy.

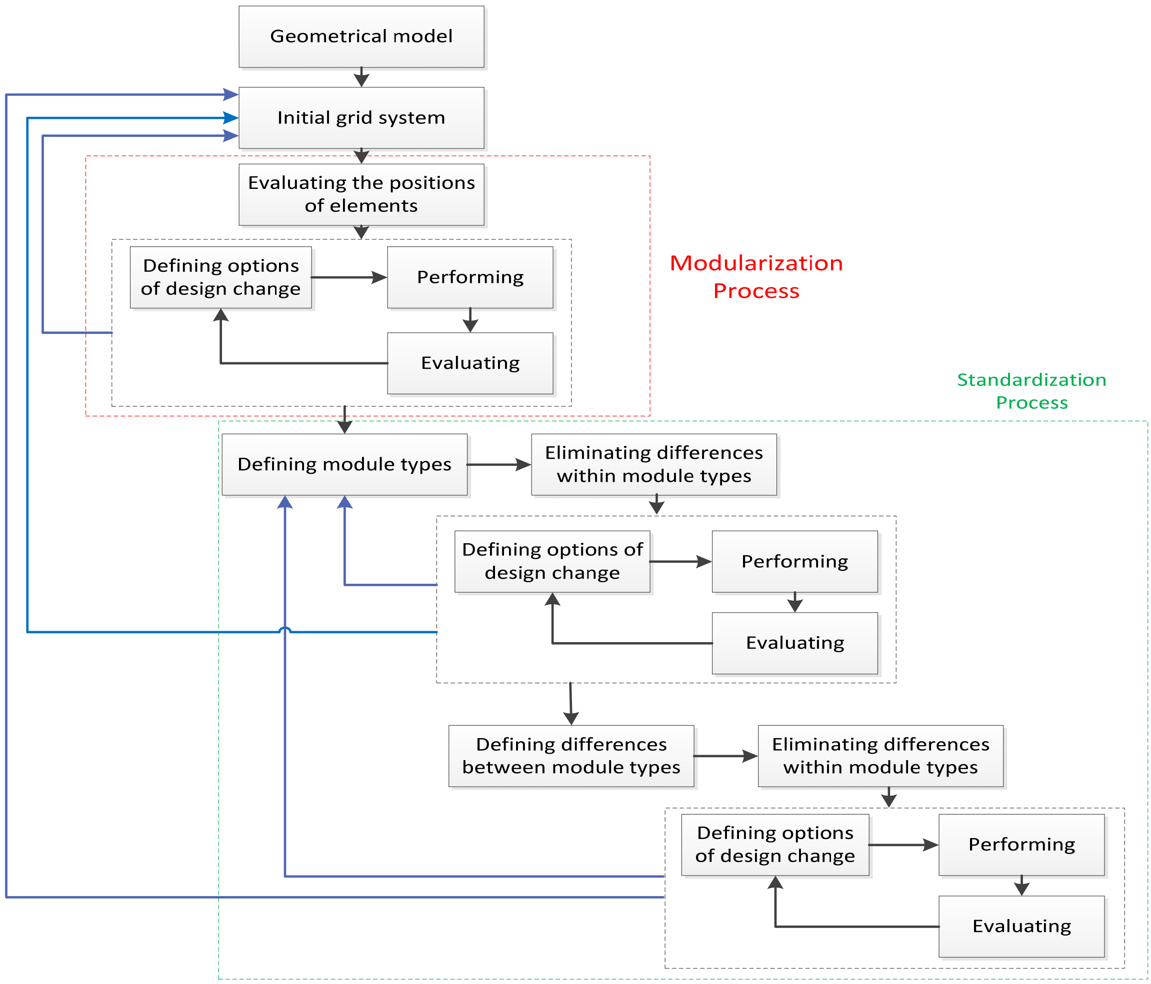

Figure 1: Working in Level 1- Building geometry

Level 2: Space utilization

Utilization is the foundation for developing MEP systems and components in the design process. Modularization and standardization processes are explained as follows:

- Modularization process: this aims to align boundaries of spaces that have different (or similar) utilizations to the interfaces between fields of the grid system (Mohamad et al 2013). A module is a chunk of the building with a certain space and boundaries aligned to the boundaries of the grid system. One utilization space may include one or more fields of the grid system. Many types of modules could be developed. Modularization process includes adapting the utilization spaces, so that their boundaries are aligned with the interfaces of the grid system, or adapting the grid system itself to be aligned with the boundaries of the utilization spaces. Modularization process includes: 1) Comparison the grid system spaces and its interfaces to utilization spaces. 2) Developing options to change the design and define modules. 3) Many options could be developed. 4) Performing the options in a reliable promising cycle of the last planer system.) Evaluating the results in terms of quality and constructability. 6) Developing types of modules.

- Standardization process: Standardization process includes, as in the previous level, standardization within one type of modules and standardization between different types of modules. The definition of types of modules depends on the components of the modules, which are: dimensions of the spaces of the modules (building's chunks), interfaces, and utilization of the spaces. One type of modules includes chunks of the building that have similar components. The process of defining types of modules affects the iterations in design greatly. Therefore, great attention must be paid in this process through participation of all stakeholders. Through standardization process many options could be developed to adapt the structure of the building as changing dimension of spaces, or changing types of utilization of some spaces. The following flowchart in figure (2) summarizes the work in this level of the hierarchy, where the iterations that can emerge between this level and the previous level are not shown:

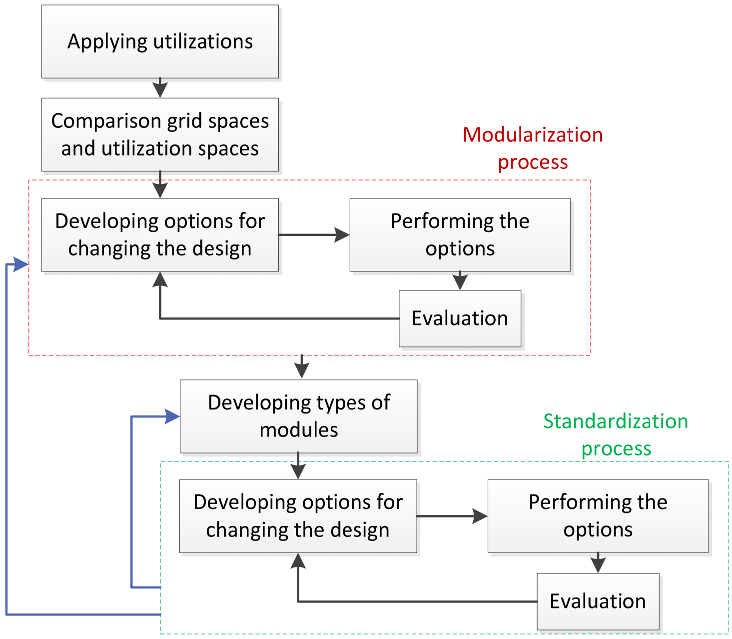

Figure 2: Work in level 2- space utilization

Level 3: Configurations and components

MEP systems have interfaces not only with the other building systems as the structural system, but they have interfaces between each other. Analyzing these interfaces is essential through the design process to identify the sequence of systems' design and the reciprocal dependency within the design process. This dependency affects modularization and standardization processes and needs further research.

The aim is to align boundaries of systems to boundaries of fields of the grid system (Mohamad et al. 2013) and to restrict the design dependencies of the MEP systems to boundaries of fields of the grid system. These affect typically the production process and supply chains. Therefore also in this level participation of all stakeholders is important to develop and to evaluate the design options in alignment with all customer values. Application of Last Planer System can facilitate this process greatly. The work in this level is similar to the work in the first two levels.

During modularization and standardization of the MEP systems, some parameters could be changed as: 1) Dimension of components (in some cases oversized components). 2) Configuration of the components and sub-systems. 3) Sequence of production process, this includes also analyzing the type of material to be used.

The following diagram in figure (3) represents the work in this level, where the iterations that can emerge between this level and previous levels is not shown.

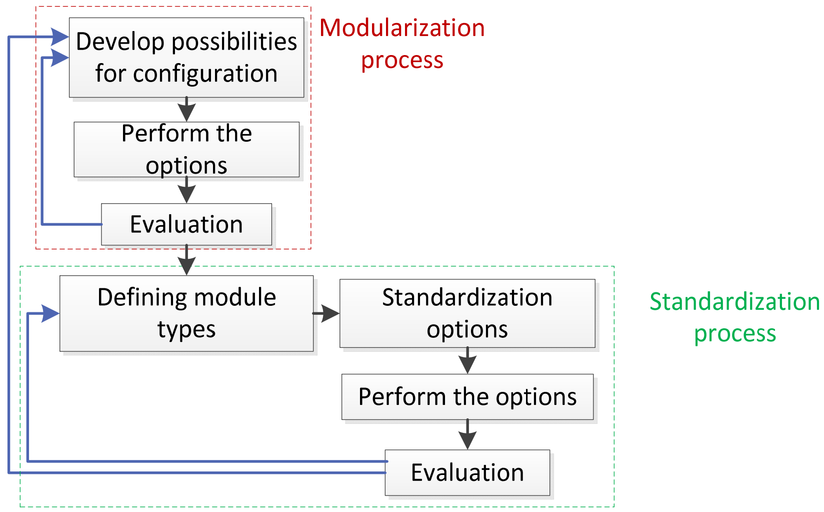

Figure 3: Work in Level 3- Configurations and components

CONCLUSION AND FUTURE RESEARCH

The workflow model shows the need to analyze work structuring principles when applying modularization and standardization to MEP systems' design. Involving the end customer/owner/user in the design process and integrating the knowledge of the construction teams to develop and evaluate the systems' structures from the constructability perspective can increase the effectiveness of modularization and standardization beyond the current implementation. This helps the participants in the design process to improve their efforts to integrate product and process design when applying modularization and standardization.

Applying Modularization and standardization in MEP design requires managing the knowledge of the participants to increase the efficiency in design process. Reliable promising cycle of the last planer system could be used to manage this knowledge. Future research includes making case studies to validate the proposals.

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