Martinez, E.H, Alvear, A.M., Tommelein, I.D. and Ballard, G., 2015. Formwork standardization and production flow: Lessons from an affordable housing project in Ecuador. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 53-62, available at www.iglc.net

FORMWORK STANDARDIZATION AND PRODUCTION FLOW: LESSONS FROM AN AFFORDABLE HOUSING PROJECT IN ECUADOR

Eder H. Martinez[1], Ariana M. Alvear[2], Iris D. Tommelein[3] and Glenn Ballard [4]

ABSTRACT

Latin America and the Caribbean are experiencing a severe housing shortage. The construction industry plays a pivotal role in housing provision and must find means to increase output and productivity in housing construction. However, inefficient production techniques, commonly associated with the building industry, exacerbate the problem. Adopting standardization and industrialization practices is seen as an option in scaling up production. Nevertheless, the complex nature of the industry (e.g., the uniqueness of projects and uncertainty) poses challenges when implementing standardization approaches in housing construction. Particularly, formwork standardization requires advanced planning and coordination across project delivery stages. Such synchronization is fundamental to balancing the production flow and optimizing the standardization process. This paper presents the case study of VillaHermosa, an Ecuadorian affordable housing developer exploring formwork standardization in the construction of reinforced concrete housing units. The authors describe their standardization process, the challenges faced by the company, the results and the lessons learned from the experience, as well as a topic for future study.

KEYWORDS

Lean construction, formwork standardization, production flow, production balancing, affordable housing, collaborative design.

INTRODUCTION

Countries in Latin America and the Caribbean (LAC) are experiencing an affordable housing crisis. Currently, nearly 23% of urban residents in LAC live in slums, equivalent to 110 million people (United Nations, 2011). Governments are challenged

[1] PhD Student, Civil and Envir. Engrg. Dept., Engrg, and Project Mgmt. Program, Univ. of California, Berkeley, CA 94720-1712, USA, +1 510 926-7210, edermartinezv@gmail.com

[2] MS, Engrg, and Project Mgmt., Project Manager, VillaHermosa Project, Duran, Ecuador, +593 98-998-8324, ariana.alvear@villahermosa.ec

[3] Professor, Civil and Envir. Engrg. Dept., Director of the Project Production Systems Lab., Univ. of California, Berkeley, CA 94720-1712, USA, +1 510 643-8678, tommelein@ce.berkeley.edu

[4] Research Director of the Project Production Systems Lab., Civil and Envir. Engrg. Dept., Univ. of California, Berkeley, CA 94720-1712, USA, +1 415 710-5531, ballard@ce.berkeley.edu

to find means to increase the availability of housing (United Nations, 1965). As a result, the construction industry is a key stakeholder in addressing the problem. However, many issues in housing provision are attributable to inefficiencies in the building sector (Lizarralde and Root, 2008; Inter-American Development Bank, 2012), poor technology implementation in building processes (CEPAL, 1996, p. 180) and inadequate project delivery methods (UN-Habitat, 2003, p. 5). This, in addition to productivity issues commonly associated with construction activity (Allen, 1985; Sanvido, 1988; Arditi and Mochtar, 2000), only intensifies the problem.

The United Nations (1965) has long recommended standardizing and industrializing the industry in order to accelerate housing construction. Arguably, the nature of the building process (i.e., uniqueness, uncertainty, and complexity of production systems) prevents mechanization of work. Despite the singularities of the building process, the housing construction sector is well-suited for the application of standard work (United Nations, 1965; Inter-American Development Bank, 2012). Woetzel et al. (2014) estimated that by Lean approaches including standardization and industrialization, construction costs for affordable housing may be cut by 16%.

Standardization stands for the use of components, methods or processes enabling regularity and predictability (Gibb, 2001). In this area, formwork suppliers have made significant progress in bringing automation to concrete related operations through the use of standard modules that can be easily transported and assembled on site (Oberlender and Peurifoy, 2011). Nevertheless, several factors must be taken into consideration when applying standardization practices in housing construction, e.g., an overuse of standardization may lead to design conflicts (Gibb, 2001) and customer dissatisfaction (Dos Santos, et al., 2014). This notwithstanding, excessive use of unique components may increase a project’s complexity, making it hard to manage (Tommelein, 2006). Therefore, a balance between customization and standardization must be struck. In addition, key decisions made at the design stage impact the construction process. The use of standard products requires a comprehensive evaluation of the production system since excessive standardization may affect flexibility at the production stage (Barlow and Ozaki, 2005; Jonsson and Rudberg, 2015). In particular, the use of standard formwork modules requires advanced planning and coordination in design and construction (Oberlender and Peurifoy, 2011). The link between product standardization and production process design must be analyzed in order to achieve a balanced production flow.

This paper examines the case study of VillaHermosa, an Ecuadorian affordable housing developer exploring the use of standard formwork for the construction of reinforced concrete houses. Based on observation, the authors describe the design process for standardization, the challenges faced by the company during this process, and the results of their experience. The paper ends with suggesting a topic for further research.

ABOUT VILLAHERMOSA

VillaHermosa is a developer based in Duran, Ecuador. The company is constructing an affordable housing project of over 10,000 single and multi-family units over the span of 8 years, starting in 2014. VillaHermosa is responsible for the design, procurement, and construction of the entire project, a position that provides it with broad control over the project delivery process. Because of its large size, the project is divided into 10 phases. This case study focuses on its first phase, which involves the design and construction of 700 single housing units to be completed by early 2017.

FORMWORK STANDARDIZATION

Standardization is the extensive use of components, methods or processes which enables regularity, repetition and a background of successful practices and predictability (Gibb, 2001). Component standardization specifically relates to the replacement of several components by a single one that can perform the functions of all of them (Perera, Nagarur and Tabucanon, 1999). Among other benefits, the use of standard products or components shortens lead times, improves quality and eases operations at the construction stage (Gibb and Isack, 2001; Pasquire and Gibb, 2002).

The performance of concrete activities generally plays an important role in the overall performance of projects that use structural concrete (Dadi, et al., 2012). Within concrete activities, formwork design has been noted as offering opportunities for standardization and industrialization (Shapira, 1999). The conventional and still widely-used system of timber and plywood formwork built on-site, has been set aside and replaced by more efficient modular systems. Formwork modular systems are fabricated in a shop and delivered to the construction site. On site, standard modules can be transported and assembled quickly. The use of standard formwork has several advantages (Oberlender and Peurifoy, 2011) over custom-built formwork:

- Simple installation that can be performed even by low-skilled workers
- Reduced erection time
- Higher number of reuses that leads to reduced overall costs of equipment
- Improved safety for the labor force
- Better quality concrete surfaces which reduces further finishing work
- Automation of formwork operations and improved productivity

Nevertheless, the implementation of standardization highlights the conflict between uniformity and variation. The tension between standardization and flexibility may result in design impotence (Gibb, 2001). In the context of housing design, the excessive use of standard products may cause customer dissatisfaction due to the variety of family profiles and the diversity of lifestyles in the population (Dos Santos, et al., 2014). In contrast, excessive customization may prolong the length of the construction process. The uniqueness of a facility may be valuable to the final customer, but using unique materials increases system complexity, making it more challenging to manage (Tommelein, 2006). As a result, developers must strike a balance between standardization vs. customization in order to handle production systems efficiently while still meeting customers' needs.

In addition, the implementation of standard components must be evaluated beyond the design stage. It is recognized that the use of standard products must match the production system design (Jonsson and Rudberg, 2015) since the incorporation of standard products may harm the flexibility of the production process (Barlow and Ozaki, 2005). For this reason, the trade-off between productivity-related capabilities (e.g., cost and lead time) and flexibility (product and process) has to be carefully analyzed when designing the project's production system (Nahmens and Bindroo, 2011). In terms of production system design, success in using modular formwork can be achieved only by proper planning at the architectural design stage and then requires advanced planning and coordination at the construction stage. Work sequence, reuse scheme, allocation of formwork sets, cranes and crews must be considered (Oberlender and Peurifoy, 2011). Consequently, it is crucial to evaluate the interface between the design of standard components and production capability in order to reach a balanced production flow.

CASE STUDY AT VILLA HERMOSA

FIRST RUN STUDY

Based on local market studies, VillaHermosa decided to design 20 preliminary house models, the smallest one being a 40 m^2 1-bedroom and the largest one being an 80 m^2 4-bedroom. As a first run study, the company built four demonstration houses. The purpose of this study was to assess the units' constructability and to evaluate construction performance in terms of time and budget. After this experience, the team identified several constructability issues related to variation among unit models. For instance, the different dimensions of concrete elements impeded the reutilization of formwork panels. The additional work required to adapt panels to different concrete elements' dimensions resulted in a significant waste of resources. Moreover, the construction team noticed formwork activities demanded a significant amount of time and resources. After this experience, the company reevaluated the house designs and decided to standardize the dimensions of concrete elements like rooms, walls, window- and door openings, and stairs.

DISCUSSION OF STANDARDIZATION VERSUS CUSTOMIZATION

As described, excessive use of standardization may lead to customer dissatisfaction. In the case study, the level of standardization vs. customization in the models became an important topic of discussion for VillaHermosa's project team members. On one hand, the sales team wanted to maximize customization. More variation in housing models facilitates sales since it is easier for sales agents to find a model that meets specific customers' needs. On the other hand, the construction team wanted to moderate variation. As experienced during the first run study, more variation considerably increased the complexity of operations on site.

After several iterations, VillaHermosa decided to keep 12 base models. However, in order to offer more customization, they decided to include certain architectural "add-on" elements to satisfy a broader range of customers. By adding iconic elements to the 12 base models (i.e., balconies or different types of finishes), the design team was able to find a balance between standardization and customization. As a result, the 12 base models became 47 types of houses.

FORMWORK SUPPLIER SELECTION

The team put special care into the selection of the formwork supplier. During this process, a bidder's technical expertise and willingness to participate in a collaborative design process was of great importance in awarding the contract. Finally, VillaHermosa selected a formwork provider with more than 50 years of experience in the market. This supplier would engineer and manufacture concrete forming systems according to VillaHermosa's specific requirements.

FORMWORK STANDARDIZATION PROCESS

VillaHermosa's goal was to come up with a project that offered options for different customers' profiles. The company also aimed to design a project that reduced variation, optimized concrete related operations and eased production flow. With this purpose, stakeholders' interests were aligned in order to balance standardization vs. customization. Team members involved in the collaborative design process stacked two types of pre-existing designs up against each other. On one side were the preliminary designs of housing units made by VillaHermosa's architectural team. On the other side were the standard panels marketed by the formwork supplier. In order to optimize formwork standardization, the existing models were adapted to the dimensions of standard panels. In doing so, VillaHermosa and the formwork provider set the following goals:

- Reduce the number of formwork equipment on site – Reduce inventory
- Standardize housing models for concrete operations – Reduce variation
- Develop one LEGO set capable of building all models – Interchangeability

Figure 1 shows how the design process proceeded for each group of housing models. Models were standardized in batches. The cycle depicted in figure 1 repeats itself several times after all the shells of houses were completed. The design process lasted four months. At this point two sets were used, each one flexible enough to build any of the twelve base models.

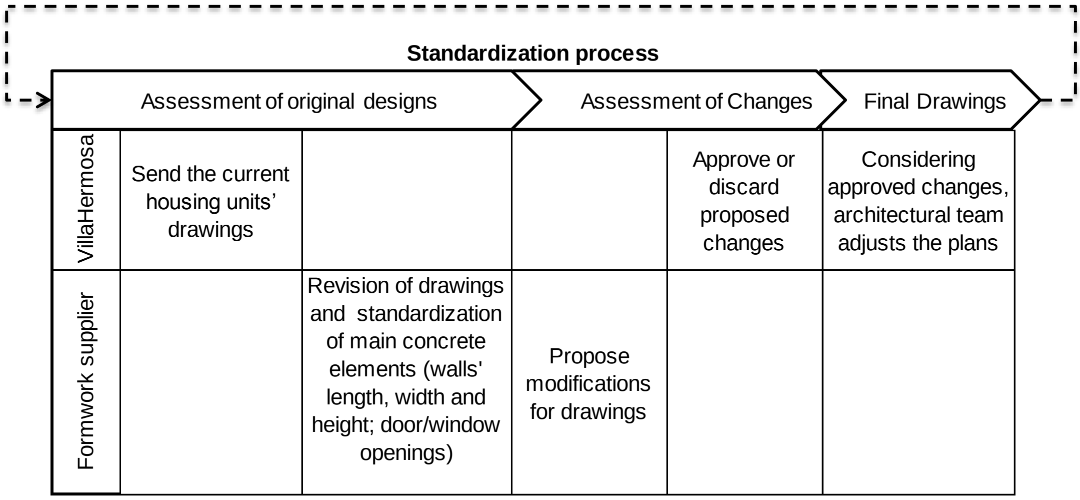

Figure 1: Standardization process at VillaHermosa

BALANCING PRODUCTION THROUGH DESIGN

Success in using standard formwork depends on proper design as well as adequate correlation with construction processes. In alignment with this statement, and considering the use of two flexible formwork sets, VillaHermosa and the formwork provider simulated construction operations. Their objective was to optimize the use of each formwork set in order to achieve a balanced production rate that met sales.

In order to meet demand, the construction team had to produce 2 houses/day. This meant having two construction crews working simultaneously, each one capable of building any model. However, the size of the models and the setup of project lots affected the production flow. During the simulation, the team identified challenges and collaboratively implemented the following solutions.

Problem 1: Idle Inventory: The initial production process design considered using two formwork sets, each one capable of building any base model. This solution was flexible since two crews working simultaneously could build any type of house. However, a typical block design has two lot sizes, one 67 m^2 and one 100 m^2 respectively with an average distribution of 30% and 70% per block. As shown in figure 2, for each lot, only certain kinds of house models are allowed to be built. The 67 m^2 lot allows for the construction of small models while the 100 m^2 lot allows for the construction of big models. Since the project had small and big models, several inventory pieces (approximately 45%) would remain unused when building small models.

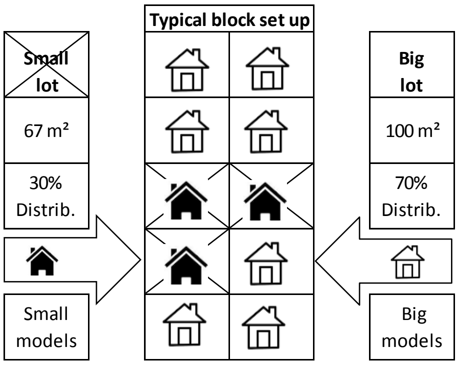

Figure 2: Typical block setup and its corresponding house model

Solution 1: In collaboration with the formwork supplier, VillaHermosa readapted the set's configurations so as to have one set for small models and one for big models, thereby reducing the idle inventory considerably during the construction process.

Problem 2: Unbalanced Production per Delivery Zones: Given one formwork set for each type of house, two specialized crews are necessary to maximize inventory use and make production efficient.

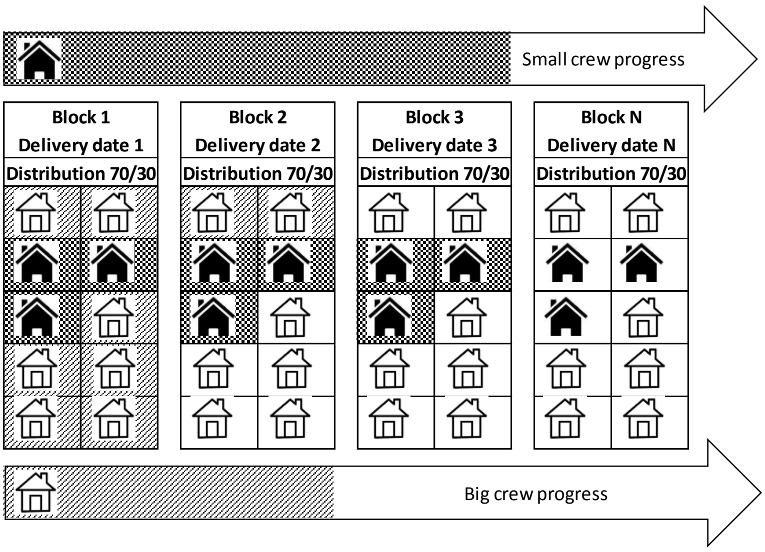

Figure 3: Unbalanced production flow through delivery blocks

Nevertheless, the specific distribution of different-sized lots (30/70) and the due dates for the completion of blocks imposed new challenges. Using two specialized crews with the 30/70 lot distribution resulted in an unbalanced production flow of small and big houses. By sharing only 30% of the work per block, the crew working on small models would work faster than the crew working on the big models. Schematically, figure 3 shows construction progress at day 9. If each crew built 1 house/day, at day 9, the crew for small models would be working on block 3. However, block 2 would still be under construction because the big models would not be completed yet. Although the production rate would still meet the demand of 2 houses/day, the production flow per delivery zone would not be met. This was a relevant issue since VillaHermosa is committed to delivering the project by block at specific dates.

Solution 2: In order to balance the production per block, the team included a specific house model in the design that could be built on either the 67 m^2 or 100 m^2 lot. This model can be used as a "wildcard" to achieve a balanced 50/50 distribution of small and big models per block. By adding a subtle design variation that indeed reduced the level of standardization in the original design, flexibility was obtained at the production level, enabling an even progression in the production flow.

Problem 3: Sales Point Coordination: By implementing this design change, the team set a balanced production system. However, the balanced distribution was based upon sales to customers since the sales representatives had to ensure that the wildcard house model was being sold in every block to keep the 50/50 distribution. Consequently, the project would require control over the sales per block or loose the balance in the production process.

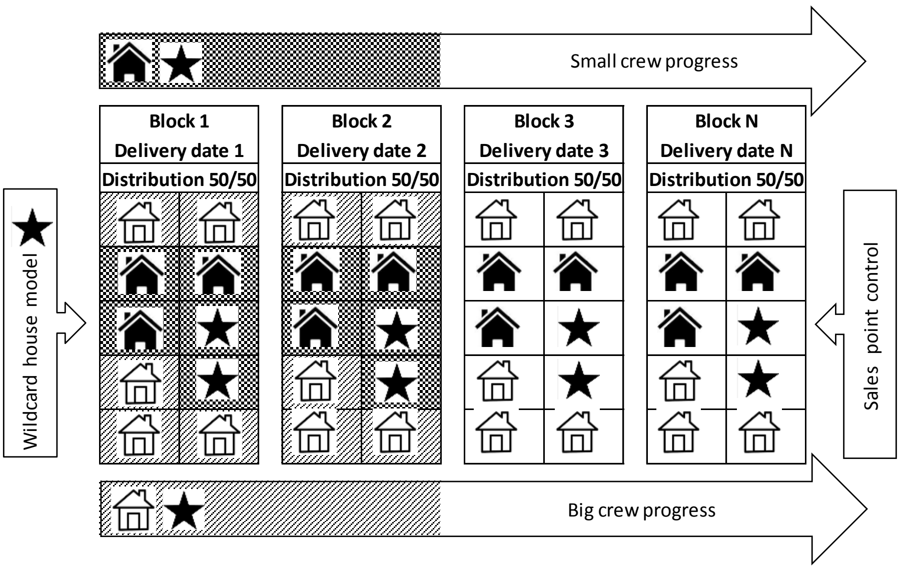

Figure 4: Balanced production flow through delivery blocks resulting from the wildcard house model and sales point control

Solution 3: In order to achieve control over the sales per block, VillaHermosa's sales software set a counting system that calculates the percentage distribution for the different house models. Once the sale of big houses per block reaches over 50%, a restriction is set to only allow the sale of the wildcard house in the big lots. Thus far, this had not been a problem since the wildcard model has sold well, thereby allowing an equal distribution between crews without limitations to the sales representatives. Figure 4 schematically represents this new balanced production, which takes into account the wildcard house model and the sales point control.

RESULTS

In the first design iteration, the team standardized the houses' concrete elements in order to have only two formwork sets capable of building any of the twelve models. However, this left 45% of formwork equipment idle when building small models. In response, the team designed two specialized sets, one for the small models and one for the big models. This alternative was efficient in terms of inventory use but inadequate when considering the balance of the production flow.

In a second design iteration, the team decided to include variation through a wildcard model that can be built with any formwork set. This design variation helped the team achieve a balanced flow of production between construction crews and allowed the team to meet project delivery dates per block. The team at this point realized that the balance in the production process could be achieved only at the sales point (Wardell, 2003) and to that effect set a subtle restriction at the sales point.

Through collaborative design and coordination among team members, the standardization process benefited the project. Table 1 shows the original setup cost $631,184. After completing the design iterations, the final setup cost $501,597. The final setup also reduced inventory by 25%, which eased operations on site.

Table 1: Final result of design standardization process

Item	Original setup	Final setup	Reduction [%]
Number of pieces	3,360	2,492	-25.8
SKUs/Items	944	687	-27.2
Total Cost USD	631,184	501,597	-20.5

CONCLUSIONS

This case study describes a successful experience of formwork standardization in an affordable housing project in Ecuador. In the first stage, the formwork standardization process focused on design, aimed to reduce variation and facilitate construction operations. However, the design team realized that further involvement of other project stakeholders was needed to optimize standardization. The success of this experience relied on collaboration among project members, as well as planning and synchronization among different project delivery stages.

Key decisions made early in design were crucial to making the final solution efficient overall. The production process simulation performed by the team identified the imbalanced production flow resulting from the original design. To overcome this imbalance, the company's construction and sales teams helped find the solution. This case study demonstrated the link between design and production. Specifically, the use of standard components affected the flexibility in construction and production flow balance. Incorporation of the wildcard model added variation and reduced standardization, yet proved to be beneficial by helping the team achieve a balanced production flow. This improvement, in addition to modifications of sales procedures, facilitated the application of a solution that optimized the whole, not parts, of the production system.

The involvement of an experienced formwork supplier had a significant impact on this success. Nevertheless, professionals participating in this project agreed that involving the formwork provider earlier in the design process could have helped the team avoid initial design iteration, leading to the development of an even more efficient final solution. A barrier impeding the application of this improvement was the competitive bidding process required by the company in awarding contracts.

An aspect relevant for discussion relates to the type and scale of the project and its relation to standardization practices. In order to maximize affordability, developers in the affordable housing industry accept small profits per housing unit so they will aim to maximize the benefits of economies of scale. In this context, the standardization of building components becomes crucial for the success of projects. Specifically in this case study, small profit margins achieved in the production of a single housing unit can be replicated in the following units, maximizing overall gains.

This case study focused only on the benefits of standardization in the design process and its correlation with production flow. However, standardization also has an impact on labor training and productivity, especially when dealing with repetitive work. This important topic is driving future research at VillaHermosa.

ACKNOWLEDGMENTS

Research for this paper was supported in part by funding from Conicyt and VillaHermosa. All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of Conicyt or VillaHermosa.

REFERENCES

Allen, S.G., 1985. *NBER Working Paper No. 1555: Why Construction Industry Productivity is Declining*. Cambridge, MA, USA: Nat’l. Bureau of Econ. Res., Available at <http://www.nber.org/papers/w1555> [Accessed 1 March 2015].

Arditi, D. and Mochtar, K., 2000. Trends in Productivity Improvement in the US Construction Industry. *Constr. Mgmt. and Econ.*, 18(1), pp.15-27.

Barlow, J. and Ozaki, R., 2005. Building Mass Customised Housing Through Innovation in the Production System: Lessons from Japan. *Environment and Planning A*, 37(1), pp.9-20.

CEPAL, 1996. *La Producion de la Vivienda en America Latina y el Caribe.* Santiago, Chile: Comisión Econ. para América Latina y el Caribe – CEPAL. Available at <http://repositorio.cepal.org/bitstream/handle/11362/30711/S30154N962P_es.pdf?sequence=1> [Accessed 7 March 2015].

Dadi, G.B., Safa, M., Goodrum, P.M., Haas, C.T., Caldas, C.H. and McNeel, D., 2012. Improving Concrete Trade Labor Productivity Through the Use of Innovations. *ASCE, Constr. Res. Congr.*, West Lafayette, IN, 21-23 May.

Dos Santos, C., Formoso, C.T., Da Rocha, G., Anesi, G., Klein, B., 2014. Method for Identifying Customization Demands in Social House-building. *ZEMCH (Zero Energy Mass Custom Homes) Int’l. Conf.*. Londrina, Brazil, 4-6 June.

Gibb, A.G.F., 2001. Standardization and Pre-assembly-distinguishing Myth from Reality Using Case Study Research. *Constr. Mgmt. Econ.*, 19(3), pp.307-315.

Gibb, A.G.F. and Isack, F., 2001. Client Drivers for Construction Projects: implications for standardization. *Engrg. Constr. Arch. Mgmt.*, 8(1), pp.46-58.

Inter-American Development Bank, 2012. *Room for Development: Housing Markets in Latin America and the Caribbean*. New York, USA: Palgrave Macmillan.

Jonsson, H. and Rudberg, M., 2015. Production System Classification Matrix: Matching Product Standardization and Production-System Design. *ASCE, J. Constr. Eng. Manage.*,141(6), pp.05015004.

Lizarralde, G. and Root, D., 2008. The Informal Construction Sector and the Inefficiency of Low Cost Housing Markets. *Construction Management and Economics*, 26(2), pp.103-113.

Nahmens, I. and Bindroo, V., 2011. Is Customization Fruitful in Industrialized Homebuilding Industry? *ASCE, J. Constr. Eng. Manage.*, 137(12), pp.1027–1035.

Oberlender, G. and Peurifoy, R., 2011. *Formwork for Concrete Structures*. 4th ed. New York, USA: McGraw Hill Professional.

Pasquire, C.I. and Gibb, A.G.F., 2002. Considerations for Assessing the Benefits of Standardisation and Pre-assembly in Construction. *Journal of Financial Management of Property and Construction*, 7(3), pp.151-161.

Perera, H.S.C., Nagarur, N. and Tabucanon, M.T., 1999. Component Part Standardization: A Way to Reduce the Life-cycle Costs of Products. *International Journal of Production Economics*, 60-61(1), pp.109-116.

Sanvido, V.E., 1988. Conceptual Construction Process Model. *ASCE, J. Constr. Eng. Manage.*, 114(2), pp.294-310.

Shapira, A., 1999. Contemporary Trends in Formwork Standards - A Case of Study. *ASCE, J. Constr. Eng. Manage.*, 125(2), pp.69-75.

Tommelein, I.D., 2006. Process Benefits From Use of Standard Products – Simulation Experiments Using the Pipe Spool Model. In: *Proc. 14th Ann.Conf. Int'l. Group for Lean Construction*. Santiago, Chile, September 28-30.

UN-Habitat, 2003. *The Challenges of slums*, Nairobi, Kenya: United Nations Human Settlements Programme.

United Nations, 1965. *Effect of Repetition on Building Operations and Processes on Site*. New York, USA: United Nations Economic Commission for Europe.

United Nations, 2011. *Sustainable Development in Latin America and the Caribbean 20 Years on from the Earth Summit: Progress, Gaps and Strategic Guidelines*. Rio +20. United Nations Conference on Sustainable Development (Preliminary Version). Available at <http://www.cepal.org/../2011-457_Rio 20-Sustainable_development-WEB.pdf > [Accessed 10 November 2014].

Wardell, C., 2003. Build By Numbers. Builder Magazine. Available at < http://www.builderonline.com/article/build-by-numbers_o > [Accessed 29 May 2015]

Woetzel, J., Ram, S., Mischke, J., Garemo, M. and Sankhe, S., 2014. *A Blueprint for Addressing the Global Affordable Housing Challenge*. USA: McKinsey Global Institute. Available at <.http://www.mckinsey.com/insights/urbanization/tackling_the_worlds_affordable_housing_challenge> [Accessed 30 November 2014].