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A LEAN APPROACH TO INDUSTRIALIZED AND MODULAR HOMEBUILDINTG: IDENTIFICATION AND ASSESSMENT OF WASTES IN MASS-HOUSING PROJECTS

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Abstract: Construction processes always encounter various wastes including unnecessary use of materials, rework, waiting time, etc. Lean production principles are considered an effective management tool since they focus on eliminating wastes and delivering value to the customers. However, processes of construction are quite different from those of production. Industrialized homebuilding bears a strong resemblance to production. Industrialized or modular homes are referred to as buildings consisting of sections which are manufactured in a factory and then transported to the project site and finally assembled. In this research three industrialized systems are examined namely, Lightweight Steel Frames, Insulating Concrete Forms and steel frames with Bolt and Nut connections. The purpose of this research is to identify, assess and rank different wastes in industrialized home building projects based on an opinion survey completed by experts who are involved in such projects in Iran. The wastes are identified, evaluated and prioritized throughout the project life cycle and finally some recommendations are presented in order to eliminate or at least decrease the identified wastes. The findings of this paper could be used by contractors and project managers concerned with mass housing projects to utilize a more effective management approach.

1 Introduction

After successful implementation of lean principles to the manufacturing sector, the managers involved in the construction sector have been trying to apply these principles to construction projects. Studying the history of lean production shows that these principles were first applied to the production line of Toyota in Japan. However, the nature of construction is different from that of production. The major differences are as follows:

1.**On-site production:** Construction is site-position manufacturing, as opposed to fixed-position manufacturing in which the product can be moved after assembly (Schemenner 1993).

2.On-of-a-kind production: Normally, manufacturing takes advantage of specialized equipment to make standardized units. In construction, customers play a key role throughout the project cycle. Under guidance from the designer, customers define their product through the bid package or contract. (O.Salem,et al 2006).

3.Complexity: In manufacturing, many components from different subassemblies can be easily managed because suppliers are selected early in the design phase. Specialized facilities with suitable technology and layout ensure the reliable flow of the product. With repetition, this supply network eventually becomes manageable and optimized. In contrast, in construction, the completion of activities is highly interrelated and complicated. Construction projects are characteristically complex, unique, dynamic systems that must rely on an initial design that involves a number of subassemblies with variable specifications (Bertelsen 2003).

If the aforementioned differences are combined into one, the result will be variability or uncertainty which decreases the efficiency and puts the processes into an unsteady state. As we all know, construction projects are always influenced by unforeseen conditions such as climate changes, customer's varying requirements and the interactions between several processes, which can impose a critical impact on the project cost.

Nowadays Industrialized homes are built in order to provide fast and affordable housing in developing countries. Industrialized or modular homes are defined as buildings which consist of sections manufactured in a factory environment and then transported to the project site and finally assembled. As a result, modular homes can be considered similar to a production line so that lean principles may be applied to improve the efficiency and productivity of the activities. In general, two strategies have been used for industrialized construction. The "product approach" aims at minimizing on-site construction activities by turning buildings into products that can be manufactured in factory environment, while the "process approach" focuses on applying a manufacturing management model to the current construction processes (Haitao Yu et al 2011). Thus, using industrialized buildings as a method to achieve a steady state to increase efficiency through repetition is justified.

2. Literature Review

The origin of lean production dates back to the automobile manufacturing industry with the Toyota Production System (Ohno1988). The complete history of lean production has been written in a book called "The machine that changed the world" by Womack And Jones in 1990. Lean means getting the right thing to the right place, at the right time and in the right quantity while minimizing waste and being flexible and open to change (Womack 2005). The ultimate goal of lean production is to deliver value to all stakeholders, including internal and external customers, and to eliminate waste (Nahmens et al 2012). Womack and Jones (1996) established the five principles for lean production as follows: (1) Precisely specify value by specific product; (2) Identify value stream for each product; (3) Make value flow without interruptions; (4) Let the customer pull value from the producer; and (5) Pursue perfection.

Ohno (1988) characterized wastes in production within the Toyota Production System into seven types: (1) Overproduction, producing an item before needed; (2) Waiting, idle time; (3) Transportation, excessive movement and handling of an item; (4) Inventory, excess inventory, increasing lead time and consuming floor space; (5) Motion, unnecessary movement of people and equipment; (6) Over-processing, unnecessary processing of an item; and (7) Defects, quality defects.

According to the previous section which clarified the different nature of construction and production, construction from a production perspective is defined as "production of a one-of-kind product undertaken mainly at the delivery point by cooperation within a multi-skilled ad-hoc team'' (Bertelsen ad Koskela 2003). Lean construction, founded by Koskela in 1993, is referred to as the application of lean production principles and practices to the construction industry. Koskela in 1993 introduced eleven heuristic principles as follows:

1.Reduce the share of non value-adding activities.
2.Increase output value through systematic consideration of customer requirements.
3.Reduce variability.
4.Reduce the cycle time.
5.Simplify by minimizing the number of steps, parts and linkages.
6.Increase output flexibility.
7.Increase process transparency.
8.Focus control on the complete process.
9.Build continuous improvement into the process.
10.Balance flow improvement with conversions improvement.

11.Benchmark.

Later on, Koskela (2000) introduces three basic conceptualizations of production: transformation, flow and value generation. In other words, lean construction emphasizes on the importance of the production process flow and converting inputs into finished products as an important element in the creation of value over the life of a project (Nahmens et al 2012).

2. Data Collection

In this research, a thorough review of the literature was conducted and 36 experts involved in Iran's mass-housing projects were interviewed. The interviewees included civil engineers, architects and project managers with working experience ranging from 2 to over 15 years in industrialized and modular buildings (see Figure 1).

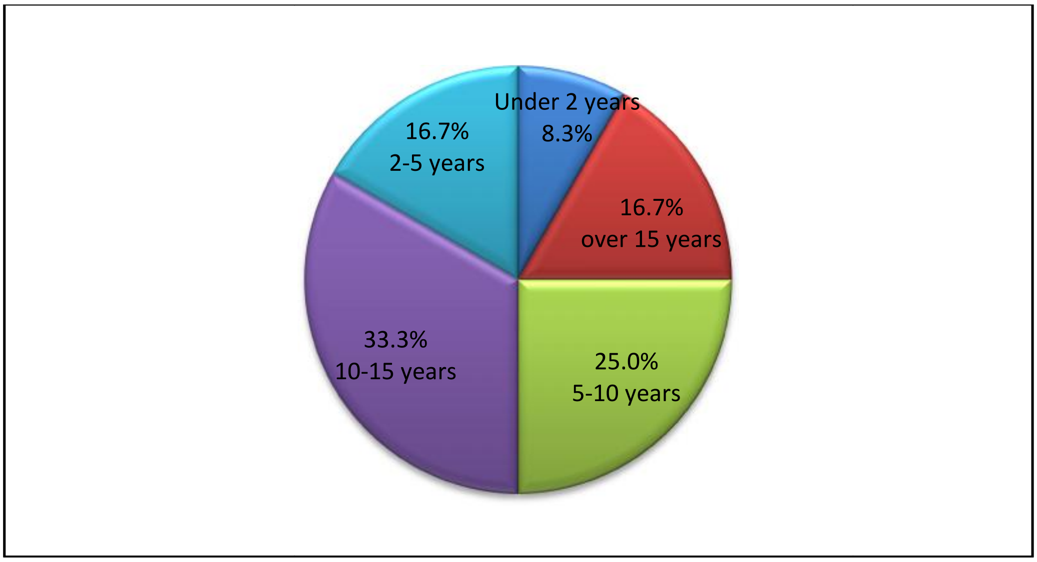

Figure1: The interviewees working experience

Three common modular systems namely Lightweight Steel Frame (LSF), Insulating Concrete Form (ICF) and Prefabricated Steel Frames with Bolt and Nut Connections (B & N) were examined. The three systems can be explained in brief as follows:

LSF: This system is composed of light cold-formed steel frames which are manufactured in the factory and then lifted at the project site. The frames are connected using bolt connections and Gypsum boards are used as walls. The height of these buildings is limited to 15 meters.

ICF: ICFs are hollow blocks or panels made of plastic foam that are stacked into the shape of the exterior walls of a home. Reinforcing steel is then added and the gap between the two layers of foam is filled with concrete. This combination of concrete, steel, and foam creates a strong and energy-efficient structure.

B & N: In this system some of the steel frames, especially those containing the critical sections, are manufactured in the factory and transported to the site. The frames are connected using Bolt and Nut connections which produce less residual stress compared to welding connections. The connection of the frames could be modified and fixed at the job site.

After explaining the seven types of wastes in lean construction, 18 most common wastes under 7 main groups in the aforementioned modular systems in Iran's mass-housing projects, were identified (see Table 1).

Table 1. The identified wastes in Iran’s mass-housing projects

NO	Main groups	The Identified Wastes	Code
1	**Overproduction**	Early production before use	101
		Additional costs due to warehousing	102
2	**Waiting and idle time**	Downtime of equipment	201
		Waiting for the parts fabricated in the factory	202
		Waiting for funds	203
3	**Transportation**	Unnecessary transportation of equipment	301
		Unnecessary transportation of materials	302
4	**Inventory**	Materials in excess of planned requirements	401
		Not delivered buildings,or undergoing legal processes	402
5	**Motion**	Unnecessary movements of workers and equipment	501
		Improper site, equipment and workers' layout	502
6	**Over-processing**	Unnecessary processes leading to excessive use of equipment and materials	601
		Quality higher than the customer's order	602
7	**Defects**	Defects due to errors in design	701
		Defects due to not understanding the customer's needs	702
		Errors in construction and rework caused by non-conormance with maps	703
		Errors in construction and rework caused by changes in maps	704
		Accidents caused by ignoring safety measures	705

In the next step the frequency and importance of each waste were asked by a five point scale, ranged from very low (1) to very high (5) importance or frequency. After that the Relative Importance Index (RII) and Relative Frequency Index (RFI) were calculated by the following equations:

[1] $RII = \frac{\sum I}{\sum A * N}$

[2] $RFI = \frac{\sum F}{\sum A * N}$

Where F and I represent the weight for frequency and importance given by the respondents, A is the highest weight which is considered 5 here, and finally N is the total number of respondents.

The Waste Value Factor (WVF) is then calculated by the product of relative frequency and importance indices of each waste (Rashid and Heravi 2012):

[3] WVF = Relative Frequency Index (RFI) × Relative Importance Index (RII)

3. Analysis of results

The Relative Importance and Frequency Indices along with the waste value factor for each waste as well as the average Waste Value Factor for each modular system are illustrated in Table 2. The Table demonstrates that ICF systems have the least wastes among the three systems since the average of identified wastes has the smallest value.

Table 2. The RII, RFI and WVF for each waste in the three systems

Waste Code	LSF			B & N			ICF		
	RII	RFI	WVF	RII	RFI	WVF	RII	RFI	WVF
101	0.617	0.467	0.288	0.650	0.567	0.368	0.583	0.500	0.292
102	0.450	0.483	0.218	0.667	0.533	0.356	0.517	0.567	0.293
201	0.483	0.367	0.177	0.733	0.583	0.428	0.567	0.517	0.293
202	0.717	0.500	0.358	0.767	0.633	0.486	0.683	0.567	0.387
203	0.883	0.817	0.721	0.900	0.767	0.690	0.800	0.767	0.613
301	0.433	0.433	0.188	0.633	0.500	0.317	0.417	0.500	0.208
302	0.533	0.483	0.258	0.567	0.467	0.264	0.550	0.600	0.330
401	0.417	0.433	0.181	0.583	0.583	0.340	0.483	0.583	0.282
402	0.600	0.617	0.370	0.667	0.617	0.411	0.600	0.633	0.380
501	0.517	0.517	0.267	0.667	0.600	0.400	0.567	0.483	0.274
502	0.617	0.633	0.391	0.633	0.533	0.338	0.633	0.567	0.359
601	0.583	0.450	0.263	0.550	0.450	0.248	0.567	0.483	0.274
602	0.667	0.350	0.233	0.500	0.450	0.225	0.700	0.367	0.257
701	0.817	0.650	0.531	0.650	0.550	0.358	0.550	0.633	0.348
702	0.750	0.617	0.463	0.533	0.483	0.258	0.650	0.533	0.347
703	0.750	0.650	0.488	0.700	0.617	0.432	0.667	0.600	0.400
704	0.817	0.600	0.490	0.700	0.650	0.455	0.600	0.550	0.330
705	0.783	0.567	0.444	0.733	0.633	0.464	0.650	0.633	0.412
Average WVF	0.351			0.380			0.338		

The comparison of Waste Value Factors for the main groups of wastes in the understudied systems are depicted in Table 3:

Table 3. Comparing seven main groups of wastes in the three modular systems

NO	Waste Group	Average WVF in LSF	Average WVF in B & N	Average WVF in ICF	Average WVF Total (%)
1	**Overproduction**	0.253*	0.362	0.292	12.8%
2	**Waiting and Idle time**	0.419*	0.534	0.431	19.6%
3	**Transportation**	0.223*	0.291	0.269	11.1%
4	**Inventory**	0.275*	0.376	0.331	13.9%
5	**Motion**	0.329	0.369	0.316*	14.4%
6	**Overprocessing**	0.248	0.236*	0.265	10.6%
7	**Defects**	0.483	0.393	0.367*	17.6%

* Minimum Value

Table 3, shows that:

1. Overproduction, idle time, transportation as well as inventory wastes are less common in LSF systems. The production is usually in line with the market demand so-that the products are neither produced too early nor they are stored in the warehouse for a long time. Also the materials and the equipment are transported less frequently since the locations of panels are usually determined at the design phase.

2. Over-processing is less common in B & N systems so-that less equipment and materials are wasted and the quality of the product less frequently exceeds the quality desired by the customer.

3. Unnecessary movements of equipment and workers do not usually occur in ICF systems since they use less equipment. Moreover, defects due to design or construction are less common in this system.

The most significant group of wastes in this study is waiting and idle time. It means projects often remain idle due to delays in funding, downtime of equipment and waiting for prefabricated sections. In addition, by considering over-processing as the least common group of wastes, it is concluded that the products seldom have higher quality than needed and undergo excessive and unnecessary processes.

In the next phase, the standard deviation of the WVF for each waste in all systems is calculated and then the standard deviation is divided by the average to obtain a dimensionless value. To better evaluate and compare the results, this value is normalized by the following equation:

[3] $$\Lambda = \frac{(SD/Ave)-Min(SD/Ave)}{Max(SD/Ave)-Min(SD/Ave)}$$

The results have been sorted from the largest to the smallest normalized values in Table 4.

Table 4. Comparison of relative WVF Standard Deviation of each waste

Waste Code	WVF (LSF)	WVF (B&N)	WVF (ICF)	Average	SD	SD/Ave	ʎ
201	0.177	0.428	0.293	0.299	0.1254	0.419	1.000
401	0.181	0.340	0.282	0.268	0.0808	0.302	0.682
301	0.188	0.317	0.208	0.238	0.0692	0.291	0.654
702	0.463	0.258	0.347	0.356	0.1027	0.289	0.646
701	0.531	0.358	0.348	0.412	0.1028	0.249	0.540
102	0.218	0.356	0.293	0.289	0.0691	0.239	0.513
501	0.267	0.400	0.274	0.314	0.0749	0.239	0.511
704	0.490	0.455	0.330	0.425	0.0841	0.198	0.400
202	0.358	0.486	0.387	0.410	0.0667	0.163	0.304
101	0.288	0.368	0.292	0.316	0.0454	0.144	0.253
302	0.258	0.264	0.330	0.284	0.0399	0.141	0.244
703	0.488	0.432	0.400	0.440	0.0443	0.101	0.136
203	0.721	0.690	0.613	0.675	0.0556	0.082	0.086
502	0.391	0.338	0.359	0.362	0.0266	0.073	0.061
602	0.233	0.225	0.257	0.238	0.0164	0.069	0.049
705	0.444	0.464	0.412	0.440	0.0266	0.060	0.027
402	0.370	0.411	0.380	0.387	0.0214	0.055	0.013
601	0.263	0.248	0.274	0.261	0.0132	0.051	0.000

As depicted in Table 4, if we consider wastes with normalized values equal or greater than 0.6 as critical, the top four

4.1. Five S's Method

5S has been recommended by many lean experts as the starting point of lean transformation (Productivity Press 2006), because compared to other lean tools, 5S, which focuses on cleaning and organizing the workplace, is easier to get worker's buy-in and produces immediate visible results (Haitao Yu et al 2011). This method consists of five steps as follows:

1.Sort: The first level includes separating materials by reference and placing materials and tools close to the work area with consideration of safety.

2.Straighten: Next, materials and tools should be piled up in a regular pattern and each contractor should take responsibility for specific work area.

3.Standardize: The next level includes preparation of a material layout design. The layout contains the key information of each activity and helps locate incoming material, reduce crane movements and walking distance.

4.Shine: The next step consists of cleaning the job site. Workers are encouraged to clean the workplace once an activity is completed.

5.Sustain: The final level of housekeeping is sought to maintain all practices throughout the project (O.Salem et al 2006).

The wastes such as *Unnecessary transportation and motion of materials or equipment* could be decreased by using ***Five S's*** method since it focuses on the proper layout of the materials and equipment. Moreover, *accidents* can be prevented since this method provides better safety for the workers and equipment.

4.2. Last planner Method

The Last Planner System (LPS) developed by Ballard (2000) seeks to identify what activities can be done. In this way, a list of activities that can be done is defined so that a Weekly Work Plan (WWP) may be designed. When an activity is included in the WWP, the project team commits to do it. Unlike the traditional planning methods which emphasize on what should be done, the Last Planner focuses on what can be done.

The steps required by this method include (Nieto-Morote and Ruz-Vila 2012):

First a master schedule, which only contains the main milestones, is prepared. The milestone dates are determined at the beginning with the project completion date and working backward to the beginning of the project.

The look-ahead schedule, which represents an intermediate level of planning, is created. This schedule contains the major activities that must be executed to complete the milestones at the times set in the master schedule. This schedule typically looks ahead six to eight weeks. The exact duration of the look-ahead window depends on the time required to eliminate the constraints.

The short-term schedule is an assignment-level schedule with duration of one week. This schedule includes all assignments or work activities that are required to be started that week to comply with the completion dates in the look-ahead schedule. Work assignments must be ready to begin before their inclusion in the WWP, i.e., all constraints, including prerequisite work, must have been eliminated, and resources must be available and properly assigned to complete the task (Choo et al. 1999).

The *waste category of waiting and idle time* could be best eliminated or decreased by using the Last Planner System since it concentrates on the current situation and revises the schedule planning based on the available resources.

4.3. Value Stream Mapping

Value Stream Mapping (VSM) is a widely used tool in lean planning. It helps managers to think about flow instead of individual wastes. Value stream is defined as a series of activities required to bring a product or service from raw state through to the customer (Haitao Yu et al 2009). It helps the managers to view processes and information flow schematically and as a result identify the wastes and values more precisely during the project life cycle.

In this method, first the current state of the processes is illustrated, then the existing practice is analyzed, after that the future state of the processes is formulated by using simulation. The ultimate goal of Value Stream mapping is to create a vivid picture of production processes and to demonstrate wastes.

Wastes like *overproduction or over-processing* may be prevented by illustrating the flow of processes as well as the information. In this regard, the products are produced at the right time, i.e neither too early nor too late. Also, if a process is identified using more materials and equipment than needed and creating higher quality than needed, the managers try to stop it and revise the value stream.

4.4. Standardized Work and Variation Management

Standardized work is regarded as the backbone of lean processes and the basis for continuous improvement and quality (Haitao Yu 2011). If a process is always shifting, then any effort for improvement just creates one more variation that is occasionally used and mostly ignored (Liker 2004). As we discussed before, construction projects are inundated with variability since the processes are completed by teams with different skills and experience.

In this method, some standard work sheets containing two elements are prepared:

1.A work combination table which contains the sequence of activities and the staff requirements at each station and clarifies the scope for which a team is accountable.

2.A standard procedure provides the staff with step-by-step instructions to make sure workers follow the best practice.

The combination table and standard procedures are posted at each station to provide a visual reference for management to check compliance with the standard. Any deviation from the standard means an undesirable state. Managers are responsible to recognize the deviation, discover the root causes and correct the problems as quickly as possible, and eventually revise the standardized work.

Defects due to errors in design, *not understanding the customer's need*, *non-conformance with maps or changing maps* may be corrected using this method since this method provides some step-by-step procedures which facilitate the processes by repetition.

5. Conclusions

With regard to differences between construction and production sector, namely on-site-production, complexity and one-of-a-kind production, applying lean principles to construction projects is quite difficult. However, industrialized and modular buildings to provide fast and affordable housing could be simulated to a production line and lean principles may be applied to increase efficiency. In this research, wastes in three widely used industrialized homebuilding including Lightweight Steel Frames (LSF), Insulating Concrete Forms (ICF) and Prefabricated Steel Frames with Bolt and Nut Connections (B & N), were examined and 18 wastes under 7 categories were identified. The seven groups comprise overproduction, waiting and idle time, transportation, inventory, over-processing, motion and defects. The ICF system was introduced as the most efficient system since it produces the least wastes compared to the other systems. Wastes under the category of waiting and idle time are identified as the most critical type of waste. Wastes related to waiting and transportation of equipment was far too different in B & N systems since they are highly dependent on the equipment. At the end, four lean construction methods were introduced: Five S's, The Last Planner, Value stream mapping, and Standardized work. Wastes under the category of motion and transportation can be decreased by Five S's, waiting and idle time by the Last Planner, over-processing and overproduction by Value stream mapping and finally defects by Standardized work.

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