# INTEGRATING THE DESIGN STRUCTURE MATRIX AND THE LAST PLANNER SYSTEM™ INTO BUILDING DESIGN

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## ABSTRACT

This paper proposes to reduce uncertainty in design management through the combined application of the Design Structure Matrix (DSM) and the Last Planner System™ (LPS) methodologies. DSM offers a powerful visualisation tool that facilitates the management of design iteration in order to achieve an optimal sequence of tasks. It will be claimed that DSM is particularly oriented towards Lean Construction, in the sense that, it creates value through dependency identification where assumptions are minimised. It facilitates the analysis of design information and decision-making process based on the real customer demands. However, the use of DSM does not extend to the application of the designed sequence in practice. In other words, controlling the implementation of the optimal design sequence is a key-missing piece in what DSM can offer. For this reason, this paper proposes the use of LPS, a Lean control methodology that forces the realisation of plans, to be integrated with DSM. The integrated application on both tools can improve the reliability of plans, enforce the optimal sequence and facilitate corrective action by the work team.

## KEYWORDS

Design, Integration, Design Structure Matrix, Last Planner System™.

## INTRODUCTION

Design is categorised as the first process of a construction project, where needs and requirements are materialised. It is viewed as a highly complex process where skilled talented designers must translate client requirements into drawings and specifications. Often, this does not happen successfully as a consequence of a fragmented relationship between design and construction. This involves recurrent problems such as poor communication to address formally what needs to be done, suboptimal solutions and constant changes. The project is affected in terms of cost, productivity, delays on schedule and quality deficiencies. For this reason, there is a need to make efforts to improve lean design management and ensure a coordinated flow of work. In this context, this research project proposes the combined use of the Design Structure Matrix (DSM) and the Last Planner System (LPS) methodologies, as a way to facilitate designers the visualisation of design tasks and the interdependencies in the process. Besides, design will be embedded in a more controlled environment that allows communicating constraints in a formal way and reinforce the effective execution of plans.

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## RESEARCH METHODOLOGY

This paper presents a model of integrating the Design Structure Matrix (DSM) and the Last Planner System (LPS) in a building design environment. Both methodologies are investigated from a theoretical and practical point of view.

In a theoretical view, the study considers a deductive approach from inventor's theories of both methodologies and authors that have gone further in their application and theory. In a practical view, little literature study is available in the application of both methodologies into building design. For this reason, the use of case studies is more suitable considering a more individual and specific focus. This holistic approach is viewed considering a retrospective case study on the application of LPS in design in a housing project. Data consisted of scheduled tasks by week, PPC analysis and causes for lack of realisation.

Finally, constructive research has been established when developing a model and framework to suit the integration between DSM and LPS. This model will be analysed and explained based on previous analysis of the LPS case study, practical and theoretical DSM and LPS literature study.

## THE DESIGN PROCESS

Design can be defined as a "sophisticated mental process capable of manipulating many kinds of information, blending them all into a coherent set of ideas and finally generating some realisation of those ideas" (Lawson, 2006, p. 14). The design process in construction does not differ from this view. It is in fact a complex and interrelated process in which massive amounts of information are processed to fulfil requirements generated from the client. It is the starting point when adding value to a customer; the customer's needs are defined and conceptualised into a physical concept (Freire & Alarcon, 2000). Not only the client is involved in defining customer value but also this initial process will affect the whole project team.  For this reason, it is important to understand the design process and the sub processes involved.

Lawson (2006) clearly identifies a design map process, divided into 4 stages (Figure 1). First, it takes into consideration the analysis process. This involves the exploration of relationships and patterns of the available information, ordering and structuring them to create a problem. Further, the Synthesis creates the response of such problems and then Appraisal evaluates the solutions towards them. It is here where solutions are compared with the objectives found in the Analysis phase in order to finally make a decision or several ones.

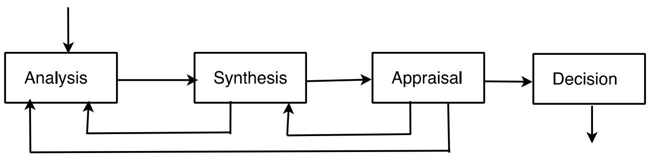


Figure 1: Map of the design process (Lawson, 2006)

As Figure 1 shows, Analysis, Synthesis and Appraisal are sub processes to make decisions. Design is not an independent process but a collaborative decision-making process in all of its components shown previously (Whelton et. al., 2001). Thus, it is important to understand the essence of design thinking is not a sequential process and therefore should not be treated like that with traditional methods such PERT, Gantt and CPM.

To solve this issue, many authors (Huovila *et. al.*, 1997; Hall, 1991; Baker & Carter, 1992; Hartley, 1992; Fabricio *et. al.*, 1999) reinforce the implementation of concurrent engineering, which is the art of integrating design and construction. To achieve this integration, it is useful to seek for group-oriented methodologies, such as the Design Structure Matrix (DSM) and the Last Planner System (LPS).

## THE DESIGN STRUCTURE MATRIX

The Design Structure Matrix (DSM) was initially developed by Steward (1981) as a way to represent the structure of a system. A precedence matrix is developed to show design dependencies where the information flow between activities is visualised.

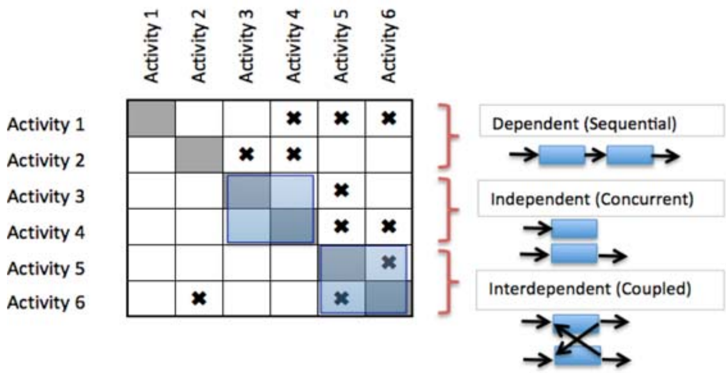


Figure 2: Activity relationships on the design structure matrix (Browning, 2002)

There can be up to four different types of activity relationships in a DSM (Figure 2). Maybe the most common of all are the dependent activities, which represent an upstream dependency on information that is provided downstream (Browning, 2002). On the other hand, independent activities have no substantial complexities because these tasks work in parallel and do not need information from each other. The difficulty comes when interdependent or coupled tasks appear in a DSM. These tasks will drive into a concurrent work and a frequent exchange of information (Browning, 2002). In Figure 2, it can be seen that in order to execute activity 5, this would require information from activity 6, which has not been yet developed. This could be the same case as the dependent relation shown earlier for Activity 1, however, in this case both of these activities (5 and 6) need information from each other. It is frequent to find in construction this problem and in such way assume much information that can affect directly the design and construction process.

Overall, DSM provides a powerful Lean Construction tool to visualise through clear representation the design processes, to communicate and organise (Browning, 2002; Huovila *et. al.*, 1997; Steward, 1981). This is valuable and helpful in concurrent engineering when trying to analyse design as Flow. In spite of this, it may not be enough and have to be complemented with a powerful control method.

## THE LAST PLANNER SYSTEM™

The Last Planner System is a Lean Construction methodology developed as a way to schedule assignments from a master plan or higher hierarchy into a Lookahead

Schedule or lower level hierarchy. This is to drive direct work to either design or production (Ballard & Howell, 1994). This system is commonly understood as getting all the work in an assignment level task that SHOULD be done to a point in which WILL be done, considering all constraints involved so that it CAN be done (Ballard, 2000). Most of the failures in planning come when this scenario is not considered and conversely the team try to follow a general schedule. Almost all the time, this will not result reliable because of the difficulty when following massive amount of detailed tasks in a long time framework and the many constraints that each task has.

## THE LAST PLANNER SYSTEM IN DESIGN

Many attempts to bring the Last Planner System into Building Design have been developed previously, however, still no evidence to conclude this methodology has been fully implemented. It is believed that when the right sequence of work is finally developed it is important to commit to this logic of work so that the right amount of work is properly balanced and understood by the project team. If there is failure in this process the causes are studied and a learning cycle develops. Root causes of incompletion in building design may refer to (Koskela et. al., 1997):

- Information. Any mistakes and failures in the information provided
- Planning. Wrong planning sequence or too many resources planned.
- Priority changes. Sudden changes of execution course.
- External. Any external reasons due to variability.

## CASE STUDY: HOUSING PROJECT

The project in study was characterised as an Engineering, Procurement, Construction and Management (EPCM) project type and involved the development of a brand new urban area. Over 430 residential houses among other non-residential buildings were going to be built in a geographically complex field of work, located in the Peruvian Andes zone (Figure 3). It was a fast-track project and the implementation started while the construction was already in progress. There was an experienced in-house facilitator on Lean Construction and LPS to aid in this implementation.

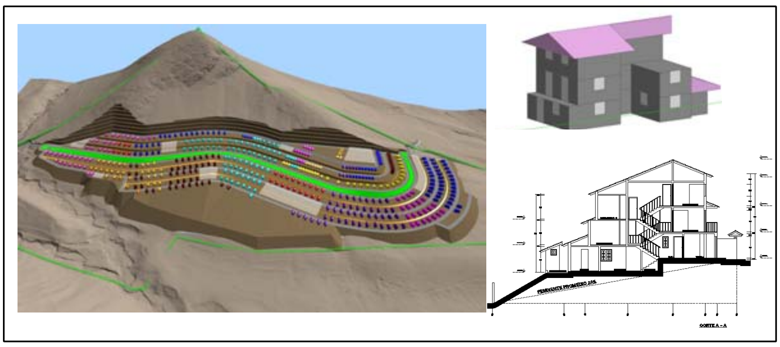

Figure 3: Housing Design project

The implementation period in this project took almost 3 months. The period of the data collected was analysed from week 13 until week 42 of the project, making a total of a 30-week analysis.

## PPC AND CAUSES FOR LACK OF REALISATION

The team scheduled an average of 200 documents in a weekly basis (Figure 4), from initial revisions to final documents approved by the client, also called 'as built'. There was a fluctuating effect in the design work balance where it can be seen low peaks of 50 documents per week while high peaks of up to 350 documents per week.

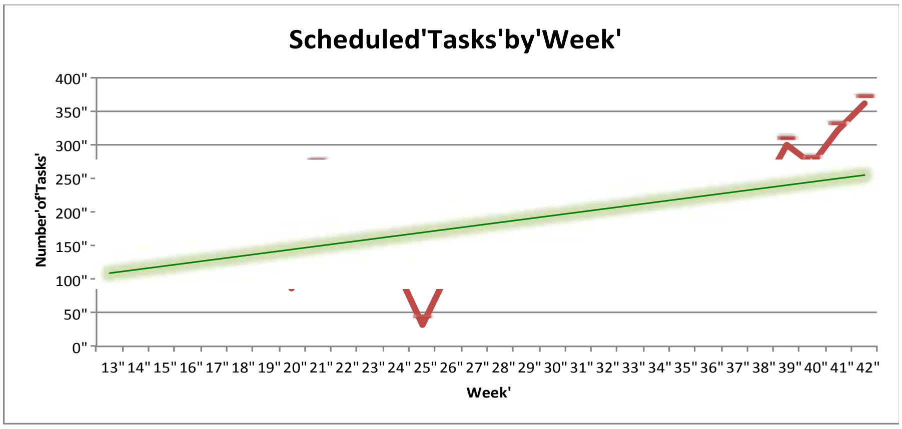


Figure 4: Documents scheduled by week in a housing project

Completion during this period went from 30% uprising to 97% in the first weeks and then went through a fluctuating period until week 20 (Figure 5). This can be related to the team's learning process when using this new methodology of control. After these initial weeks, PPC trend was downward from week 20 and slightly upward trend until week 31. From this edge, it hit a peak in week 33 with 58% completion while the trend was slightly fluctuating until the end of the period, remaining above 80%.

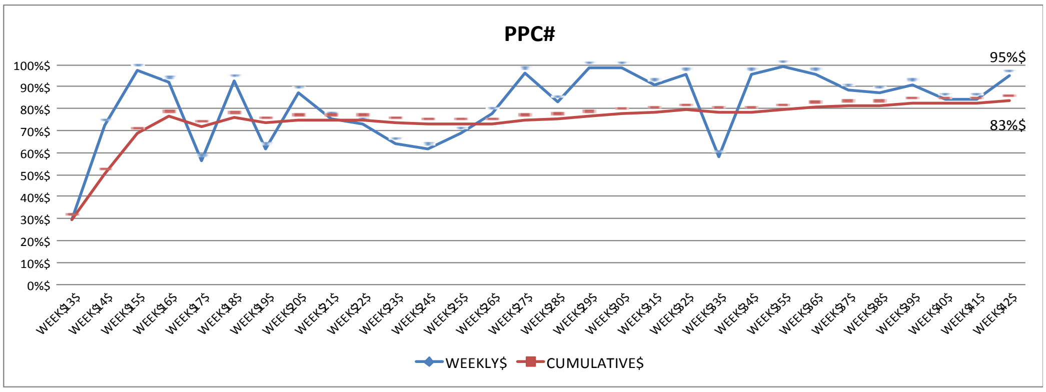


Figure 5: PPC for design work in a housing project

Completion is apparently very high and there is a gradual improvement among the period of time. On the other hand, Figure 6 shows the most common causes for lack of realisation whereas the Client has the higher influence with 36%, meaning all the faults due to the client, Design with 24%, referring to all the faults due to the design team and Planning with 18% due to planning mistakes.

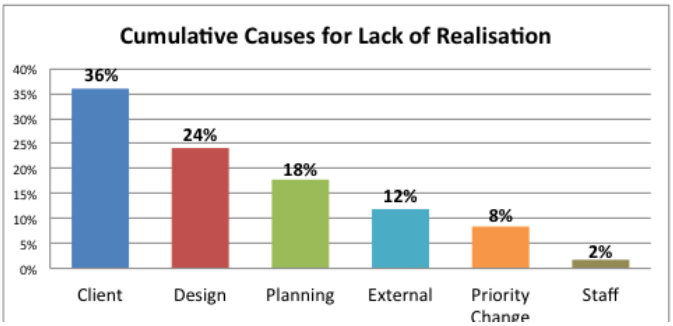


Figure 6: Causes for Lack of Realisation for design work in a housing project

Other causes were found in External with 12%, which represented basically faults due to variability, Priority Change and Staff. All of these causes were stated from the beginning of the implementation. There was a weekly meeting held where the main focus was to learn from these mistakes in order to not repeat them again.

## OBSERVATIONS

*Design* causes are probably one of the most difficult to learn from, because there is not sufficient detail to know the particular effect that caused this incompletion. This is why is difficult to know what does *Design* with 24% stands for. On the other hand, one of the most common issues in a design team is to put the client as the main cause for incompletion. This percentage could as well be biased in the sense that could cover some planning mistakes or other that could arise with a deeper analysis of the root cause.

Nevertheless, PPC shows a high result in the way that weekly planning is committed. Still, is highly fluctuating week after week which could affect sustainability in the results. In this project, LPS implementation brought:

- Improved teamwork
- Higher pressure to fulfil promised weekly tasks
- Order in the planning process

Despite these benefits, there is evidence of late deliveries from the construction site and RFI's were highlighted as bureaucratic. The design office was far from site leading to communication issues in design approvals and further decisions. This is probably why the client could perceive two different firms involved in the project in design and construction when actually was one. Overall, the problems faced in spite of the LPS implementation were:

- Fragmented planning. The design team was planning according to its own needs without a clear view of the project needs.
- Lack of integration with site. There was an issue of distance between the design office and the construction site.
- Bureaucratic Flows of Information. There is a latent root problem of uncertainty in design detailing.

It is important to note this was the company's first design implementation and these problems were already rising during this time. Therefore, a high success wasn't expected with just the implementation of the Last Planner System. Even so, this helped the company to learn through this implementation process.

### LEARNINGS

LPS was effective in bringing a more collaborative planning as well as achieving more control during this process resulting in high PPC percentages (e.g. cumulative 83% on Figure 5). This result indicates that LPS helped getting a clear view of constraints and anticipates them. Further, in all of these implementations the design team gained expertise and the Design Structure Matrix could have been implemented to solve the communication issues and show a visual state of the project's needs, with correct task sequencing. There was no virtuous iteration in design, probably the reason of a delayed input of information. Though this project seems repetitive, the massive amount of logistics work and the fast-track scenario raised the need for a better design management methodology like DSM.

## INTEGRATING DSM AND LPS

There is no fundamental methodology approaches when integrating both DSM and LPS into lean design management. It has been clear that first DSM is oriented to achieve the best possible design sequence to reduce all possible changes, RFI's and communicate client's requirements. On the other hand, LPS forces this sequence to get it through correctly in a controlled production environment with continuous improvement promoting a teamwork environment. These characteristics are shown in Figure 7.

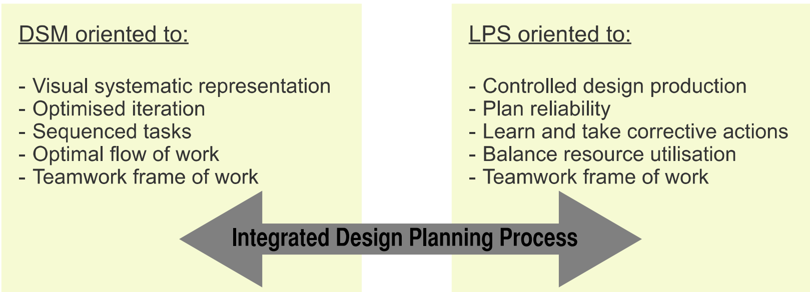


Figure 7: The characteristics between DSM and LPS

### DSM-LPS MODEL

Figure 8 shows a graphical sequence of sub processes that are involve in the integration of DSM and LPS. Most of the considerations on the first attempt integrating DSM and LPS in Hammond *et. al.* (2000) are considered in this model. The same basic structure is followed, from the initial activities setup, through DSM and the partitioning process until a planning schedule. In this way, this model has been divided into three blocks. The first one involves the project analysis where project objectives are defined and the most important outcome is the Work Breakdown Structure (WBS). A collaborative view has been added up from the Tuholski & Tommelein (2008) experience, incorporating brainstorm activities.

An effective DSM should be dependant upon this process, defining activity sequencing and dependencies. In the same way, feedback from the LPS process should avoid failures in dependency identification. LPS also needs collaboration in order to be effective. From this view, DSM is viewed as the input of the LPS process and therefore serves as feedback. The final step involving performance indicators is collected from the LPS experience in the housing project. It is important to cross-reference PPC and causes for lack of realisation with progress and RFI indicators.

## Project Analysis

The initial stage of any design process should be setting the project goals oriented in a lean construction approach in order to understand client objectives (Figure 8). This process is necessary to be understood by all team members from the beginning of the project in the pre construction stage. As seen in Figure 8, brainstorm activities (Tuholski & Tommelein, 2008) are presented as a way to identify major constraints of the project, resources and allocation of such. This sub process will enable to get a better understanding of the project, its major complexities and early solutions to overcome them. The project analysis phase ends with activity setup where the main deliverable is the WBS, a necessary input for DSM that should be developed in a collaborative way by all team members. This tool will present all design tasks in an ordered way and surface initial constraints.

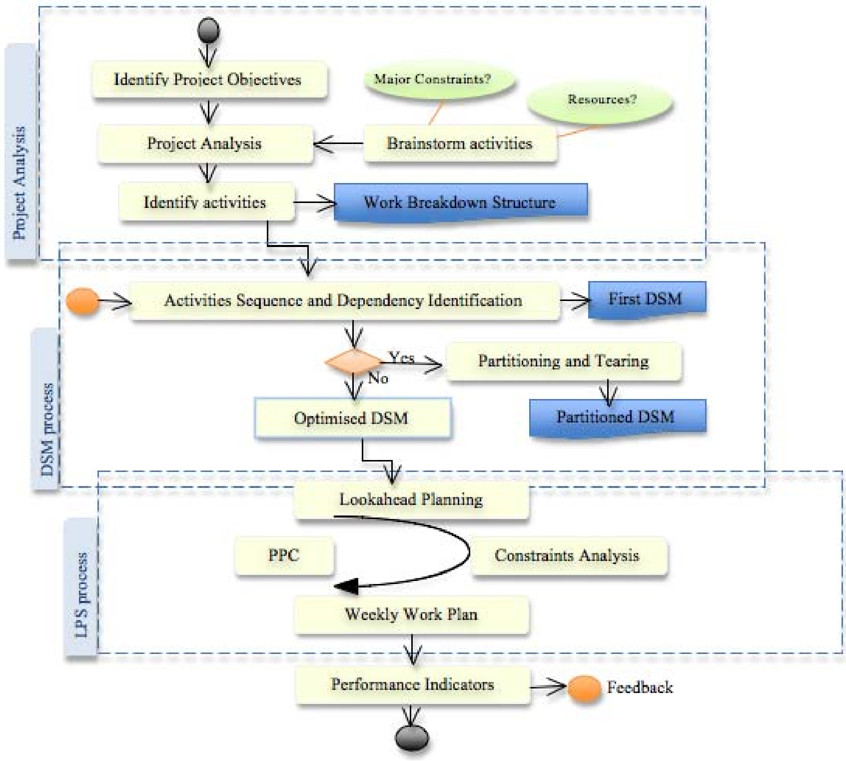


Figure 8: Integrated DSM-LPS model

## DSM Process

Having all design activities identified, the next step is to sequence them and identify all dependencies (Figure 8). This is crucial to find out all interactions between tasks, all wasteful activities and the level of assumptions necessary. The idea is to reduce the making-do effect (Koskela, 2004). In other words, all information necessary should be in place to execute according to construction priority sequence.

The next process would involve the initial DSM, developed collaboratively, where all design activities are translated in a precise and detailed in a logical construction sequence. Probably the most important sub process is partitioning and tearing, where all the design sequence is optimised and all dependencies are reduced to its minimum. Again this involved a highly complex iteration and should be aided by software.

### LPS Process

Further in Figure 8, it is seen that Lookahead is one of four steps of a continuous improvement process. The Constraints Analysis should be relatively simple once DSM has already identified information dependencies. However, it is necessary to formalise all aspects that can prevent from completing the Lookahead Schedule. The Weekly Work Plan and PPC are as discussed. It is important to stress the use of PPC as a measure of planning performance and corrective actions.

Finally, it is also necessary to cross-reference PPC with other performance indicators such as progress, cost and RFI evolution. The combined effect of DSM and LPS would have a positive effect in all aspects; hence a more controlled process.

## CONCLUSIONS

The integration of DSM and LPS is an effective methodology for lean design management because of its ability to enhance visualisation and control. These are group-oriented tools best applied to reduce uncertainty; on one hand DSM provides clear understanding of task interdependencies lowering assumptions commonly made and raising predictability. On the other hand, LPS complements the model with plan reliability and a controlled system of work. The DSM-LPS integration brings flow of work, having faster decision-making with the various alternative sequences that DSM can bring and the fact that LPS straightens work to be done, so flow is never interrupted. This is important to make information reliable, a major concern in design management. In such way, quality is also positively affected because documents regarding design projects result more accurate and therefore fewer reprocesses are needed. The investment when applying this model should be beneficial in design management. The possibility of cost reduction could be subject for future investigations in order to provide incentive on this application. Still, there are not sufficient case studies to make an estimate of savings in construction projects because this subject is still innovative for building design.

## ACKNOWLEDGMENTS

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