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Use of the Design Structure Matrix During the Construction Phase of Building Production Process in Turkey

Jıbid Bulğan and Elçin Filiz Taş
Department of Architecture, Istanbul Technical University, Istanbul 34367, Turkey

Abstract: This paper aims to investigate several process development models and finally focus on the Design Structure Matrix which is one of most up to date methods. It can be seen that the use of the DSM not only benefits the real estate development project in whole, but also enhances the construction phase of the building production by providing clear planning of the process, by defining relationships between actors and tasks, by the ability to see future risks and agility in taking action in unexpected scenarios during construction phase. In order to use the DSM in Turkey during the construction phase of building production process, some adaptations should be made. The construction phase may be considered the most structured phase in the Turkish market. Since the application of the project must have a defined schedule and budget, and all the actors are tied with contracts, there is not much space for disorder. However still compared to the original Design Structure Matrix, the Turkish construction industry lacks some of the formal agreement tasks, has unequal task distribution and should be more inclusive of marketing and sales activities.

Key words: Construction phase, design structure matrix, process models.

1. Introduction

As researchers in the real estate development field started seeing empty spots in the development process, they tried to define them by models. Real estate development models can be grouped as agency, economic, event sequence, structure and systems models. (Healey, 1991; Trevillion, 2002; Sullivan, 2009) Each real estate development model observes the previous model, decides on what is missing and does the appropriate research to create a new viewpoint. When Grasskamp created the Fundamentals of Real Estate Development, he focused on the relationships between the actors and the highest and best use analysis, but did not pay much attention to financial aspects of the real estate development (Grasskamp, 1981). So when Wheaton's Four Quadrant was created, DiPasquale & Wheaton focused on how the four main financial factors in a real estate development project are affected from each other. This model brings together the actors and the financial market together. (DiPasquale & Wheaton, 1996). Then the Miles' Eight Stages came with the idea that the tasks in the development process can be put in a standardized order. This model lists the eight main steps in a real estate development process and tells the developer to evaluate his work at the end of each step and decide if the project should be continued (Miles et al. 2015). Kohlhepp's 56-Cell Development Matrix not only focuses on the actors and the tasks but also considers the exterior factors and how they mıght affect the project and what the developer should do at the each of stage respectively (Kohlhepp, 2012) Finally, this paper looks into Bulloch and Sullivan's Design Structure Matrix which views the real estate development process as a whole system and brings together the actors and the tasks. In addition to that, it gives the developer information about their relationships and the information flow between the

Corresponding author: Elçin Filiz Taş, Dr., professor, research fields: built environment and design.

tasks. (Bulloch & Sullivan, 2010).

According to Medin, the main problems of the real estate sector in Turkey were "the state of the Turkish economy, the lack of investors, developers and qualified workforce, the inability of the construction companies to get organized properly, the lack of professionalism' education and technology in real estate organizations." (Medin, 2000) After looking into major development projects over the last 10 years, it was realized that there were no process models used in the construction industry. This created a lot of problems where projects were either not completed on time, or on budget, or lacked aimed quality. There is a gap in process models for building production process in Turkey and a model such as DSM in construction projects might improve these problems. By having a holistic view, it is aimed to see the whole process in a single chart, which provides information about what may cause problems and what aspects of the project would be affected. This paper will only focus on the construction phase of the DSM for traditional construction delivery methods.

The purpose of this study is to minimize the problems encountered in the construction phase, which is the most problematic area of the building production cycle and directly affects the duration, cost and quality of the building, the information flow between the people / groups involved, transmission of tasks to the relevant actors and their timeliness is very important. In this paper, a visual tool will be developed with the help of DSM in order to help the production and transfer of information between those involved in the construction phase.

2. Design Structure Matrix

The Design Structure Matrix aims to provide a process management model and lower the risk by defining the whole process even before the project starts. In order to use the DSM properly, one should have very clearly defined tasks and actors, as well as having standardization in all analysis, permits, and data.

2.1 Stages of Development in the Design Structure Matrix

Bulloch & Sullivan has divided the development process into six stages which are: Idea Inception, Feasibility, Preconstruction, Construction, Stabilization, Asset Management and/or Sale (Bulloch & Sullivan, 2010) At the end of each Stage, information is collected, synthesized, and reviewed to determine whether the project should: Move forward and expend further resources, Stop and lose the investment made to date, Go back to an earlier phase and reexamine assumptions and decisions in an effort to create a more viable path. (Bulloch & Sullivan, 2009), or Pause and wait for certain input factors to change. These Decision Gates are crucial steps in the building production process and can assume a variety of forms. (Bulloch & Sullivan, 2010)

2.2 Disciplines in the Design Structure Matrix

In order to categorize the numerous tasks in the real estate development model the creators of the DSM have grouped them into five disciplines: Market & Competitive (yellow), Legal & Political(red), Financial (green), Physical & Design(blue), and Project Management (grey) (Bulloch & Sullivan, 2009). Since this paper will only focus on the construction phase, instead of the above-mentioned five, only two disciplines will be used: disciplines that are directly connected to construction (blue) which is a combination of Physical & Design (blue), and Project Management (grey);and disciplines that are not crucial to construction but still relevant to the overall process (orange) which is a combination of Market & Competitive (yellow), Legal & Political(red), and Financial (green) disciplines.

2.3 Informational Relationships between Tasks

The tasks in the DSM come in three different relations. Those are;

- Dependent tasks (series); task B needs the information from task A, and thus task B has to follow task A.

- Independent tasks (parallel); task A and task B can be done separately.
- Interdependent tasks (coupled); repetitive because they need feedback from each other.

"Modeling and managing coupled tasks, which describes much of building production process, is much more challenging because this arrangement implies iteration and feedback loops" (Bulloch & Sullivan, 2009). DSM in general is a model trying to categorize and coordinate all the tasks. It shows which tasks are independent, dependent or interdependent and thus, which information should be received from what step and which action should be taken next.

DSM lists all tasks in both vertical and horizontal axes of a matrix and shows how each and every task is related to each other once completed. As can be seen in figure 2, where two same tasks intersect a black line is drawn. As we read down a column, we see the outcomes of the task that would be needed for the upcoming tasks. Therefore, it is what the task provides. As we read across the rows, we see the requirements needed to complete the task and which other tasks those requirements come from. Therefore, it is what the task depends on. "In the figure below, Task 5 is dependent on information received from Task 3 for completion. Task 1 sends information to Tasks 3 and 6." (Bulloch & Sullivan, 7/2010, pg.80) Additionally because all the tasks are placed sequentially on the matrix some of the interdependent tasks are marked by crosses above the black line. This means the marks above the diagonal line are the tasks which require us to go back and rework. For example, Task 2 depends on the information from task 5. Son once task 5 is completed the developer should go back and reconsider / redo task 2.

2.4 Applying DSM to Construction phase of Building Production Process

The DSM helps to visualize the whole project in one great chart. It helps the construction phase to see and predict many problems that might occur in the project process and have precautions beforehand. It is also used to sequence tasks in the most efficient way and have a work schedule before the project starts. But apart from

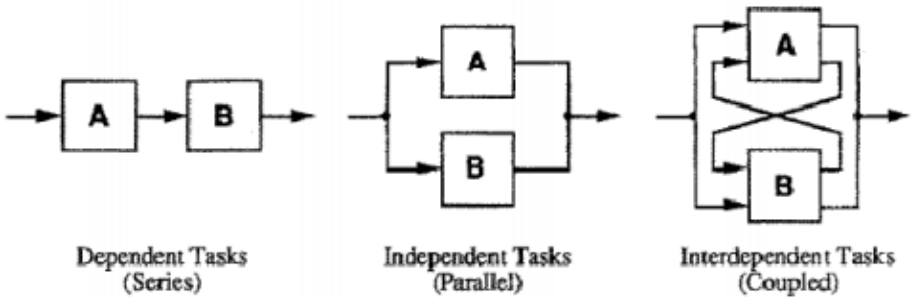

Fig. 1 Types of relationships between two tasks (Bulloch & Sullivan, 2009).

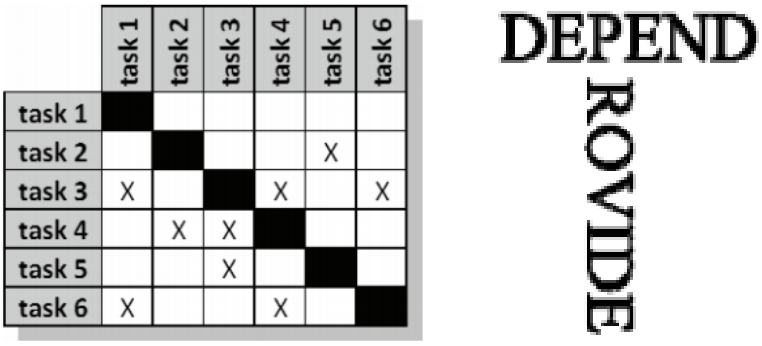

Fig. 2 Guide to Reading the Design Structure Matrix (Bulloch & Sullivan, 2009).

all the DSM is most beneficial in "highlight relationships between tasks and identify where rework risk might occur". It is hoped that in an ideal project all tasks would be sub-sequential and no rework would be needed. That means that all the X's would be below the black line. However, rework can be beneficial to the project in ways that revising each step with each other makes construction phase crosscheck his estimations / predictions and therefore reduces risk. "The desirable level of rework and iteration is unique for each project, because the information being generated and the associated risks are project specific". (Bulloch & Sullivan, 7/2010, pg. 82)

2.5 Methodology

Using the structure of DSM which is originally developed for real estate; this paper only focuses on the construction phase. In order to do so, categories and list of tasks were fixed according to their actors and their order. Then each task was gone over according to the information it needs and the information it provides. Twenty-five professionals and academicians from the industry with at least 5 years of experience have been consulted at various steps of the adaptation. They were shown the draft of the model in person and asked to make comments on its accuracy according to their experiences. The model was simultaneously revised.

3. Application of DSM in Turkey to Construction Phase of Building Projects

According to Bulloch & Sullivan, the contractor and the subcontractors are provided building design prepared at the preconstruction stage. Most of the responsibility is on the contractor at this stage because he is bound by the contracts to deliver a quality project in time and in budget. Throughout the construction phase, the constructor should keep updating his budget and financial assumptions. If the construction takes too long the market situation might be very different from the time project started, affecting the costs of materials (Bulloch & Sullivan, 2009, pg. 57). A process model as the DSM allows making educated predictions.

3.1 Changes in the Categories and Order of Tasks

The construction stage may be considered the most structed stage in the Turkish market. Since the application of the project must have a defined schedule and budget, and all the actors are tied with contracts, there is not much space for disorder. However still compared to the original DSM, the Turkish real estate development lacks some of the formal agreement tasks. List of tasks that can be found in Table 1 was decided upon by combining the original Design Structure Matrix of Bulloch and Sullivan (2009) with the research made in the graduate thesis by Bulgan (2017) and later developed during doctoral studies at Istanbul Technical University.

As can be seen in table 1, some of the changes made are as such: First tasks are divided into two disciplines: disciplines that are directly connected to construction (blue) and disciplines that are not crucial to construction but still relevant to the overall process (orange). Tasks as "secure construction loan" or "update development budget" are not actual construction tasks but they indirectly affect the construction. If the loan is not secured or there is a major change in the budget, then construction cannot continue. By also monitoring indirectly related tasks, the contractor can be prepared for uncertain conditions that might affect the project.

With the commentary received from various professionals on the adaptation of the DSM some tasks have been added and some have been removed. Design Development was a preconstruction task in the original DSM but in today's world, design process extends into the construction stage to shorten overall project time. For example, interior drawings of a building can be made as the excavation for the land begins. Tasks such as "Execute GMP agreement", "Procure Major Trade Buyouts", "Obtain Building Permit" have been moved to the preconstruction stage because the construction cannot start before these steps are completed. Since DSM is a real estate model, it doesn't go into detail in

Table 1 Tasks of stage 4 – Construction.

	Construction tasks	Action Taken
1	Design Development	Continued from PreConstruction
2	Execute "Good Manufacturing Practice" (Quality) Agreement	Moved Construction →PreConstruction
3	Secure Construction Loan	Moved Construction →PreConstruction
4	Obtain Building Permit	Moved up in order
5	Acquire Property	
6	Procure Major Trade Buyouts	Moved Construction →PreConstruction
7	Excavation Works	added
8	Build Project Infrastructure	
9	Build Core and Shell	
10	Rough Construction	added
11	Build MEP systems	added
12	Build Interiors	added
13	Fine Works	added
14	Build Client Requirements	
15	Monitor Schedule	Moved up in order
16	Construction Inspection	
17	Building Turnover	
18	Settlement of Claims	added
19	Update Development Budget	
20	Update Market Conditions	

the construction stage. So, tasks such as “Excavation Works”, “Build MEP systems”, “Build Interiors”, “Settlement of Claims” are added in order to make this stage more detailed. The more detail put into the model, the more certain it gets.

3.2 Changes in the Relationship of Tasks

After reordering the tasks in the previous section, they are now listed horizontally and vertically to see their relationships with each other. As the table is read from left to right we see what the tasks depend on. As the table is read top to bottom we see what information the tasks provide. For example, as can be seen in table 3, Rough construction depends on information from previous tasks such as Acquire Property, Excavation Works , Build Project Infrastructure, Build Core and Shell and Design Development, which makes sense because the rough construction cannot start before these tasks are complete. They are serial / dependent tasks. Rough construction task also depends on information coming from development budget and market conditions. Although not directly connected the overall financıal situation of the market and the project would affect the construction. When read from top to bottom rough construction provides information for the following steps such as Build MEP systems, Build Interiors, Fine Works, Build Client Requirements, Monitor Schedule, Construction Inspection.

From reading this chart the contractor or the project manager can get to these conclusions:

- If most of the relationships are below the diagonal black line, this means that the risk is lower in the project because the tasks are mostly serially connected. There is no need for rechecking or rework. (Bulloch & Sullivan, 2009) Compared to previous stages the construction stage is mostly straight forward.
- When tasks from two different categories come together, these relationships are more critical than a similar category relationship (Bulloch & Sullivan, 2009). Information flow between two blue tasks would be easier because the professionals speak the same language whereas a relationship between a blue and an orange task might be harder to communicate since the professionals come from different backgrounds.

Table 3 Construction Stage - Relationships between Tasks Matrix.

	Design Development	Secure Constrctn	Obtain Building	Acquire Property	Excavation Works	Build Projct Infrastruct.	Build Core and Shell	Rough Construction	Build MEP systems	Build Interiors	Fine Works	Build Client Req.	Monitor Schedule	Construction Inspection	Building Turnover	Settlement of Claims	Update Develpmt Bgt	Update Market Cond.
Design Development											x	x						
Secure Construction Loan			x															
Obtain Building Permit		x																
Acquire Property		x	x															
Excavation Works		x	x	x													x	x
Build Project Infrastructure	x	x	x	x	x												x	x
Build Core and Shell	x		x	x	x	x											x	x
Rough Construction	x			x	x	x	x										x	x
Build MEP systems	x				x	x	x	x									x	x
Build Interiors	x					x	x	x	x		x	x					x	x
Fine Works	x					x	x	x	x	x		x					x	x
Build Client Requirements	x					x	x	x	x	x	x						x	x
Monitor Schedule	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		
Construction Inspection					x	x	x	x	x	x	x	x	x		x	x		
Building Turnover														x		x	x	x
Settlement of Claims					x	x	x	x	x	x	x	x	x	x	x		x	x
Update Development Budget		x	x										x		x	x		x
Update Market Conditions		x	x										x		x	x	x	

• This chart helps the contractor to see exactly which tasks would be affected if a problem occurs at a certain part of the project. For example, if there is a problem at the fine works task, then it is visible that there will be problems with the information flow to Build Client Requirements, Monitor Schedule, Construction Inspection, Settlement of Claims tasks. Also interestingly, tasks such as Design Development and Build Interiors which happened before the problematic task have to be revised.

• It is important not just to think about building activities during the construction stage of building production but also constantly be aware of the surrounding factors. The DSM allows the contractor /project manager to integrate these factors into construction planning. As an example in this stage, tasks such as secure construction loan, obtain building permit, development budget, market conditions etc. are integrated into the overall chart allowing us to see their effects on the physical construction.

4. Evaluation of the Adaptation of the Design Structure Matrix

1. Unclear task distribution: In Turkey, actors and tasks are not always defined clearly which creates ambiguities in task division. Sometimes, too much work is loaded on the incorrect professionals which increases the amount of risk in construction projects. In order to fix this issue, the construction industry should have very clear job and task definitions. When tasks are done by experts in their fields, the risk is decreased since the decision is made by combining the knowledge of many.

2. Different timing of tasks: Some tasks are done at different times in Turkey compared to the original order of the Design Structure Matrix. This difference sometimes cause the construction to be more risky or for processes to take longer. One of the other issues

encountered about the timing of the tasks is that since the Turkish construction industry is less structured and lead by mostly practical knowledge, the order of the tasks are more likely to change during the construction of the project. When this happens the X's on the chart would change and might change into a less stable, more risky scenario.

3. Longer span of tasks: In today's construction industry simultaneous tasks are a must considering that the less time spent on construction means faster return of capital. In order to do so task are not achieved back to back but some continue at the same time. For example the design of a project no longer starts and ends during the preconstruction stage but also extends over the construction stage. In some cases it even continues after the opening of the property.

4. Interdisciplinary tasks: In today's construction industry some tasks are no longer the responsibility of a single professional category. Most tasks require two or more professionals from different fields to come together and work together on a single task. For example, obtaining building permit task is handled by the client or the contractor depending on their agreement. There is no clear definition of who should do it.

In conclusion, it was realized that the Turkish industry is still a bit unorganized compared to the original Design Structure Matrix and most tasks require more re-working or re-checking. However, the adaptation of Design Structure Matrix to the Turkish real estate development industry promises a lot of benefits such as better structural organization, better time management, and more stable budgets. It also solves major problems of the Turkish real estate industry since using the proper development models would encourage standardization and research, thus changing the Turkish real estate development in a more beneficial, efficient and stable state.

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