MANAGING COMPLEXITY IN LEAN CONSTRUCTION DESIGN – USING THE MDM METHODOLOGY TO CREATE ORGANIZATIONAL MODULARITY

Michael Krinner[1,2], Fatos Elezi[1], Iris D. Tommelein[2] and Udo Lindemann[1]

[1]Institute of Product Development, Technische Universität München, Germany
[2]Department of Civil and Environmental Engineering, University of California, Berkeley, USA

ABSTRACT

This research reports on the application in the Architecture-Engineering-Construction (AEC) industry of the Multiple-Domain Matrix (MDM) methodology, originally established for product development processes.

AEC project delivery features significant organizational complexity. Our use of the MDM methodology aims at characterizing and managing such complexity while following the Lean Construction philosophy. Lean Construction refers to using lean thinking principles that stem from the Toyota Production System (TPS) and new ones that address challenges particularly prominent in the AEC industry.

We conducted a case study in the Design Phase of a healthcare facility's delivery to examine applicability of the methodology. We linked those involved in the project to the processes they followed to prepare a design for review by the building permitting agency. Our MDM analysis of the organizational interactions resulted in identifying highly correlated groups of individuals from different companies. This result encourages further use of MDMs to manage AEC Design.

Keywords: AEC industry, project delivery, complexity, modularity, lean construction, design, Multiple-Domain Matrix, Design Structure Matrix, project organization

1 INTRODUCTION

Lean principles in construction industry aim at improving performance with regards to safety, cost, and time, but also aims at delivering customer value. The overall goal of lean construction is to design production systems so as to avoid wasting materials, time, and effort and to generate the maximum possible amount of value (Ballard et al., 2002; Koskela et al., 2002). Lean Construction is a relatively new approach to designing and building capital facilities. This approach is particularly useful on complex, uncertain, and quick projects. Lean strives for perfection, an ideal, future state, valuable only as the ultimate goal for improving processes, which takes time (Howell, 1999). It is important to accentuate that the main resource in the processes that make up construction projects – and successful business endeavors in general – are the people doing the work, and how they perform as individuals relative to the overall organization. A management goal therefore is to organize individuals and companies so that they can effectively manage certain work packages, and vice versa, to define such work packages so that they can be executed in a way that takes advantage of the capabilities of the selected individuals and companies.

People generally think of construction projects as being complex (Klir, 1985). Influencing factors are (1) the fragmented nature of the construction industry and the number of participants involved in a construction project; (2) increasing engineering and contractor sophistication, and therefore specialization resulting in increasing interaction of contributors needed in projects and inter-relatedness of project components and system, (3) demand for increased speed of delivery of projects, and therefore the need for more processes to run in parallel (aka. concurrency). The risk exists, therefore, for these processes to interact much more than is the case in more simple, slow, and sequential projects; this makes the effort to manage these processes much larger (Howell and Koskela, 2000).

In this paper, project management for the delivery of capital projects is viewed through the lens of structural complexity. Organizational issues involve how people communicate with each other and how they work individually or in teams, in the process of delivering the project. One way to address organizational issues is to implement modularity in projects. Modularity assumes that one can divide a larger system into subunits which creates inner structures that are more-or-less independent from each other but linked together to function as a whole system. Identifying the optimal grouping of subunits (so-called modules) can provide advantages compared to the competitors not only when the use of such modules benefits a single project, but more importantly, when they can be applied on other projects as well. The initial step of identifying reasonable units of whole project organization is crucial for this method to be effective. Useful in this case means that the formed units are capable of accomplishing a significant part of the project work themselves but still can be combined to a whole functional system of units (Clark and Fujimoto, 1991; Elezi, 2010). To sum up, modularity provides a design structure for an organization with parameters and tasks that act interdependently from one another within the created modules and are, to the greatest extent possible, independent across the borders of the units with other tasks. To apply and create modularization, it is necessary to analyze the given structures (Baldwin and Clark, 2000).

2 APPROACH

Different methodologies, including the DSM and the MDM methodology can reduce negative iteration, which is seen as a significant source of waste in design, and can help to reduce the occurrence of iterative activities. The MDM methodology is also an invaluable tool for the illustration of complex structures (Maurer, 2007). A reason for the reduction is the deriving of modules of functional teams of highly interacting partners to manage the design in an intelligent way. The design phase of construction projects can be handled through better control of existing handoffs (Ballard, 2000). The methodology can also help to generate additional value with creating positive iteration within the functional teams. An instinctive feeling is necessary to manage an existing tradeoff of both and to find a good balance with eliminating task dependencies. The aim is to eliminate (or minimize) only unnecessary complexity without removing value adding complexity (Braha and Bar-Yam, 2004).

As an **Intra-Domain Analysis** the Design Structure Matrix (DSM) approaches are used to analyze the structure of a system. Within this domain mainly two algorithms are deployed to obtain the desiderated results: Partitioning and Clustering algorithm. With the **Inter-Domain Analysis**, different domains are combined that are intertwined with each other in the structural organization. The main algorithm used for the inter-domain analysis is the Clustering algorithm. **Matrix Deduction** from existing matrices is used to retain a new matrix which in the best case fits better in the matrix system than the persisting ones. Like with the existing matrices it is possible to enforce all algorithms. So the inter- and intra-domain analyzing tools can be applied and possible optimization can be deduced to manage and reduce the complexity in the system. Organizational, structural and informational improvements can be made. Figure 1 shows the basic pattern that is used in this case and Figure 2 shows the schematic procedure of the whole MDM methodology in detail. The transformation of the matrices results in the modularized organizational DSM with the clusters and efficient modules for the structural organization. The outcome is a proposition for organizational expertise cluster groups.

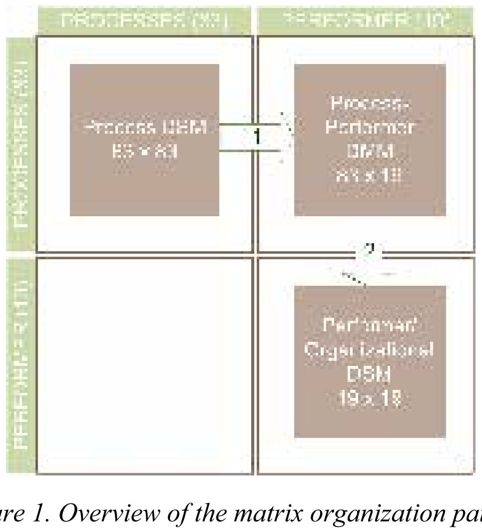

Figure 1. Overview of the matrix organization pattern

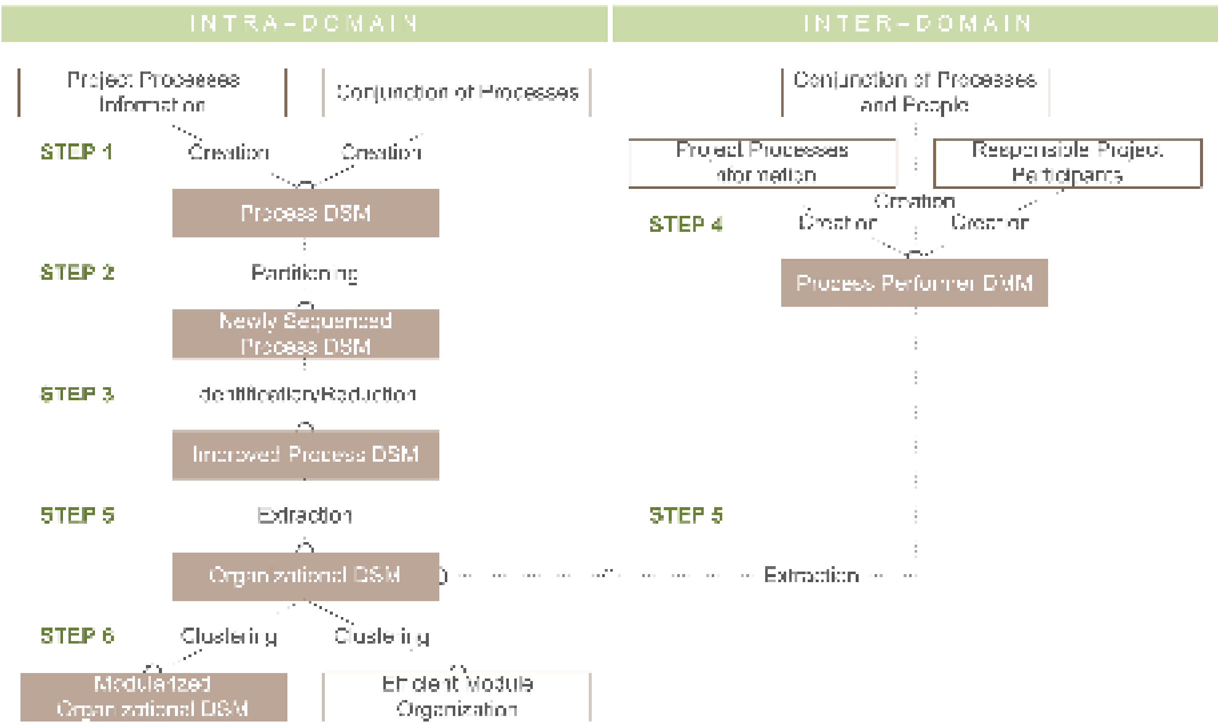

Figure 2. Schematic procedure of the Multiple-Domain Matrix methodology

3 APPLICATION OF THE METHODOLOGY

The outlined methodology is applied to the Design Phase of the delivery of a healthcare facility and in particular for the preparation of design submittals to the building permitting agency. This submittal is required for the Design Phase of a hospital project. The size of the project is defined with a $250 million budget for 80 licensed hospital beds on 5 stories and approximately 140,000 square feet. For the current project, the first domain is the process domain in the design phase of the construction project. These tasks are derived from requests made by different companies to other companies for processes to be performed. Mostly every request stands for a task, process, or effort that has to be done. The second domain is the companies or participating groups itself.

3.1 Methodology Utilization

Step 1: The creation of the process DSM is the basis for the analysis. Requests from partners in the design phase of the facility constitute the basic information of the process DSM. The requests are projected to the processes to fulfill the request. The abstraction of the processes results in a total of 83 different process types for the creation of the necessary design phase documentation.

Step 2: The following step states the result of a newly sequenced process DSM, emerged from partitioning the initial process DSM. The partitioning algorithm yields a partitioned matrix with only 4 tasks that are located in the lower half below the diagonal line in the matrix, which represent feedback loops in the Design Phase. All other feedback loops have been eliminated. The implication of this fact is that the coupled tasks are joined together close to the diagonal line so that this process can be performed quicker because of a faster iteration of information. However, the partitioned process DSM shows interdependencies from the process and does not take limitations that exist in reality into consideration (e.g., interdependencies that are time related, where one step must come before the other). The reason is that partitioning is a context-free algorithm. In the project some tasks have to be performed prior to others in the design phase. The sequence in the partitioned process DSM is a proposal for an efficient chronological order, but has to be aligned with the possibilities of the sequence of the waterfall process.

Step 3: The purpose of this step is the identification and reduction of unplanned iteration in the partitioned process DSM, in order to implement improvements and receive a newly sequenced process DSM with less iteration. The partitioned process DSM features remaining pairs of coupled tasks. It is planned that these iterations are consciously set together and have to be run coupled. The partitioned process DSM shows an almost perfectly triangular DSM. In reality, several constraints exist. A possible process DSM, which is based on the current sequence of tasks in the project, and is superimposed upon the optimal process DSM can be drawn. The result shows a large number of dependencies in the lower half of the matrix and deviates from the optimal DSM.. This shows a large potential to implement improvements in the planning process.

Step 4: To create the process-performer DMM, information on the project processes is necessary that have been determined in the preceding step 1. According to the projection of requests to processes, these processes and their responsible companies or cluster groups have to be derived and listed and subsequently connected with each other, which results in the process-performer DMM.

Step 5: The next step is the deduction of an organizational DSM showing the interdependencies between partners according to the performed processes. The process-performer DMM contains the list of companies and cluster groups and the process DSM the processes necessary in the design phase. The provided information in the deduced DSM is the interaction of the cluster groups and companies in the design phase with the performed processes in the construction project.

Step 6: The final step of the described methodology application in the case study is the clustering of the deduced organizational DSM in order to obtain a modularized organizational DSM which can be further analyzed. This DSM illustrates the interaction of the different companies and cluster groups. This DSM is the basis for further discussion about the structural organization and cooperation of the different teams.

3.2 Evaluation

Figure 3 shows the final clustered organizational DSM as a result of the approach. This is the basis for some predicates that can be made. The DSM shows that there is a main cluster group of companies. This is obviously the group which performs the main tasks in the design phase, and is illustrated with the red square frame. The interaction between these companies is very high because of the high amount of interdependencies. This group will be called the *design team*.

Figure 3. Clustered and evaluated organizational Design Structure Matrix

Apart from this main group of companies, two side groups can be identified. These groups are marked with the yellow and blue bars in the figure. These companies are linked to the main cluster group in a unidirectional way. The yellow marked group at the bottom of the matrix with two companies represents a *transmitting* and the blue marked group above with 7 companies a *receiving group*. This means that the partners only have to provide information or receive information from other companies. Therefore the interaction is limited and both parties are separated from the management process of the design team.

The architect – marked with a red bar – plays an important role as a point of intersection and ensures the communication flow in the project. Figure 4 summarizes the companies and their roles. The underlying approach and principle in lean construction is to involve participating companies and partners early in the design phase in order to reduce the cycle time of the project. This set based design called attempt for construction projects originates from the set based concurrent engineering approach.

So, the information for the design is gathered from all cluster groups in the venture. The project is developed faster in parallel (Tommelein et al., 2009).

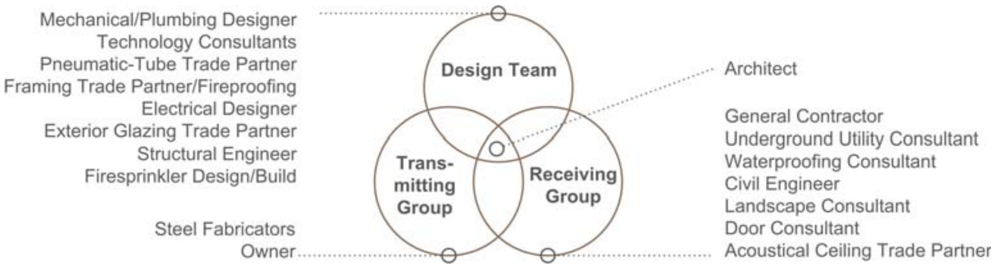

Figure 4. Identified Groups

The challenging issue is the point of time during the process in which to involve what amount of details in the design phase. A too early involvement of too many cluster groups might cause extensive complexity for the project management. The results from this project can be a guiding principle for hospital construction projects in general. In order to guarantee the early involvement but also to keep the accompanied organization complexity low, the following structure is proposed. Besides the design team marked in Figure 3, a second design supporting team can be identified. This second team consists of companies from the transmitting and receiving group with a higher amount of interdependency amongst each others, but no interaction with the main design team except through the architect. Figure 5 shows the defined groups. The design team and the design support team play the important role in the process. In order to ensure information flow between the two groups, the architect has the function as an intersection point between the groups. The remaining transmitting and receiving groups play a minor role in the design process but are involved regarding the time their information and input is needed to apply the advantages of a set based design approach although these groups could be separated from the main process.

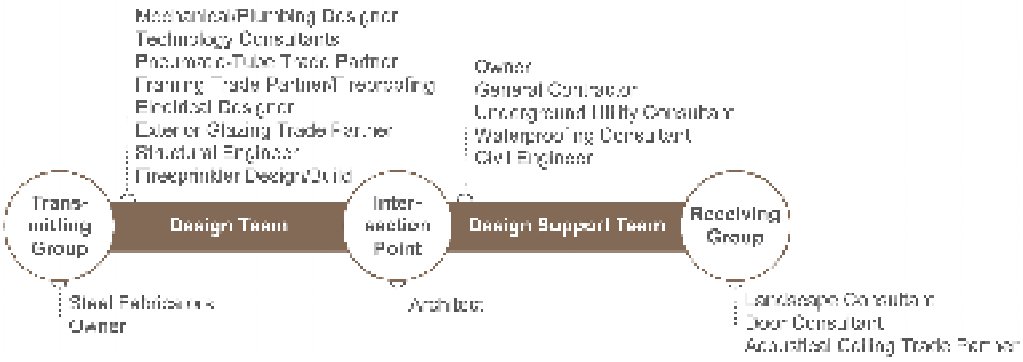

Figure 5. Structural Proposition

4 CONCLUSIONS

Matrix-based methodologies, including the MDM methodology, can reduce negative iteration, which is seen as a significant source of waste and complexity in design. The design phase of the organization is managed in an intelligent way and can be handled through better control of handoffs. Also, value can be added with the creation of positive iteration within the functional teams. The examined hospital project provides a high degree of structural complexity. In addition to the high degree of complexity of AEC industry, health care facilities have a large amount of additional material flows. Regulations and special requirements are set up by several authorities to secure a proper standard of the quality of the facility. The goal is to identify suitable structural designs for the management of the venture. The structural design that is being considered is the implementation of a modularized project organization. A modularization of design groups for hospital projects is the goal to be derived from the analysis. An organization form with the architect as a coordination point has been developed with a design group and a design support group to be managed in the project. The involvement of the remaining partners is executed according to their point of time in the design phase. The results show that a core design group necessarily performs the main process. The repetitive characteristics in health care facility design phases cause a high degree of suitability for the proposition. The results of the examined case study support the use of a modularized structure. The results may serve as a guiding principle for hospital construction projects in general. This ensures the approach of a set-based design phase to include all participants as early as possible, but keeps the complexity to manage all participants low.

ACKNOWLEDGMENTS

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Contact: Michael Krinner
Institute of Product Development
Technische Universität München
Boltzmannstasse 15
85748 Garching
Germany
Tel.: +49 171 7789493
e-mail: michael.krinner.tum@arcor.de

Department of Civil and Environmental Engineering
University of California Berkeley
760 Davis Hall
Berkeley, CA, 94702-1710
USA

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Michael Krinner[1,2], Fatos Elezi[1], Iris D. Tommelein[2] and Udo Lindemann[1]

[1]Institute of Product Development, Technische Universität München, Germany
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INVEST ON VISUALIZATION

Lean Construction

Lean principles in construction industry

Improve performance, with regards to safety, cost, time, and delivering customer value

Avoid wasting materials, time, and effort in order to reach a maximum amount of value

Professor Iris D. Tommelein, University of California, Berkeley:
"*Lean construction embraces new principles and methods for product development and production management specifically tailored to the AEC industry. It advocates the simultaneous consideration of product and process development, using concurrent engineering tools among others.*"

Gregory A. Howell, Lean Construction Institute:
"Lean construction much like current practice has the goal of better meeting customer needs while using less of everything. The result is a new project delivery system that can be applied to any kind of construction but is particularly suited for complex, uncertain, and quick projects."

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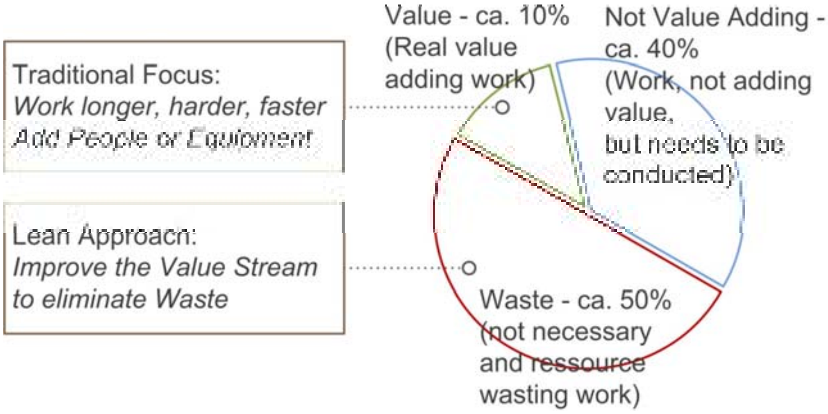
Lean Construction

Set based design approach

Design processes are performed concurrently to defer the point of specification to a later time, with better understanding of the object

Focus on value and waste

Identification of value and waste in the design phase with a subsequent reduction of waste



Complexity in Health Care Construction Projects

Complexity due to industry characteristics

- Increasing interaction in construction projects
- Increased speed of construction
- Parallel processes
- Focus more on customer's needs

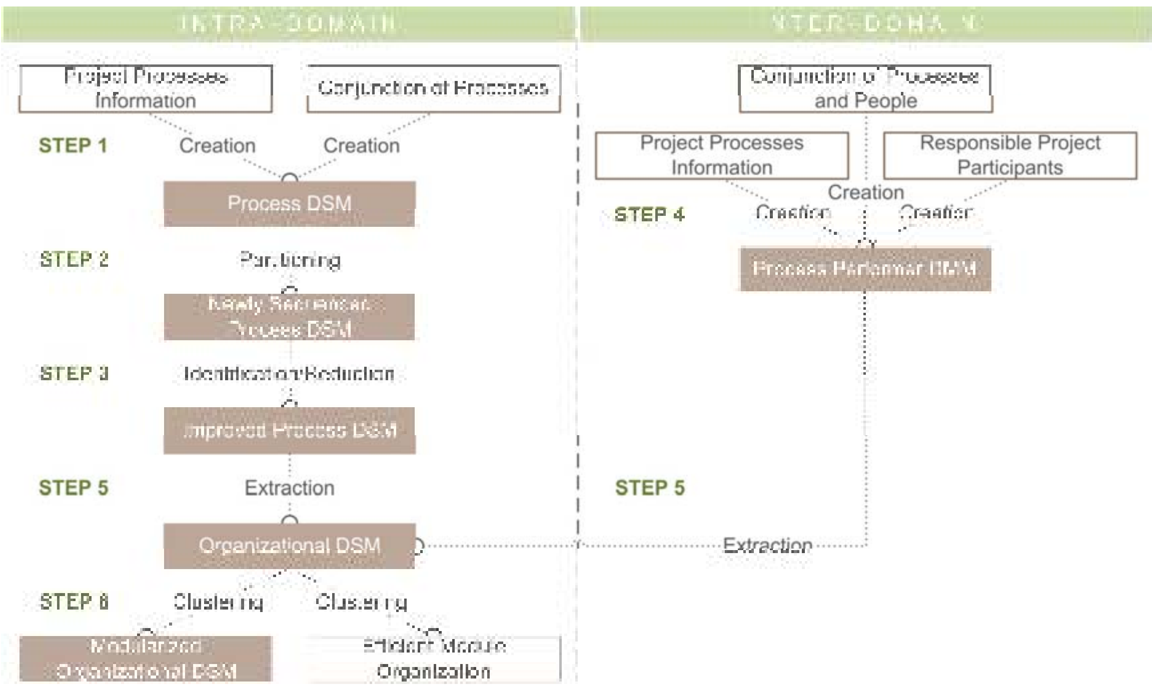
Complexity due to technical development

- New technologies are used
- Increasing specialization of partners

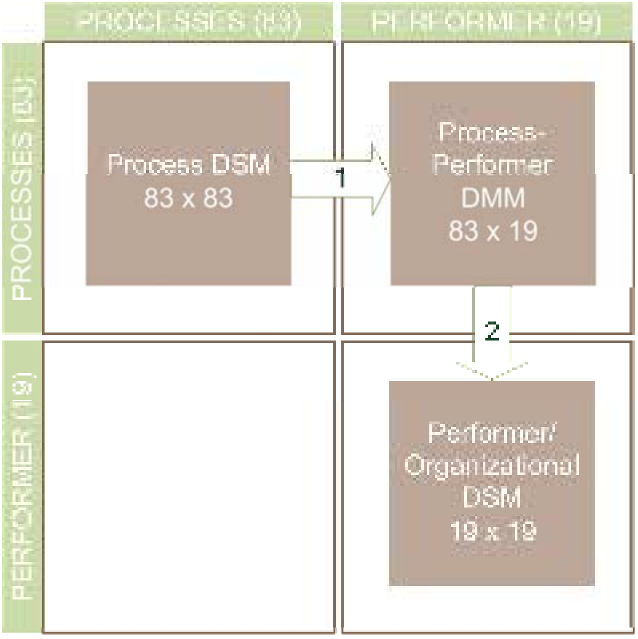
Additional complexity in health care facilities

- Additional supply systems
- Compatibility with different medical equipment required
- Additional regulations and laws

Methodology Approach



Methodology Approach



Processes derived from project work plan

Performers of the processes derived from project work plan

Creation of performer groups with their interaction and a proposition for an organization form of the design phase

Case Study: Hospital Project Design Phase

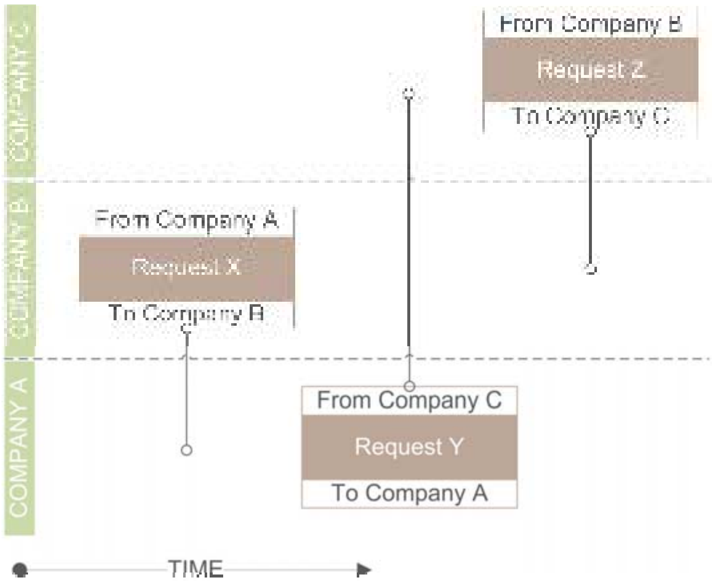
Functions/Performers

- Owner
- General Contractor
- Architect of Record
- Steel Fabricator
- Underground Utility Consultant
- Waterproofing Consultant
- Civil Engineer
- Landscape Consultant
- Door Consultant
- Acoustical Ceiling Trade Partner
- Mechanical/Plumbing Designer
- Technology Consultants
- Pneumatic Tube Trade Partner
- Framing Trade Partner/Fireproofing
- Electrical Designer
- Exterior Glazing Trade Partner
- Structural Engineer
- Elevator Trade Partner
- Firesprinkler Design/Build

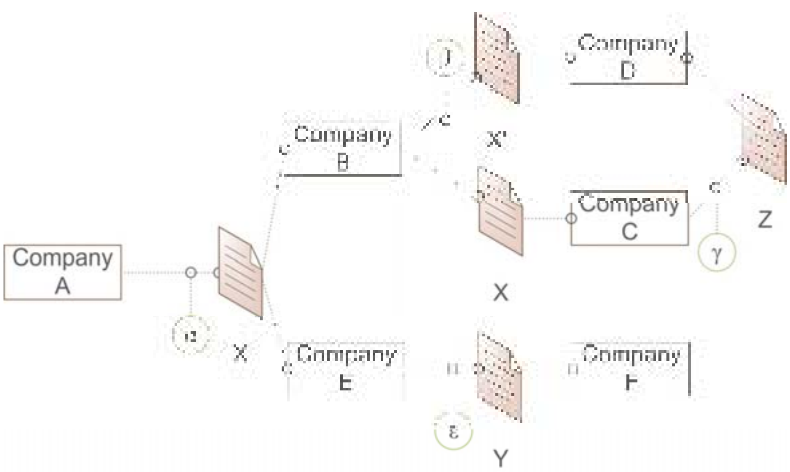
- $ 250 Million budget
- 80 licensed beds
- 140,000 gross square feet
- 4 stories

Step 1: Process DSM Creation

- Performers list their requests
- Performers name addressees
- Requests are linked to each other if interfaces exist
- Requests are sorted on a timeline regarding constraints and requirements



Step 1: Process DSM Creation



- Requests are translated to processes to be performed
- Resulting processes are listed
- Process DSM is being created
- 83 processes were identified for the design phase

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Step 2 & 3: Process DSM Partitioning & Identification/Reduction of Feedback Loops

Step 2:

• Process DSM is partitioned and newly sequenced

• 4 tasks remain in the lower half of the matrix, but are located close to the diagonal line

• Existing problem: Interdependencies, that are time related are not considered, although in the design phase, some processes have to be performed prior to others

• Partitioned process DSM is a proposition for an ideal (not considering constraints) and efficient chronological order

Step 3:

• The goal is to identify/reduce unplanned iteration

• Marks in the lower half of the matrix are feedback loops

• Due to time constraints and a required sequence of tasks, a removal of all feedback loops is not possible

• The result is the realistic process DSM for the process

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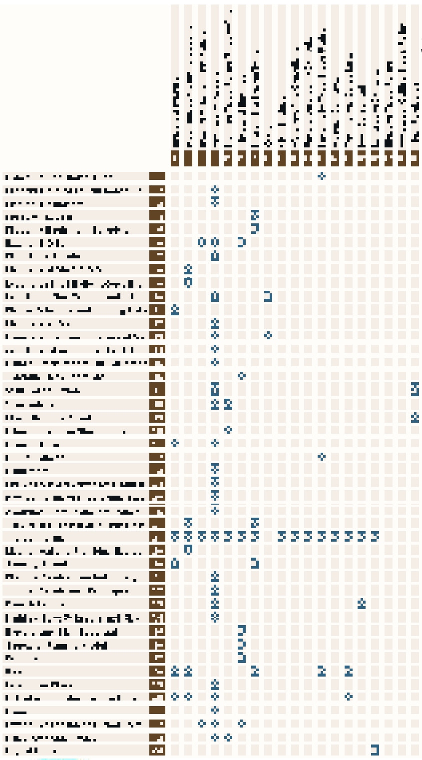
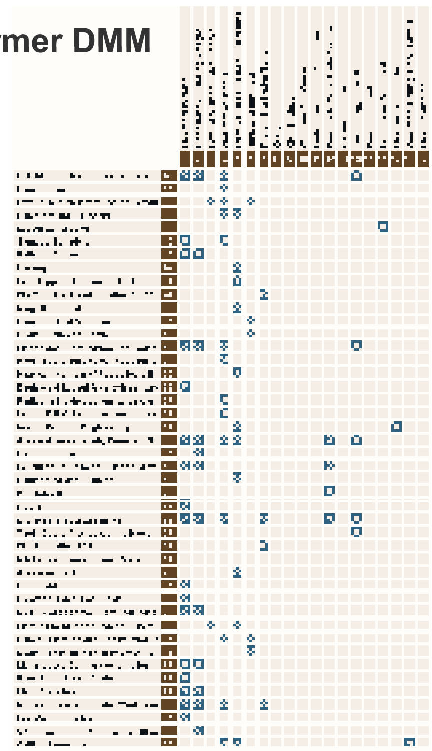
Step 4: Process Performer DMM



• Identified processes are linked to the responsible performers in the design phase

• The result is the process performer DMM



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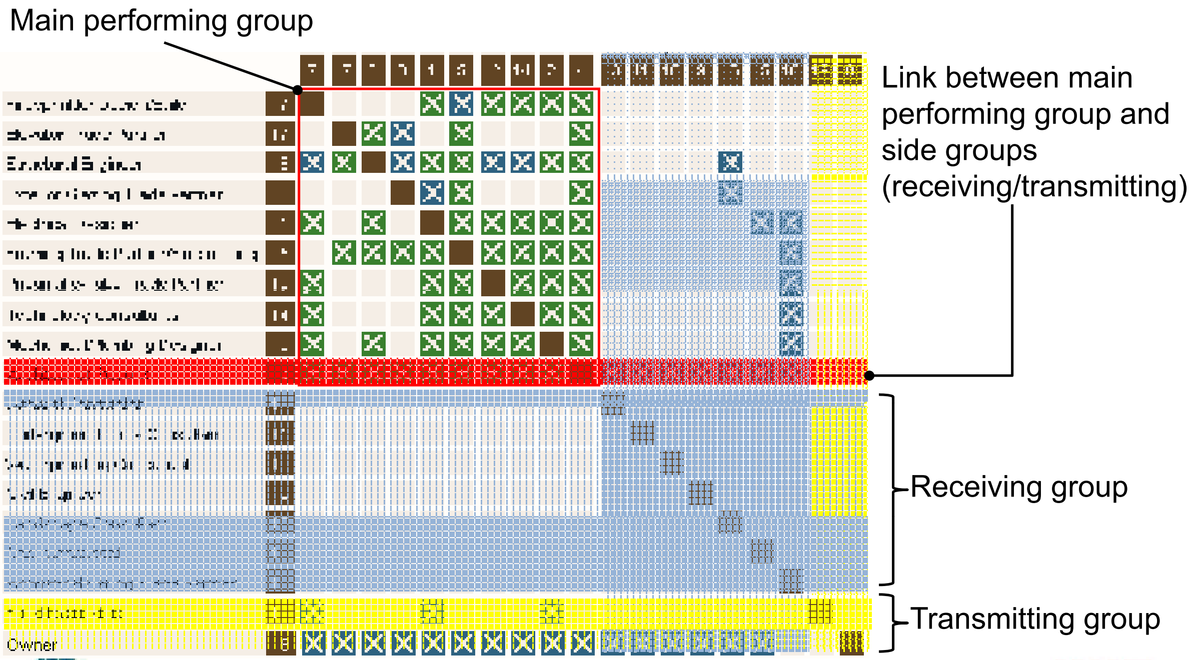
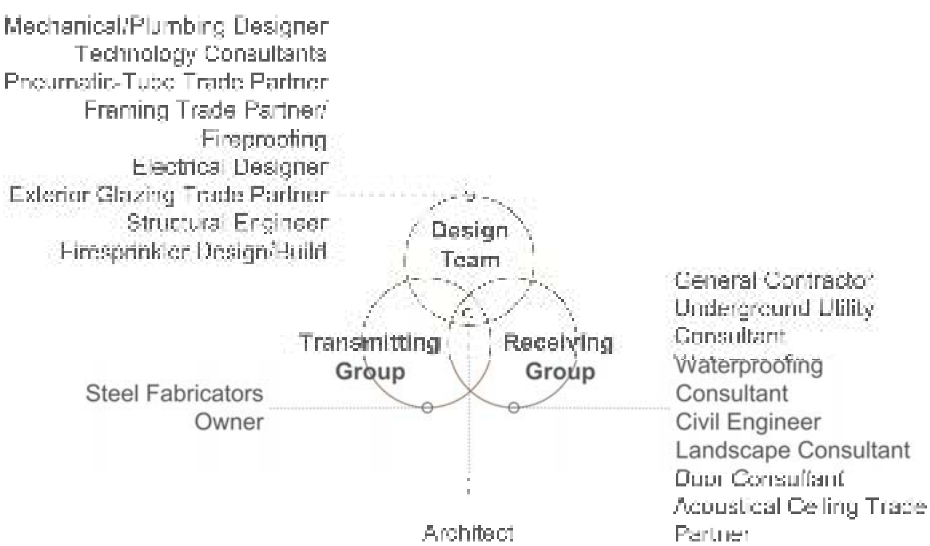
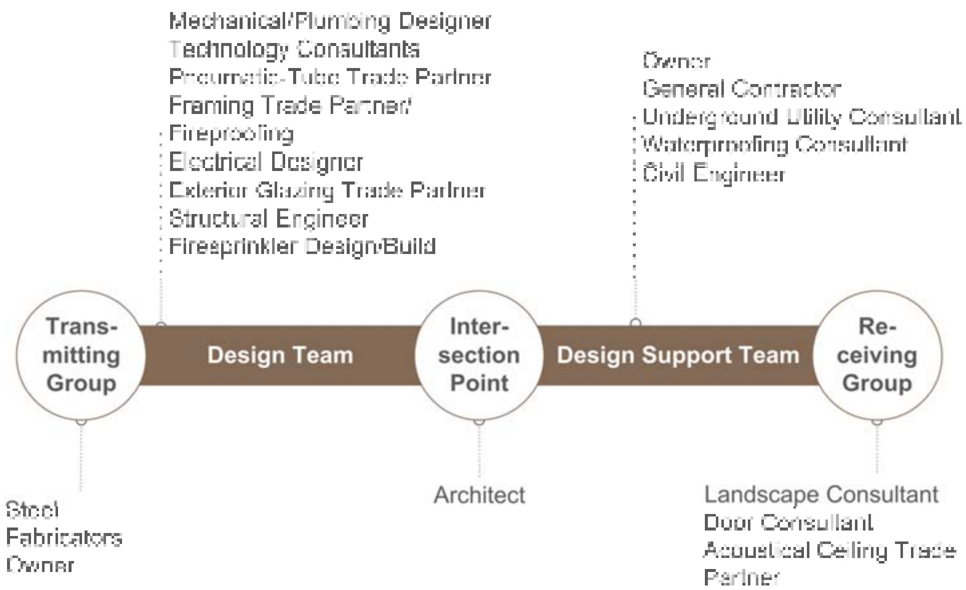
Step 5 & 6: Organizational DSM Creation and Clustering



Organizational Proposition



Organizational Proposition



Conclusion & Outlook

- MDM methodology is a powerful tool for reducing waste in lean construction projects
- MDM can help the managers to have a better view of the organization of the construction projects and help them in identifying teams
- High correlation between different design groups in the design phase with the architect as the focal point
- Right abstraction level of the MDM model is essential for obtaining relevant results

- Expansion of the MDM methodology to the whole life cycle of the project and other projects would provide more information
- Higher level of detailling would provide more information
- Better awareness of the construction industry of the MDM methodology would support research in this industry