MODEL FOR DESIGN MANAGEMENT IN COLLABORATIVE ENVIRONMENT USING DESIGN STRUCTURE MATRIX AND DESIGN PARAMETERS' INFORMATION

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ABSTRACT: Design is an act based on multidisciplinary information. The involvement of various stakeholders makes it difficult to process, plan, and integrate. Iteration is frequent in most of the engineering design and development projects including construction. Design iterations cause rework, and extra efforts are required to get the optimal sequence and to manage the projects. The simple project management techniques are insufficient to fulfill the requirements of integrated design. This paper entails two things: design structure matrix and design parameters' information based model. The emphasis has been given to optimal sequence and crucial iteration using design structure matrix analysis technique. The design projects have been studied using survey data from industry. The optimal sequence and crucial iterations results have been utilized for proposed model. Model integrates two things: information about produced- required key design parameters and information of design changes during the design process. It will help to get familiar with Design management in order to fulfill contemporary needs.

Keywords: Design Management;, Design Structure Matrix; Design Parameters; Project Management

1. INTRODUCTION

The construction project involves various kinds of stakeholders from start of project to the end of execution phase. The objective of project is to provide the facility to the user within stipulated time and budget, while avoiding risks. The search of most critical part of construction project is not a difficult task. Most of issues including cost in construction industry are related to the design. Design is an iterative, generative, and multidisciplinary process by its nature. Poor design process performance has a significant effect on the performance of subsequent activities and constructed facility. Also, design is a result of team effort of various interdependent individual design disciplines or design subsystem (DS). But it is essential to differentiate between design and design information. Design is an act of designing by each designer / subsystem based on the information from other subsystems. Design information is a raw material on which individual subsystem acts. Therefore, steady flow of this multidimensional design information is a key of well integrated design. It is because of close interdependency regarding tremendous information flow among various professionals of different design subsystems and organizations. Besides the tremendous magnitude of information involve, the complexity with which this information flows contributes considerably to the difficulty of design [4]. Figure 1 illustrates the general design process.

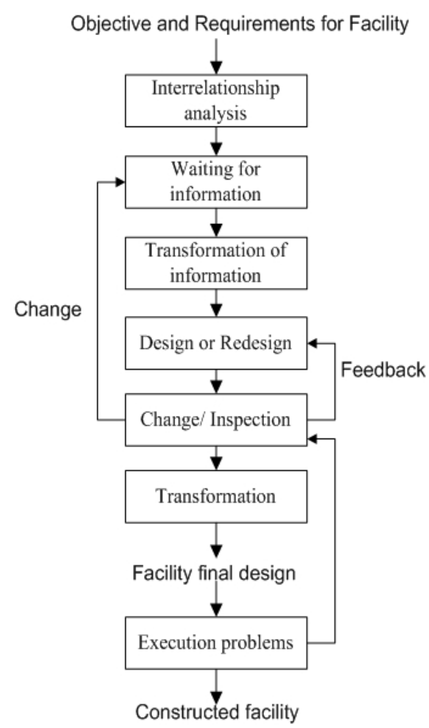

Figure 1. General Design Process

Design management (DM) is an emerging discipline, which can be helpful for connecting the design and construction process. It is akin to project management and can be controlled by a design manager or team of managers. Conventional wisdom tells us that design managers supervise the creators of tangible "things". These things are often used to fulfill or meet an organization's strategic goals [3]. While providing the opportunity to monitor and coordinate design activities of a project, it can also be possible to work on other projects at the same time. Design management strives to create understanding and awareness among personnel at all levels that conscious actions in even the smallest decisions are the core of design management[3]. Therefore, design management is essential in order to attain collaborative and integrated solution for future construction projects. In ideal terms, design management is a holistic, long term activity, encompassing all levels of corporate functions [3]. In construction, for cases of general contracting the design and management are two different things. Traditionally, architectures and engineers have dominated role, and the design is in complete authority of architectures. The construction industry has entered in a new era because of modern construction techniques and methods, new contracts and legislation, and consortium & joint venture. If a company has a growing interest in such aspects, then they have to adopt design management approach, as managers will have to involve in design role.

By and large, the current problems associated with design management of construction projects are following: managing information, planning & scheduling, design changes, and design - construction integration. The most imperative part of design management of any project is processing of the information. There is a possibility of poor consideration of interdependent information flow, as each discipline doesn't know its contribution in the whole design process. In common practice the design is managed and controlled by concentrating on design deliverables, like percentage of complete drawings and specified review mile stones. This technique demands that design information should be available and coordinated among all design participants formally or informally through design reviews and drawings. But intention behind any change is difficult to read and reaching of information at right time to right person is also questionable. One key point is that design should be planned, managed, and controlled around the flow of information rather than deliverables, if effective solution in collaborative environment is required [1]. Moreover, the scheduling plays a predominated role over information which causes the problems if not properly coordinated.

2. INTERRELATION REPRESENTATION

In complex and large projects, the representation of interaction among various design subsystems' parameters is a difficult task. But Design Structure Matrix (DSM) provides an easy and compact method to allocate and understand interaction. In design systems analysis, it is also called precedence matrix. A precedence matrix is a square matrix with as many rows and as many columns as there are vertices in the graph [5]. The design is always an easy prey for internal and external uncertainties. The application of matrices in design management of construction projects is not very common, but for simulation or modeling it is widely acceptable. Moreover, complexity in design can be addressed using DSM based analysis model and is easily readable regardless of size.

2.1 Design System Configuration

Any design system is a result of interaction of its various subsystems' parameters or components. Relationship among these can be characterized by three fundamental building blocks; Parallel (independent), sequential (dependent), and coupled (interdependent), as shown in Figure 2. The knowledge about the interaction types is important for the steady flow of information and its management.

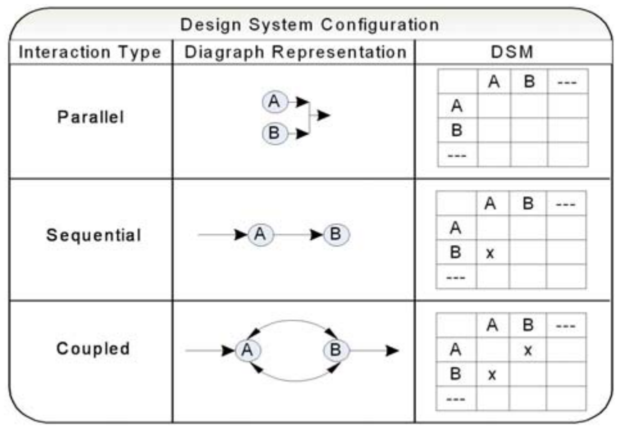

Figure 2. Interaction Types in Design

2.2 Design Structure Matrix

The Design Structure Matrix method is chosen as it can efficiently eliminate or reduce iterative loops by re-sequence design parameters / tasks. In addition to this, it is also helpful for finding an optimal sequence. The use of matrices in system modeling can be traced back to Warfield in the 70's and Steward in the 80's.

DSM configuration is as following: place down the design parameters / activities names on the left side of matrix as row headings and across the top of matrix as column headings in the same order (square matrix) as shown in Figure 3. The dependency of one parameter to other is represented by "x" or "1" marks in the off-diagonal cells. Otherwise it is left empty or assigned "0" mark. Usually the diagonal elements of DSM left empty or blackened-out. But for DSM analysis where the binary numbers (0 and 1 only) involve, it should be zero. The dependency has to be read along the rows as "information required from" and along the columns as "information provided to."

DSM can be used as a method to eliminate or minimize iterative loops by re-sequence of design parameters involved. Iterative loops can be identified by "x or 1" mark above the diagonal line of DSM. It depicts that information is required from downstream (later listed) parameter, and is called feedback mark. Similarly, such mark below the diagonal depicts that information can be transferred later, and is called feedforward mark. Feedback mark in Figure 3 depicts that design parameter (C) requires information from later parameter (D) and DSM is not in lower triangular form. The main objective of DSM method is to keep it in lower triangular form to obtain a sequence where each one can be executed only after it receives all information from its predecessors [2]. But, it may happen only in simple design project cases. Therefore, for large complex design projects it is suggested to keep feedback marks minimum and close to the diagonal line, in order to get optimal sequence and crucial iterations.

	A	B	C	D
A				
B	x			
C	x			x
D		x	x	

Figure 3. DSM Sample

2.3 DSM analysis

DSM analysis implies the reordering of the given sequence resulting in optimal sequence including the crucial design parameters which require rework. It consists of partitioning and tearing algorithms [5] & [6].

2.3.1 DSM partitioning

It is the process to reorder rows and columns of DSM in order to get a new sequence having no or least feedback marks. The partitioning algorithm is stated as following:

1. Identify the design parameters that require no information, which can be noted by observing empty rows in DSM. Separate such parameters from DSM (i.e. from rows and columns both) as "high order design parameter" in sequence. If more empty rows are found after separating then repeat this process until a DSM, having no empty row, is achieved.
2. Identify the design parameters that provide no information, which can be noted by observing empty columns in DSM. Separate such parameters from DSM (i.e. from columns and rows both) as "low order design parameter" in sequence. If more empty columns are found after separating then repeat this process until a DSM, having no empty column, is achieved.
3. If all design parameters have separated, then DSM is already partitioned after step 2. Otherwise, after completing step 1 and 2 or in cases where DSM has no empty rows and column then identify the loops causing rework.

Loops in DSM can be identified using path searching method, powers of adjacency matrix method, and reachability matrix method etc. The powers of adjacency matrix and reachability matrix method have been studied in detail, and it is noted that both method provide the same results. In this research, the power of adjacency method was decided to use in DSM analysis and DSM user interface was utilized for analysis [7].

2.3.2 DSM tearing

It is the process of further reordering of design parameters within the blocks of partitioned DSM. This process is applied because the design parameters partitioning provides the blocks / loops having two paths of entrance. Shunt diagram can be used for tearing purpose [5]. But this process entails both management and engineering judgment, and is extremely dependent upon the individual's knowledge of interrelationship [8]. Therefore, it is suggested to limit the DSM analysis up to partitioning, and leave the tearing upon the managers. Then, managers can apply their knowledge to further reorder the blocks of partitioned DSM, by keeping in view the lower triangular form. In addition to this, a survey can also be performed to rank the priority of design parameters within the blocks. Therefore, tearing involves heuristic approach and may consist of the following steps:

1. Place the design parameter at the top within block having empty / minimum input requirement by observing partitioned DSM rows.
2. If more than one such parameter is found then determine which one delivers maximum output by observing partitioned DSM column, and schedule it first.
3. Repeat the process till all loops are scheduled.
4. If it is still not possible to order within blocks then arrange the design parameters, keeping in view the required result i.e. to form lower triangular matrix having no feedback marks or try to schedule to get dependency close to diagonal line.

3. MODEL FOR DESIGN MANAGEMENT IN COLLABORATIVE ENVIRONMENT

It is proposed to divide design management into three interlinked but intricate parts: information management, scheduling, and change management for construction design process. Then, it is linked to construction phase for design and construction integration. In order to achieve collaborative environment, all participants involved in design management can be connected through internet or work group computers by using database. Figure 4 depicts the proposed model. The proposed model is based on the two fundamental questions: what you will produce? and what you require to accomplish this? In this way interdependency among designers can be conceived. This information is treated as first stage of the model. The same first stage was used in ADePT, representing design activities and their information requirements for building design [9]. In Adept, design information are designated by classes but in this paper only key design parameters are identified.

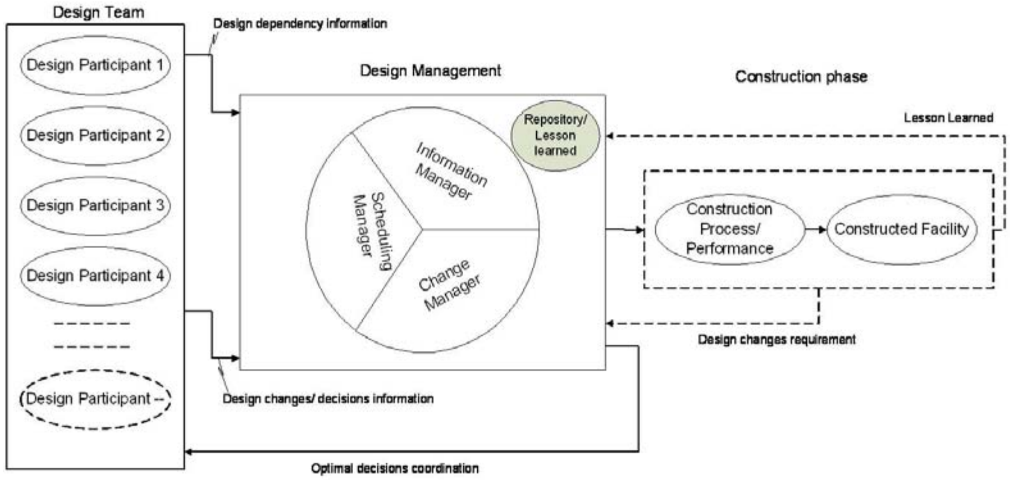

Figure 4. Model for Design Management in Collaborative Environment

Designer interfaces provide designers a tool to input production-requirement and change information. The best way for information management is allow each participant to define his role and responsibility. Role means what he will produce for which he is responsible. All such information is gathered to process under information management. Therefore, information management can be helpful to represent the complex relationship among designers in a definite manner. The information management can act as a bridge, facilitating all designers. All kind of information whether dependency or change can be processed through a single domain of information management.

The dependency information about design parameters involved in design process is helpful to find optimal sequence and crucial iterations. The optimal sequence of design parameters and crucial iterations are required tools to control the design changes. Both of these tools can be used not only during design process, but also during the construction phase of any project. In design change management, prior knowledge of parameters to be affected because of any changes, is very essential. In this way, relative changes can easily be disseminated to the requisite stakeholder at right time.

The identification of responsibility is very complex issue in cases of multidisciplinary tasks. It becomes more critical when the early failure of constructed facility happens. In the proposed model, information from each participant is suggested to be saved automatically in database, when input through interfaces. At the end of design process, whole data may be shifted in a separate design repository. Similarly, changes during construction phase can also be saved in this design repository. This design management database can be used as case study to mitigate errors in future projects, as well. The Figure 5 depicts the model engine.

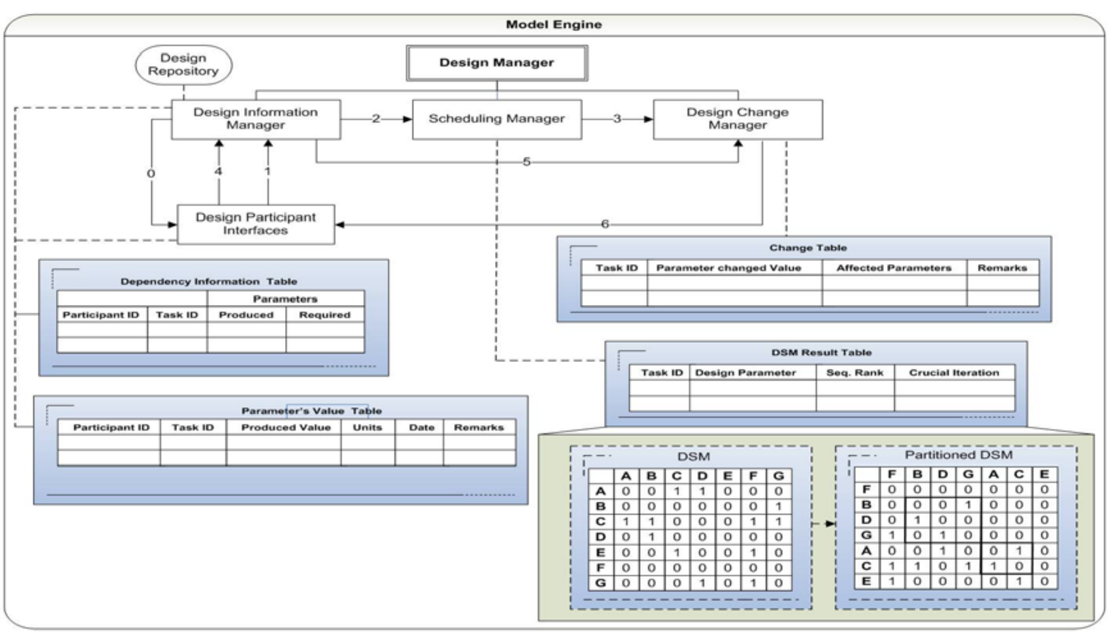

Figure 5. Model Engine

4. CASE STUDY

In order to specify design participant interdependency the identification of relationship among various design disciplines / subsystems is required through key design parameters. In this aspect, detailed study of roadway design project has been made in addition to survey from industry. This study has been divided into two parts: work flow of roadway design project and design process analysis. Design process analysis implies interrelationship analysis among design subsystems and key design parameters / design tasks. The design process analysis also requires interrelationship study among various design parameters. The integrated collaborative environment can be achieved using key design parameters dependency and change information. Therefore, the interrelationship among key design parameters involved in roadway design has been studied and summarized as shown in Figure 6. The analysis has been performed as scheduling manager utilizing DSM user interface to get partitioned-DSM. The results about optimal sequence & crucial iteration have been integrated using DSM results table interface of scheduling manager. The "design parameters produced values" by each participant and subsequent changes can be made available when required, through parameter's value table. After this, change manager can make change table using scheduling manager data and changed data. This change table may be used for alarming affected design participants in integrated and collaborative manner.

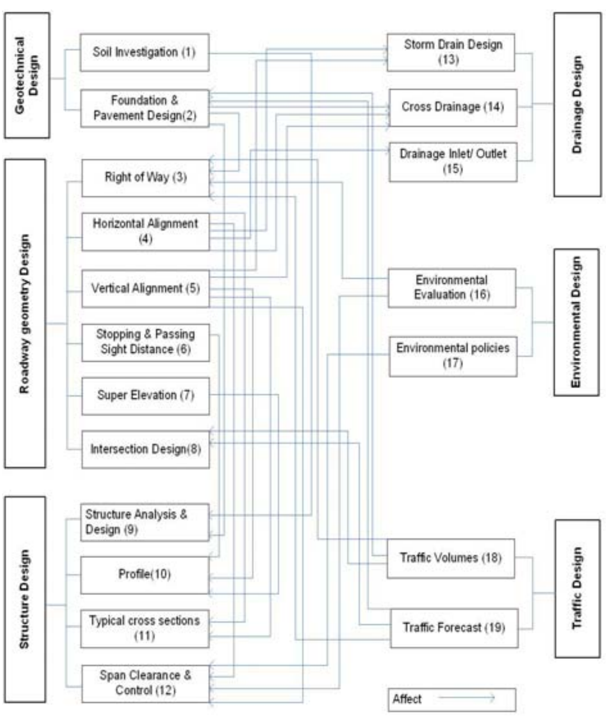

Figure 6. Interrelationship Analysis among Key Design Parameters

So using prototype for the model, all key design parameters dependency has been determined below the diagonal line which is the result of integrated communication among various DM participants. And any change can also be disseminated depending upon the situation. Figure 7 depicts the user interface of roadway design parameters' information based model for design management.

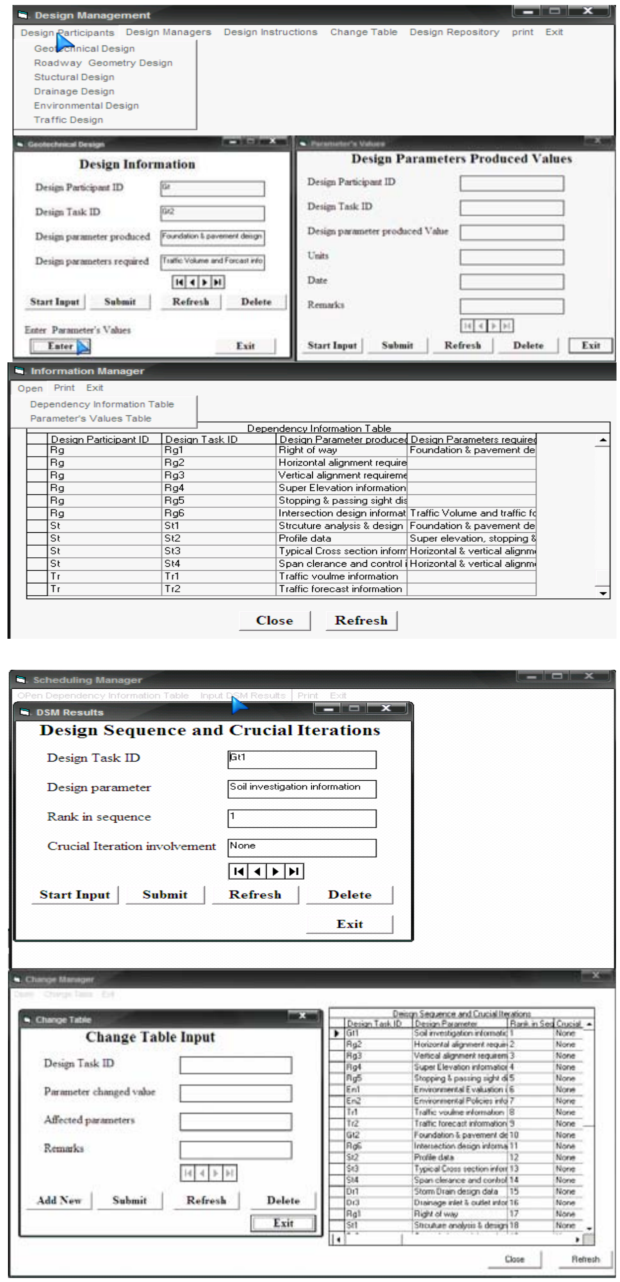

Figure 7. User Interface for DM of Roadway Design Project

5. DSM RESULT ANALYSIS OF ROADWAY DESIGN PROJECT

The DSM analysis of roadway design project yields an optimal sequence with no crucial iteration. The parameters devised from case study fall in the category of simple case of DSM. Three possibilities of finding no crucial iterations are following:

• The devised data for DSM was already communicated in collaborative and efficient environment. i.e. The sequence devised was very good to avoid rework

• The assigned dependency of devised parameters is more theoretical rather than practical (survey) and conform ideal conditions.

• The number of devised parameters is less.

6. CONCLUSIONS

The significance of information flow in design is widely acceptable but the multidisciplinary nature of design always causes hindrance in it due to iterations. Design management needs team players with skill to utilize the benefits of integrated thinking, common objective, and collaborative approach. Interdisciplinary education is important for all design professionals so that they can work together in a unify manner. The nature of construction projects is going to be more multidisciplinary, precisely based on design. Design management is simply a matter of ensuring that design professionals and managers can work together in effective manner. The optimal sequence and lessen the rework have been challenging tasks for managers. The DSM has the capability to represent the information requirements of complex design projects and is a tool to get crucial iterations and optimal sequence. Therefore, DSM user interface has been utilized to get optimal sequence and crucial iterations. In this way, the managers have had little experience are believed to involve in design control in proactive manners. The objective of research has been achieved by developing DM user interface with case study of roadway project as an implementation example. The whole process of designers and managers communication has been saved in database. It is also believed to use database as learning source to know the behavior of various kinds of design projects. This research indicates the problems associated with DM and addresses suggestions for it. DSM results have also been analyzed, but the results still required the vetting from construction industry. Nevertheless, this research is an effort to demonstrate the design management needs so that less rework requires not only in design, but also during the construction phase. The proposed model is an implementation example for the development of effective software system and can be integrated with internet. The survey data obtained is also a source about regional trend of design management. The more involvement of construction companies is still suggested so that real situation can be exposed. More research work is required in design management and need to study it as separate discipline is quite suitable.

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