RESEARCH ARTICLE

Design Delays in Building Projects in India: Effects and Remedies

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Abstract

Empirical evidence shows that design-related challenges influence delay in building projects in India. Based on case studies of building projects from the capital region of Odisha Province of India, the factors relating to consultants and design have been identified and policy interventions were compiled to reduce design linked delay. A survey method to collect data, statistical analysis and a Systems Dynamics modelling approach were used according to different scenarios to propose strategic interventions. The findings suggested that complexity of design and compilation of documents, and the combined complexity of both can cause substantial delay. The model results revealed that the combined effect of appointing competent consultants and communicating effectively could reduce delay significantly. The novelty of the study lies in using a systems approach to develop causal feedback relationships among variables, as opposed to considering one origin of the problem at a time. The study makes three contributions: (1) design-linked challenges and mechanisms of delay, based on causal feedback relationships in building construction, can be diagnosed to evolve appropriate remedial measures; (2) impacts of different interventions can be visualised quantitatively under different scenarios; and (3) an alternative methodology to examine the trend of the project period is offered.

Keywords

Construction; Consultant; Delay; Design; Systems Dynamics

Introduction

The building sector in India has grown in recent years with the rise in demand for housing and commercial buildings. However, in the current situation, there is a large gap between supply and demand in buildings (Firstpost, 2018). To meet this demand, many real estate development companies have responded positively and are engaged in developing building projects. However, concurrently, the real estate companies are experiencing severe challenges in completing projects and handing over to clients within the scheduled period, resulting in severe dissatisfaction among the consumers and litigations between the consumers and the developers. Delay in construction is argued to be one of the major reasons for the poor completion rate of the buildings (Doloi, et al., 2012; KPMG and PMI, 2012; Singh, 2010).

Project management-related issues linked to clients, contractors, design, and consultants are some of the challenges that cause delay in the delivery of building projects (Aiyetan and Das, 2016, 2015; Han, Love and Pena Mora, 2013; Love, et al., 2011; Wu, et al., 2019). Similarly, challenges related to materials, equipment, quality of work, and budget contribute to the delay in building projects although they can be ascribed to client, contractor or design-related challenges. Also, environmental and socio-political challenges can cause delay (Mäki, 2015; Singh, Bala and Dixit, 2018). However, the scope of this reported study is confined to design-related factors in building projects and, thus, other factors were not emphasised.

It is argued that design-related challenges contribute significantly to the delay in the delivery of building projects. For example, design-related challenges and errors generally contribute to a substantial quantity of re-work leading to schedule delay and cost overruns (Aiyetan and Das, 2016; Han, Love and Pena-Mora, 2013). The design-related errors are generally attributed to the consulting firms, design teams, or individual designers (Wu, et al., 2019). The various factors that cause design errors could range from lack of knowledge and competence, poor conceptual understanding, computational errors, and errors in the mathematical and graphical representation to poor communication among the stakeholders, and poor understanding of the client's requirements (Mäki, 2015; Wu, et al., 2019). Nonetheless, the errors linked to design are caused by a chain of events that lead to further actions that cause delay. The designers or the consulting firms should examine the factors to understand the chain of actions that contribute to the delay, and take corrective measures to prevent unwarranted consequences that might happen (Mäki, 2015).

In the Indian context, it has been argued that design-related challenges contribute significantly to construction delay (Bagrecha and Bais, 2017; Doloi, et al., 2012; Das, 2015; Mali and Warudkar, 2016; Pandya and Malek, 2018; Rivera, Baguec and Yeom, 2020). Therefore, using the study context of building projects in India, the objectives of this investigation were: (1) to identify the influential consultant- and design-linked factors that cause delay; (2) to map causal feedback relations among the most influential consultant- and design-linked factors; and (3) to examine the occurrence of delay in building projects under different scenarios, based on which strategic interventions can be undertaken. For this purpose, a Systems Dynamics (SD) Modelling approach was used.

Building projects at the stage of construction in the capital region of Odisha Province in India were used as the context for this study. The region includes the twin cities of Cuttack and Bhubaneswar, and their hinterland. The location of a large number of manufacturing industries, Information and Communication Technology (ICT) industries, business, educational and governance activities in and around the region, during the last two decades, has attracted a large population to the region, which has created a significant demand for the development of infrastructure, particularly in the housing and commercial building sector. Consequently, there has been a spurt in building activities in the region. However, in recent times, the sector has been plagued by delay in the completion of projects, consumer dissatisfaction, conflict between the real estate companies and consumers, fraud, court cases and judicial interventions. It has been alleged that consultant- and design-related challenges have contributed significantly to the delay of projects in addition to the other factors associated with clients, contractors, materials, investments and regulations.

This article has been structured in the following manner. The next section contains the literature review. The research methods, including modelling, results and discussions have been presented in the subsequent two sections. The final section includes the conclusions and implications of the study.

Literature Review

DELAYS IN CONSTRUCTION PROJECTS

Construction projects are complex in nature because their successful completion is dependent on the interaction of many variables, some of which are unpredictable. Delay is one of the problems that occur as a result of project complexities. Delay is defined as the difference between actual and planned progress of a project (Guo, Yiu and González, 2015). Delay involves time overruns either beyond the scheduled date specified in a contract or beyond the date agreed upon by the parties responsible for the deliverables. In construction, delay constitutes the additional days of work required to complete a project/activity, or a delayed start of an activity (Assaf and Al-Hejji, 2006; Das, 2018).

Factors that cause delay include, *inter-alia*, challenges related to the performance and involvement of stakeholders, resource availability, environmental conditions, and contractual relations (Alaghbari, et al., 2007; Bon-Gang and Lay Peng, 2013; Deep, et al., 2018; Han, Love and Pena-Mora, 2013; Mäki, 2015; Singh, Bala and Dixit, 2018). However, delays in building construction projects are attributed to the three traditional project actors, being the clients, the contractors, and the consultants engaged in planning and design activities (Aiyetan and Das, 2016; Das, 2015; Han, Love and Pena-Mora, 2013; Love, et al., 2011). In India, the factors related to these three stakeholders are also predominant causes of delay in the construction industry (Das, 2015; Das, 2018; Bagrecha and Bais, 2017; Deep, et al., 2018; Doloi, et al., 2012; Mali and Warudkar, 2016; Pandya and Malek, 2018; Rivera, Baguec and Yeom, 2020; Singh, Bala and Dixit, 2018).

DESIGN-LINKED DELAYS IN BUILDING CONSTRUCTION PROJECTS

Design-linked errors, engendered by the consultants (architects and engineers) at the planning and design stage of projects, contribute significantly to delay in projects (Doloi, et al., 2012; KPMG and PMI, 2012; Han, Love and Pena-Mora, 2013; Mäki, 2015; Singh, 2010). Design-linked errors can happen because of both human and technical reasons. For example, erroneous design happens because of impaired human cognition, specifically when designers lack experience and are under stress because of schedule and cost pressures (Han, Love and Pena-Mora, 2013; Love, Edwards and Irani, 2008; Love, et al., 2011). Designers also might omit important aspects such as involving other stakeholders in design decisions, informing them of assumptions made, eliciting the needs and schedules of clients, contractors, and users (Han, Love and Pena-Mora, 2013; Mäki, 2015). Also, erroneous design can result from exogenous factors that include schedule pressure, design fees, client procurement strategy, and skilled labour supply, which influence designers' ability to perform tasks effectively (Love, et al., 2011). Moreover, many design firms and construction organisations pay limited attention to errors, which might result in re-work or failures when the design is implemented (Han, Love and Pena-Mora, 2013; Love, et al., 2011). Also, the size and complexity of a project, the number of professionals engaged in its design, and the complexities of procurement and price determination for services have a significant impact on the occurrence of design-linked errors (Love, et al., 2011).

Furthermore, some of the systemic challenges, which influence design-linked delay, include clarity in initial information, lack of design reviews, checks and verifications, re-use of specification and details, unrealistic schedules, understaffing, and lack of project governance (Love, et al., 2011; Mäki, 2015). Similarly, if design errors that might be deemed minor in nature are overlooked, it might take significant

time to correct them, leading to delay in the projects (Love, et al., 2011). Furthermore, according to Al-Hazim, Salem and Ahmad (2017), error in design, and design changes at the time of construction lead to cost overruns, which adversely affect the schedule of the projects (Singh, 2010). The several factors that cause design-linked challenges (summarised in Table 1 below) work through chain reactions and mechanisms with cause and effect relations, leading to delay. Therefore, it is necessary to understand the mechanisms of the occurrence of the design-linked challenges and errors, and their consequent impact under different scenarios, to devise appropriate strategic interventions.

CONSTRUCTION DELAY ANALYSIS METHODS AND THE USE OF SYSTEMS DYNAMICS METHODOLOGY

Different methods have been used to assess delay in construction, including project management methods, such as As-Planned *vs.* As-Built, Impacted As-Planned, As-Planned but for, Collapsed As-Built, "Window" Analysis, Time Impact Analysis, Contemporaneous Period Analysis Method (CPA), Computerised Schedule Delay Analysis Methods, and Integrated Decision Support System (DAS), aided by statistical techniques and computer modelling, to cite a few (Braimah, 2013; Salunkhe and Patil, 2013). However, the major limitation of these methods is the lack of consideration of the dynamics, interaction and cause-and-effect relationships among the various variables (Braimah, 2013). As an alternative, network causal mapping and SD Modelling have been used to explore the challenges of construction project management and challenges of delay, and their impact on projects (Aiyetan and Das, 2016; Das and Emuze, 2017, 2018; Ford and Lyneis, 2019; Han, Love and Pena-Mora, 2013).

SD as a modelling technique has been used in construction project management to understand the behaviour of different aspects such as re-work, project delay, and improving the effectiveness of the decision-making process (Aiyetan and Das, 2016; Das and Emuze, 2017, 2018; Han, Love and Pena-Mora, 2013; Lyneis and Ford, 2007; Ford and Lyneis, 2019). The focus of SD as a modelling method is mainly on feedback structure and the resultant behaviour to understand a complex system holistically. SD provides a powerful perspective on the complexity and dynamics of construction management, including delay (Hans, et al., 2013; Ford and Lyneis, 2019; Lynes and Ford, 2007). Since SD modelling could be used to consider the inter-connectedness of complex feedback processes, it is argued that it could be used to help in understanding the inter-related factors involved in the construction process and assist in developing plausible policy interventions to resolve delay. Based on this premise, SD Modelling was employed to resolve delay at a specific attribute level, such as design-linked delay.

Table 1.   Consultant and design-related delay factors

Consultant and design-related delay factors	Sources
Consultant related factors	
Delay in performing inspection and testing	Aibinu and Odeyinka (2006); Al-Kharashi and Skitmore (2009)
Delay in approving major changes in the scope of work	Aibinu and Odeyinka (2006); Al-Kharashi and Skitmore (2009)
Inflexibility (rigidity)	Doloi, et al. (2012)
Poor communication/co-ordination between consultant and other parties	Aibinu and Odeyinka (2006); Al-Kharashi and Skitmore (2009)

Table 1.   continued

Consultant and design-related delay factors	Sources
Consultant related factors	
Late review and approval of design documents	Aibinu and Odeyinka (2006); Al-Kharashi and Skitmore (2009)
Conflicts between consultant and design engineer	Aibinu and Odeyinka (2006); Al-Kharashi and Skitmore (2009)
Inadequate experience of the consultant	KPMG and PMI (2012); Singh (2010)
Lack of site experience of consulting staff	Mali and Warudkar (2016)
Lack of use of advanced technology and software	Mali and Warudkar (2016)
Lack of understanding of environmental impact	Mali and Warudkar (2016)
Inaccurate cost estimation or under-estimation	Mali and Warudkar (2016); Rivera, Baguec and Yeom (2020)
Design related factors	
Complexity of project design	KPMG and PMI (2012); Singh (2010)
Mistakes and discrepancies in design documents	KPMG and PMI (2012); Singh (2010)
Delay in the production of design documents	KPMG and PMI (2012); Singh (2010)
Unclear and inadequate details in drawings	KPMG and PMI (2012); Singh (2010)
Insufficient data collection and survey before design	Doloi, et al., (2012); KPMG and PMI (2012); Singh (2010)
Misunderstanding of client's requirements by the design engineer	Doloi, et al., (2012); KPMG and PMI (2012); Singh (2010)
Quality assurance and control	Bagrecha and Bais (2017)
Inconsistency and incomplete technical specifications	Bagrecha and Bais (2017)
Insufficient data for design	Pandya and Malek (2018)

Research methods

The flow chart of the research steps is shown in Figure 1. A survey research method was used to collect data. Statistical analyses, involving descriptive statistics and Cronbach's Alpha Test, were used to check the reliability and suitability of the data set. Standard Deviation and Z tests were conducted to observe the consistency, veracity and variability of the responses to the survey. The parameters and influence of the variables causing delay, which were used for the model building, were evaluated by using a Likert Scale.

Thereafter, a quantitative SD Model was developed and simulated to examine the trend of the project period and delay period under different scenarios. For SD Modelling, the parameters were established by concurrent evaluation of the influence of the variables derived from the survey, discussion with stakeholders and the literature review. However, for the purpose of developing the quantitative SD model and

scenario analysis, one of the building projects, from the 22 projects considered in the survey, that could be representative of the majority of the building projects was selected and the data from this project were used. The detailed data collection, analysis and modelling are presented in the following sections.
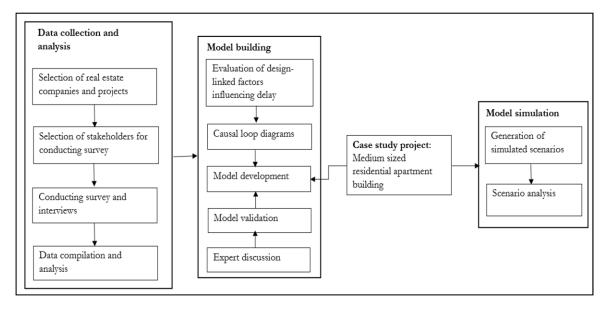

Figure 1.   Flow chart of methodology used in the study

SURVEY, DATA AND DATA ANALYSIS

The primary data were collected from the various stakeholders of the building projects in the study area through a questionnaire using a Likert Scale. In total, 120 questionnaires were administered among the stakeholders of 12 real estate companies engaged in building projects and 6 consulting companies engaged in the planning and design of building projects. The real estate and consulting companies chosen for the survey were selected after initial contact and careful scrutiny of their engagement in building project activities. The survey was conducted by applying a purposive sampling method. The companies, which were engaged largely in building projects, such as residential housing projects and commercial centres or malls, were initially shortlisted and contacted. Then, the willing companies, which had been active in the business for a minimum of 5 years, had completed at least 1 project and were engaged in another, were selected. The respondents were chosen from 22 projects being carried out by the 18 selected companies (both real estate and consulting) that included: residential building projects (54.5%), shopping complexes (19.2%) and social infrastructure building projects (26.3%). The stakeholders surveyed included: consultants (18.0%), contractors (16.0%), clients (11.0%), project managers (12.0%), engineers (14.0%), architects (10.0%), estimators (11.0%), and skilled technicians (8%). The respondents had a minimum of 5 years of work experience and were aged from 28 to 59 years. They were purposively chosen based on their experience, engagement with building projects and willingness to participate in the survey. Out of the total of 120 questionnaires administered, 100 were returned (approximately 85% response rate).

Care was taken to incorporate most of the key factors under the consultant- and design-linked aspects in the questionnaire, as found in the literature reviewed (Table 1) (Aibinu and Odeyinka, 2006; Al-Kharashi and Skitmore, 2009; Bagrecha and Bais, 2017; Doloi, et al., 2012; KPMG and PMI, 2012; Love, et al., 2011; Mäki, 2015; Mali and Warudkar, 2016; Pandya and Malek, 2018; Rivera, Baguec, and Yeom, 2020; Singh, 2010). The questionnaires were reviewed and finalised after initial discussions with some of the

stakeholders (A sample questionnaire has been included in Appendix-1). A Likert Scale, ranging from 1 to 5 (1 = not influential, 2 = less influential, 3 = influential, 4 = significantly influential and 5 = most influential) was used to collect the responses. The respondents were asked to offer their opinions on the influence of the various parameters that caused delay from their experiences in the projects in which they were involved. The Likert Scale was deemed suitable because the identification of the factors was based on the perceptions of the stakeholders in the absence of structured statistical data and it can offer perceptions more objectively on a quantifiable scale. Such a scale has been used in understanding the factors of delay in the construction industry (Das and Emuze, 2017; Doloi, et al., 2012; Gravetter and Wallnau, 2008).

The survey data were used to evaluate the delay index (DI) of various parameters that caused delay in the projects. The DI is the mean score obtained from the responses of the respondents on the Likert Scale (Das and Emuze, 2017). In other words, Likert Index is considered as the proxy of DI. The DI was evaluated by using equation (1).

$$DI = \frac{\sum_1^n LI}{N} \tag{1}$$

Where LI= Likert Index assigned by each respondent

N = Total number of respondents

Further, the veracity and acceptability of the DI values were corroborated by checking with the Z probability values of the variables that influence design-linked delay.

Furthermore, statistical data on different variables from one, medium-sized residential building project were collected for the model building (Table 3). The design of the building was conducted by an architectural consulting firm with more than 10 years of experience in building design (both commercial and residential).

MODELLING

SD Modelling was used to understand the behaviour of building projects in terms of project period and delay. The SD Modelling process involves systematic steps of initial crafting of the problem, defining parameters, developing causal loop diagrams (CLD), structural modelling, validating the model and model simulation.

The causal loop (feedback) diagrams (CLDs) were developed by using SD Modelling principles. The building project was considered to be the system while developing the model (Forrester, 1968; Sterman, 2000). The influential factors, their positive and negative influences on related factors, and the causal relationships among them were considered to develop the CLDs. Published literature, discussions with experts and the experiences of professionals were used to establish causal relationships among the variables within and across the major parameters.

EVALUATION OF DESIGN-LINKED FACTORS INFLUENCING DELAYS (PARAMETRISATION)

The consultant- and design-linked parameters that influenced delay and were evaluated in the stakeholder survey have been presented in Table 2 below. The high Cronbach's Alpha values for consultant-linked factors and design-linked factors (0.90 and 0.87 respectively), and the low standard deviation values (between 0.17 and 0.80) indicated the reliability and consistency of the data. The high Z probability values (between 0.88 and 0.94) indicated that the majority of the responses were similar within the range of responses. Thus, the Likert mean scores or DIs could be used to evaluate the influence of the parameters on delay.

The parameters that influence delay were chosen according to the concurrence evaluation of the Likert Indices (DI) and Z probability values. The parameters which had higher DI values and Z probability were considered to have significant influence and thus were used for model building. However, the design-linked

parameters that had marginal influence and the exogenous variables (client, contractor, environment, socio-political, financial, etc.) were excluded from the modelling effort.

The evaluation suggested that the significant consultant-related factors that caused delay were: delay in reviewing and approving design documents (DI = 4.10); delay in approving major changes in the scope of work (DI = 3.94); delay in performing inspection and testing (DI = 3.85); poor communication/co-ordination between consultant and other parties (DI = 3.80); and inflexibility of consultant (DI = 3.65). Similarly, the design-related factors that were the main cause of delay in building projects were: the complexity of project design (DI = 4.25); unclear and inadequate details in drawings (DI = 4.19); mistakes and discrepancies in design documents (DI = 4.15); and delay in the production of design documents (DI = 4.11) as shown in Table 2. These parameters were considered in the model building. However, the factors with relatively low DI values and the exogenous factors, such as investment, the contractor- and client-specific factors, environment, procurement, equipment and labour, were kept out of the scope of the modelling.

Table 2. Significance of attributes and factors influencing delays in construction

Group/Attributes	Factors*	Delay Index (DI) (Likert Scale Mean Score)	Standard Deviation (σ)	Z Score	Z Probability
Consultant (Cronbach's α = 0.90)	Delay in performing inspection and testing	3.85	0.60	1.404	0.91
	Delay in approving major changes in the scope of work	3.94	0.64	1.456	0.92
	Inflexibility (rigidity)	3.65	0.48	1.360	0.91
	Poor communication/ co-ordination between consultant and other parties	3.80	0.61	1.408	0.91
	Late in reviewing and approving design documents	4.10	0.72	1.512	0.93
	Conflicts between consultant and design engineer	3.20	0.17	1.192	0.88
	Inadequate experience of the consultant	3.25	0.21	1.201	0.88
	Lack of site experience of consulting staff	2.76	0.65	-0.369	0.35
	Lack of use of advanced technology and software	2.81	0.54	-0.352	0.36
	Lack of understanding of environmental impact	2.87	0.59	-0.220	0.41
	Inaccurate cost estimation or under-estimation	2.56	0.52	-0.846	0.19

Table 2.   continued

Group/Attributes	Factors*	Delay Index (DI) (Likert Scale Mean Score)	Standard Deviation (σ)	Z Score	Z Probability
Design related (Cronbach's α = 0.87)	The complexity of project design	4.25	0.80	1.548	0.94
	Mistakes and discrepancies in design documents	4.15	0.75	1.520	0.94
	Delay in the production of design documents	4.11	0.73	1.524	0.93
	Unclear and inadequate details in drawings	4.19	0.78	1.524	0.93
	Insufficient data collection and survey before design	3.45	0.32	1.400	0.91
	Misunderstanding of owner's requirements by the design engineer	3.39	0.29	1.344	0.91
	Quality assurance and control	2.62	0.47	-0.808	0.19
	Inconsistency and incomplete technical specifications	2.84	0.52	-0.307	0.38
	Insufficient data for design	2.48	0.43	-1.733	0.04

*(Factors were extracted from Aibinu and Odeyinka, 2006; Al-Kharashi and Skitmore, 2009; Bagrecha and Bais, 2017; Doloi, et al., 2012; KPMG and PMI, 2012; Love, et al., 2011; Mäki, 2015; Mali and Warudkar, 2016; Pandya and Malek, 2018; Rivera, Baguec, and Yeom, 2020; Singh, 2010)

CAUSAL LOOP DIAGRAMS

The Causal Loop Diagrams (CLDs) were developed by considering the consultant- and design-related issues in an integrated manner, as illustrated in Figure 2 below. As observed from Table 2, complexity in the project design is a major aspect that adversely affects the project period as it takes more time to produce the design document. So, complex design increases the delay in the completion of a project (KPMG and PMI, 2012; Singh, 2010) through a reinforcing loop represented by CLD R1 (Figure 2). Further, complex design engenders mistakes and discrepancies in the design document that might lead to unclear and inadequately detailed drawings, which also cause delay in the production of the design documents (KPMG and PMI, 2012; Singh, 2010) represented by CLD R1A. This phenomenon reinforces CLD R1. Furthermore, unclear and inadequate drawings increase the construction time, which consequently escalates the project period (KPMG and PMI, 2012; Singh, 2010) through CLD R2A. Similarly, delay in approving major changes, and late review and approval of the design document by the consultant lead to an increase in the time to produce it. Additionally, delay in performing tests and inspection by the consultants during construction also increases project duration (Aibinu and Odeyinka, 2006; Al-Kharashi and Skitmore, 2009). Thus, an increase in the project period occurs through the combined reinforcing mechanisms represented by R1, R1A and R2A (Figure 2).

However, if a highly competent consultant and design team are appointed, they would be able to meet the challenges of complex design, eliminate the problems of mistakes and errors, and enhance clarity in detailed drawings, thereby reducing the time to produce the design documents (Doloi, et al., 2012; KPMG and PMI, 2012; Singh, 2010) by balancing the feedback mechanism (B1). Further, ensuring effective communication between the consultant and other stakeholders would assist in conflict resolution to

reduce delay ([Al-Khalil and Al-Ghafly, 1999](#); [Al-Kharashi and Skitmore, 2009](#)) through causal feedback mechanism B2. Effective communication would eradicate the challenges of delay in approving major changes, in reviewing and approving the design document by the consultant, and would reduce the delay in performing tests and inspection, which essentially would reduce the delay in construction time ([Al-Khalil and Al-Ghafly, 1999](#); [Al-Kharashi and Skitmore, 2009](#)) ([Figure 2](#)). Therefore, two dynamic hypotheses emerged, which need to be considered while developing policy interventions to reduce consultant- and design-related delay. They were: (1) the causal feedback relationships linking the appointment of a highly competent consultant and design team to the reduction in delay in producing the design documents required for construction; and (2) links between effective communication, conflict resolution and delay in construction could alleviate the challenges of design delay.
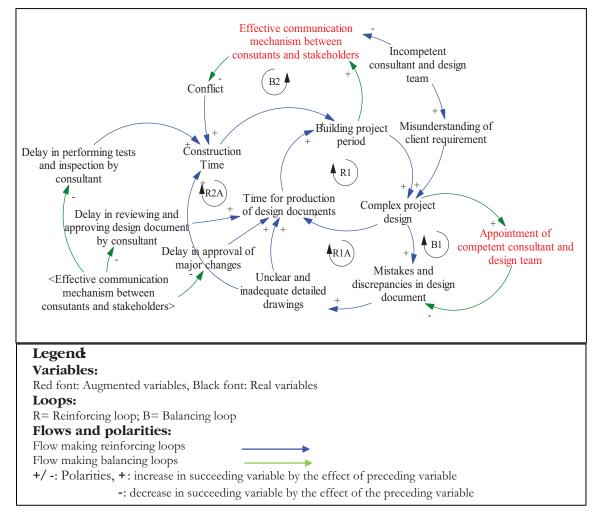

Figure 2.   Causal feedback relations among the consultant- and design-related factors causing delays

MODEL BUILDING AND SIMULATION

By using the postulated CLDs, a quantitative SD model was developed and simulated to observe the trend in terms of project period and delay in the selected building project. The flow diagram showing the structure

of the model is presented in Figure 3 below. The flow diagram was based on the CLDs and interaction of the associated variables presented in Figure 2 above. The case-study project chosen for developing the quantitative SD model was one of the 22 projects (identified as Project 6). It was a medium-sized, residential apartment complex with an estimated project period of 4 years that included an estimated 775 construction days. This project was chosen as it could represent the majority of building projects in the region because of its similarities with regards to the type, size, project cost, duration of the project, and challenges faced. The various project attributes, project boundary and simulation variables used in developing and using the model have been presented in Table 3. The various fractions were calculated based on the historical data and expert opinions of the project managers and consultants.

The structure of the model (Figure 3) was developed by using three variables: stock, rate variables, auxiliary variables and flows (Sterman, 2000). In this particular case, while building the model, the project period was considered as the stock variable, which can increase or decrease depending on the influence of other design-related variables. There were three rate variables: normal construction rate (NCR), construction rate owing to delay in producing design documents, and construction rate owing to the complexity of the design. Delay in inspection, delay in making appropriate changes in design and drawings, and delay in the approval of drawings were the auxiliary variables, which contributed to the construction rate owing to delay in finalising design. Similarly, mistakes and discrepancies in design documents, unclear and inadequate details in drawings, and misunderstanding of owners' requirements by design teams were the auxiliary variables that influenced the construction rate variable because of the complexity of the design. However, auxiliary variables, such as effective communication and appointment of competent consultant, were the augmented or perceived variables, which influenced the rate variables. The intangible qualitative variables, for example, the interpersonal skill, persuasive ability, commercial awareness etc. of the consultants, and informal methods of communication were not considered in the model building.

The maximum construction period (project time horizon placed) was taken as 48 months, over which the simulation was conducted, which was considered as the model boundary. Mathematical algorithms, based on the inter-relationship of the variables were used for the model building, which was carried out by using STELLA software. Equations 2 to 7 were the algorithms that were used in the model to calculate the project periods and delay. The model variables were initialised by using the values of the variables obtained from the selected, residential case study project.

The model was then validated by the concurrent use of a three-step process of structure verification, checking of algorithms and verification of behaviour (Sterman, 2000). Firstly, a structure verification test was conducted by checking the causal logics among the variables. Secondly, the correctness of the algorithms, i.e. the mathematical equations, were verified for their correctness. Finally, a comparative analysis of the model results and an actual project duration of another two, similar, completed projects was made, which showed marginal variations of 3.4% and 7.6% respectively, indicating validation of the model (Figure 4). The validated model was used for simulation.

While doing simulations under different scenarios, inputs on the influential variables were given in terms of rate variable fractions. The inputs were made in increments either increasing or decreasing from the base value.

Stock:

$$\text{Project Period (T)} = \text{Project Period (T - Dt)} + (\text{NCR} + \text{Delay\_Docu\_R} + \text{Delay\_Complex\_Desi\_R}) * \text{Dt} \tag{2}$$

Inflows:

$$NCR = Project\ Period*NCRF \tag{3}$$

$$Delay\_Docu\_R = Project\ Period*DPDR \tag{4}$$

$$Delay\_Complex\_Desi\_R = Project\ Period*DCCR \tag{5}$$

DCDR = Graph((MISTF+MISUF+UDRF) *1.1-(APCONSF+EFFCOMF)) (0.00, 0.00), (10.0, 0.00), (20.0, 0.00), (30.0, 0.00), (40.0, 0.00), (50.0, 0.00), (60.0, 0.00), (70.0, 0.00), (80.0, 0.00), (90.0, 0.00), (100, 0.00) (6)

DPDR = Graph((CGNAPR+DRWAF+INSF) *1.2-(APCONS_F+EFFCOMF) *1.2) (0.00, 0.00), (10.0, 10.5), (20.0, 18.5), (30.0, 20.5), (40.0, 20.5), (50.0, 21.5), (60.0, 23.0), (70.0, 24.5), (80.0, 25.0), (90.0, 25.0), (100, 27.0) (7)

Where:

NCR = Normal construction rate

Delay_Docu_R = Delay rate in documentation

Delay_Complex_Desi_R = Delay rate for complex design

DCDR = Delay variable for complex design

DPDR = Delay variable for production of documents

NCRF = Normal construction rate fraction

MIST F = Mistakes in design rate fraction

MISUF = Misunderstanding of design rate fraction

UDRF = Unclear drawing rate fraction

CGNAPR = Change approval rate fraction

DRWAF = Drawing approval rate fraction

INSF = Inspection rate fraction

APCONSF = Appointment of competent consultant fraction

EFFCOMF = Effective communication fraction

Table 3.   Project variables and simulated scenarios

Project variables	Variable attributes/values	Remarks
Type of project	Residential complex (Apartment)	Obtained from the building project case study.
Maximum project period	4 years (48 months)	
Units of construction duration considered	in days	
Initial estimated construction duration (scheduled period)	775 days	

Table 3.   continued

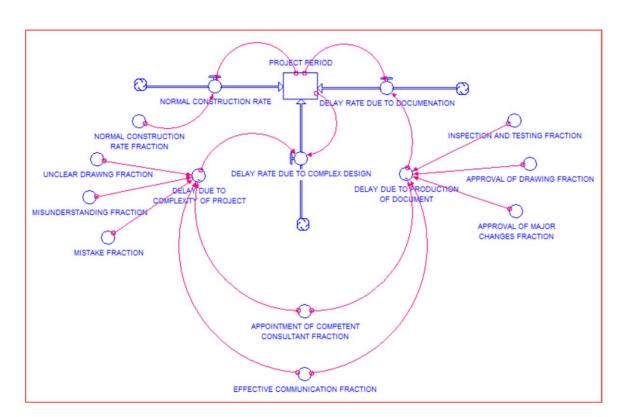| Project variables		Variable attributes/values	Remarks
Construction rate factions			
Normal rate of construction		0.0012 units/day	Obtained from the stakeholders' discussion and historical data of projects.
Initial effective communication fraction		0.0016	Obtained from historical data of projects.
Initial availability of competent consultant factor fraction		0.0011	Obtained from historical data of projects.
Initial rate fractions		0.001-1.0	Based on experts and stakeholders' discussion.
Simulated scenarios			
Scenarios		Simulation variables	Remarks
Normal scenario	BS	Business as usual (normal rate of construction as envisaged during project planning).	Business as usual scenario (following the schedule).
Scenarios causing delay	S1	Delay in production of design documents.	Independent effect.
	S2	Delay due to Complex design.	Independent effect.
	S3	Combination of delay in the production of design document and complex design.	Combined effects considered.
Scenarios of reduction of delay under policy interventions	S4	Effective communication.	Independent effect.
	S5	Appointment of competent consultant.	Independent effect.
	S6	Combination of appointment of competent consultant and effective communication.	Combined effects considered.

Figure 3.   Stock flow diagram (integrated model) for project delays
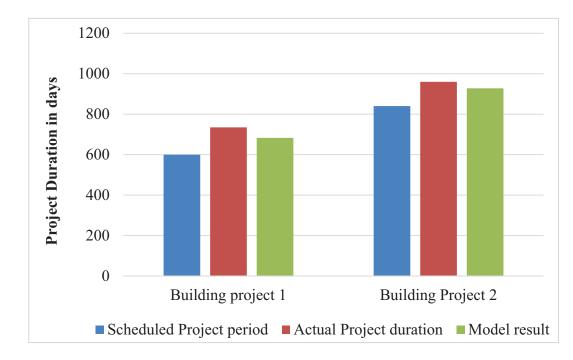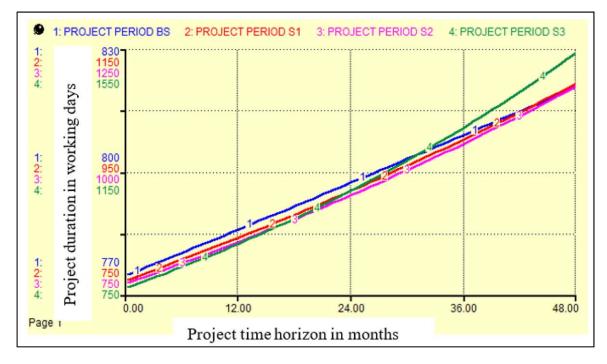

Figure 4.   Comparative project periods as per the original schedule, actual and model results

Model Results and Discussion

The validated model was applied to simulate the progress of a project, in terms of project period, under different simulated scenarios. As shown in [Table 3](), the scenarios were categorised under business as usual, scenarios causing delay, and scenarios under policy/strategic interventions. From several simulations generated under the influence of independent, and combinations of, variables based on the causal feedback relations, seven important scenarios were depicted and considered for discussion. The seven scenarios selected were: (i) business as usual (BS) (ii) delay due to production of design document (S1), (iii) delay due to complex design (S2), (iv) combination of delay in the production of design document and complex design (S4), (v) effective communication (S5), (vi) appointment of competent consultant (S5), and (vii) combination of appointment of competent consultant and effective communication (S6) ([Table 3]()). As shown in [Figure 5](), under the business as usual scenario, if the project runs as planned and no delay occurs because of any reasons whatsoever, the maximum project duration might be exceeded by a maximum of 5.9% of the original estimate, which is marginal. However, such a situation is ideal, which was not happening in the building projects in the cities of India.

[Figure 5]() shows the trend of the project period under business as usual, and delay conditions. [Figure 6]() shows the trend of the project period under the business as usual, worst-case scenario, and policy interventions. In scenario S1, under the conditions of delay in production of design documents, the extended project period would be fairly high (41.29%) compared with the estimated schedule or the ideal case of business as usual. Similarly, under scenario S2, because of complex design, the project period might increase by 51.74%. Furthermore, if a scenario of combined delay in the production of design documents and complex design occurred, as mentioned in scenario S3, the project period would be expected to rise sharply (by 98.84% of the original estimate). Thus, it can be ascertained from these simulated scenarios that, while delay in design documents and complex design independently will cause considerable delay in the construction project, the combined effect is much higher. Therefore, policy interventions are needed to avoid such scenarios.

Figure 5.   **Project period under different simulated delay scenarios of design linked factors**

The trend of project period under policy intervention shows that, if communication is effective (scenario S4), or a competent consultant is appointed (scenario S5), then the rate of delay would be expected to be reduced ([Figure 6](#)). However, the reduction might not be adequate to mitigate the challenges that might occur because of the increase in project period as a result of the combined effect of complex design and delay in the production of design documents.
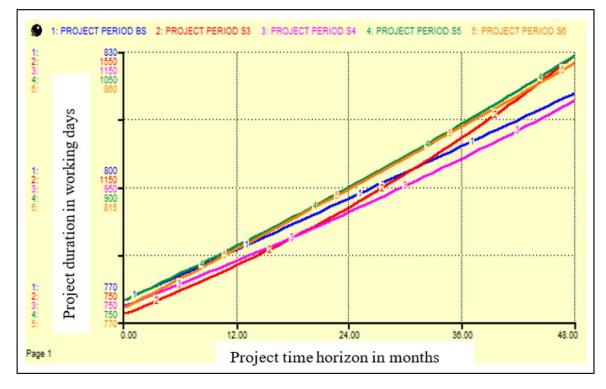

Figure 6.   Project periods under different simulated delay and policy intervention scenarios of design-linked factors

However, scenario S6 indicated that, if a competent consultant is appointed along with the provision of effective communication, then the increase in project period would be restricted significantly (a maximum of 10.45% over the original schedule). The comparative analysis among the seven scenarios indicated that, while delay caused by delay in the production of design documents and complex design independently would be significant, the combined effect could be much worse ([Figure 7](#)). Delay can be limited to 39.09% and 35.10% respectively with respect to the original estimate (reduced by 49.74% and 43.73% from the worst-case scenario) under policy interventions of effective communication and appointment of competent consultants. However, if a policy intervention comprising effective communication and appointment of a competent consultant is implemented, then the delay will be limited to a maximum of 10.45% from the original schedule, which seems to be marginal.
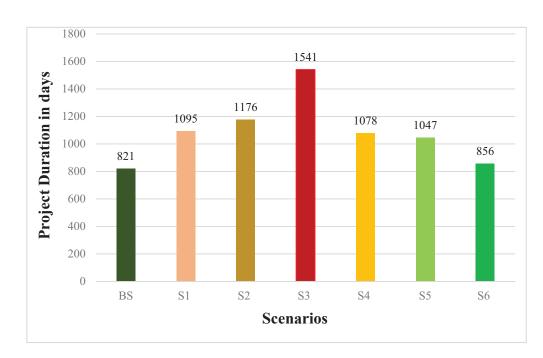
Figure 7. Comparative scenarios of project periods under different simulated scenarios of design-linked factors

Thus, although delay in building projects might happen because of the design-linked factors, policy interventions such as effective communication and appointment of a competent consultant independently or in combination (preferably together) are expected to keep the project period close to the original schedule by limiting the challenges of complex design, mistakes and errors in design, and lack of effective communication affecting construction. Therefore, effective communication and appointment of competent consultants or design teams are the two important strategic interventions that would address the design-linked challenges that lead to delay in building projects, not only in India but in similar contexts in other developing countries.

Conclusion

The various consultant- and design-linked factors that influence the occurrence of delay because of their detrimental impact on project performance, individually or in combination, were examined in this study. SD Modelling was used to map causal relationships among the various factors, to assess the influence of critical variables on the occurrence of delay and to examine how the challenges could be resolved in building projects in India. Before the SD model was developed, the factors influencing the building project period were evaluated using delay indices developed from exploratory survey data obtained from the stakeholders engaged in the building project.

The results indicated that the complexity of the project, unclear and inadequate details in drawings and design, mistakes and discrepancies in design documents, and production of design documents were the design-related factors which influenced delay. Late review and approval of design documents by consultants, delay in approving major changes in the scope of work by consultants, delay in performing inspection and testing by consultants, and poor communication were the significant consultant-related factors. Some of these variables worked through causal feedback mechanisms and caused delay, consequently affecting the total project period or delay.

The results of the simulated scenarios revealed that the complexity of design and delay in producing design documents were the main reasons which increased the project period substantially. Therefore, this requires the use of policy interventions that could handle the complexity of design in tandem with issues concerning design documentation, given the finding that the combined effect of appointing a competent consultant, and effective communication, could address the design-linked challenges appreciably.

The study makes two significant contributions in addition to offering an alternative approach to examine delay. Firstly, the design-linked challenges in construction, based on the causal relations (CLDs) that cause delay, can be diagnosed and appropriate, remedial measures can be developed by the stakeholders, including consultants and design team(s). Secondly, the impacts of different factors and their impact as feedback on delay, and the impacts of different policy and strategic interventions can be visualised quantitatively under different scenarios by the consultant and design team(s) by using the model.

The research limitation was that, although several project actors were surveyed in a particular Province in India, the modelling was done by considering one building project to offer insights into the dynamics of delay caused by design-linked challenges. Also, the scope of the study was limited to consultant- and design-linked factors only and the modelling was done in isolation without considering other aspects of the project, such as clients, contractors, investments, procurement, and environment-related factors. Furthermore, the model was developed by using a limited number of design-linked factors because only the factors which influence delay significantly, as established from the survey results, were considered, albeit without compromising the model's robustness and predicting power.

Appendix 1

Survey questionnaire

Project: Design-linked delay in building projects in India

GENERAL INFORMATION:

The survey questionnaire consists of questions on various aspects related to delay in construction of building projects in India. The results from this survey will be used for academic and research purposes only. No sensitive and personal information is sought. The participation in the survey is voluntary and based on the willingness of the respondents.

Questionnaire ID   Date of survey:

Name of the respondent (optional):   Place of survey:

Company/Affiliation:

Section A: Demographic, academic and professional attributes

Please answer the following questions as relevant (Please fill the response cells in the table below).

Questions No	Question	Response	Questions No	Question	Response
1	Age		2	Gender	
3	Position in the company/ project		4	Academic qualification	
5	Professional qualification if any		6	No of years of experience (Total)	
7	Type of project handled		8	Number of projects handled/ engaged in	
9	Type of current project engaged in		10	Duration of involvement in the current project	
11	No of building projects engaged in		12	Experience in Building projects (in years/ months)	

Section B: Influence of factors on delay in building projects

Please answer the follwong questions based on your actual professional engagement and experience in projects on a scale of 1 to 5, in which 1 = not influential, 2 = less influential, 3 = influential, 4 = significantly influential and 5 = most influential. Please tick (√) the relevant cell in the table below.

Sl No	Factors influence delay	Likert scale points					Remarks
	Consultant related factors	1	2	3	4	5	
C1	Delay in performing inspection and testing.						
C2	Delay in approving major changes in the scope of work.						
C3	Inflexibility (rigidity).						
C4	Poor communication/ coordination between consultant and other parties.						
C5	Late in reviewing and approving design documents.						
C6	Conflicts between consultant and design engineer.						
C7	Inadequate experience of the consultant.						
C8	Lack of site experience of consulting staff.						
C9	Lack of use of advanced technology and software.						
C10	Lack of understanding of environmental impact.						
C11	Inaccurate cost estimation or underestimation .						
	Design related factors						
D1	The complexity of project design.						
D2	Mistakes and discrepancies in design documents.						
D3	Delay in the production of design documents.						
D4	Unclear and inadequate details in drawings.						
D5	Insufficient data collection and survey before design.						
D6	Misunderstanding of owner's requirements by the design engineer.						
D7	Quality assurance and control.						
D8	Inconsistency and incomplete technical specifications.						
D9	Insufficient data for design.						

Section C: Plausible remedial measures to reduce delay (open-ended questions)

1. Please mention what delay challenges you have experienced in the projects you have handled and what remedial measures you or your company have undertaken to meet the challenges (Please write in the space below).

2. Please mention what design-linked challenges you have experienced and what mitigation strategies you or your company have taken (Please write in the space below).

3. According to your opinion, what strategies are important to reduce design-linked delay in building projects (Please write in the space below).

4. Any other information relating to resolving design-linked delay in building projects.

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