

A MATRIX-BASED FRAMEWORK FOR MODELING CHANGES ACROSS MULTIPLE ENTITY TYPES IN CONSTRUCTION PROJECTS

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INDIAN INSTITUTE OF TECHNOLOGY DELHI
AUGUST 2020**

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by

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

AUGUST 2020

This thesis is dedicated to

My Wife, Children, and Parents

CERTIFICATE

This is to certify that the thesis titled “**A Matrix-Based Framework for Modeling Changes Across Multiple Entity Types in Construction Projects**”, being submitted by **Mr S P Sreenivas Padala** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirements for submission of this thesis, which to our knowledge has reached the requisite standard.

The contents of this thesis have not been submitted either in part or in full, to any other University or Institute for the award of any degree or diploma.



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ACKNOWLEDGEMENTS

First of all, I would like to express my deep gratitude to my supervisors, Dr. J Uma Maheswari, Department of Civil Engineering and Prof. Harish Hirani, Department of Mechanical Engineering for their thoughtful guidance, immense knowledge, and enthusiastic encouragement, which made me capable of undertaking this exciting but challenging journey.

I am also grateful to my honorable student research committee members, Prof. Rakesh Khosa and Prof. K. C. Iyer, Department of Civil Engineering, Prof. P. V. Madhusudhan Rao, Department of Mechanical Engineering for their encouragement and insightful comments, and also for the criticism that encouraged me to widen my research from various perspectives.

I express my heartfelt thanks to Mr. Ratnesh Kumar, Dr. Purva Mujumdar, Mr. Santu Kar, and my fellow research scholars for their valuable inputs and continuous support.

I wish to thank several industry practitioners for offering their time and sharing data to understand the existing practice, to conduct case studies, and also for providing feedback on my research work. I am especially thankful to Mr. Sachin Sain, Interface manager, Mr. Anshul Goyal, planning manager, Mr. Prasanna kumar, Senior structural design manager, Mr. Shobit Dixit, senior architect, Mr. Dhermender, senior planning engineer, Mr. Prasanth Kumar, site execution in – charge, Mr. Rajender, architect of Larsen and Toubro Limited. Mr. Amit Chandan, assistant executive engineer and Mr. Pradeep Singh assistant executive engineer of Employees State Insurance Corporation (ESIC) Limited. Mr. Lal Kishan, assistant manager and Mr. Shamim Ahmad, chief architect, Delhi metro railway corporation (DMRC). Mr. Harsimran Singh of Tandon Consultants Private Limited, Mr. Jai Saraswat of Design Associates Private Limited. Mr. Siraj Ahmed and Mr. Mayank Varshney of NKG Infrastructure Limited. Mr. Shrinath Tandur, FBA Consulting India Private Limited.

Special thanks to Dr. Sean T Regan, President International Operations, OnTrack Engineering, Dr. Laurie Bowman, Principal, Synchrony for providing insights on international practices in change management.

I appreciate the efforts of My father, Mr. Prasada Rao, mother, Mrs. Santhi, and my brother Mr. Vamsi Krishna for their spiritual support. I also extend special gratitude to my father in law Mr. K M Chidananda, mother in laws Mrs. V Laxmi, Mrs. Roja kumari, Mrs. Saraswati who encouraged me to work hard.

Lastly, I owe my utmost sincere gratitude to my beloved wife Mrs. K M Manjuvani who always stood beside me and motivated me in achieving my dreams. I am in debt to my daughter Diva Aashrathi and my son Mahesh Aaryan for keeping me charming and happy always.

A handwritten signature in blue ink on a yellow rectangular background. The signature reads "P Sreenivas..".

S P Sreenivas Padala

ABSTRACT

Changes are inevitable in a construction project, and they can occur for various reasons. Such changes can cause severe disruptions, however, and in particular they can impact a construction project's time, costs, and other aspects such as labour productivity, safety, and working relationships. Change management in construction is an essential aspect of project management. A key challenge in change management is to identify changes and predict their impacts before their implementation so that the negative impacts of changes can be minimized. However, the large variety of entity types such as teams, components, deliverables, activities and parameters, as well as the complex interdependencies that exist among these entity types, makes it difficult to predict change impacts. Changes made to any type of entity are likely to propagate to others. It is necessary to be aware of not only individual change impacts but also complex change propagations and their impacts across entity types. Hence, the overall objective of the research is to develop a framework for modeling changes across multiple entity types in construction projects.

The literature review reveals that existing methods lack a structured approach for early change identification and that these methods are limited to predicting changes and their impacts in single entity type only. Certain studies have recognized the need for multi-entity modeling; however, these studies are limited to the classification and generation of propagation paths, and they lack a quantitative approach to quantify change propagations. Further, the exploratory case study reveals that practitioners also find it difficult to predict change impacts because techniques and tools used for the design and construction planning of projects do not facilitate the quantification of change impacts across entity types prior to change implementation. Hence, there is a need for a modeling framework to manage changes proactively.

The proposed change-prediction framework integrates two matrix-based modeling methods: axiomatic design (AD) and a multiple domain matrix (MDM). The framework consists of three

major segments: 1) identification of changes, 2) the tracking of change propagations, and 3) estimation of change propagation impacts. Initially, relationships between functional requirements and design parameters must be modeled and analyzed using AD to finalize the entity types. When any change in functional requirement is initiated, changes in entity types can be identified in a structured manner. Next, the interrelationships of entity types must be modeled in the MDM to track change propagations. A quantitative approach is proposed to quantify changes in terms of time at parameter level in the MDM. Further, change impacts on other entity types are estimated semi-automatically from the revised durations of parameters in the MDM.

An abductive-based case study research method has been adopted to develop the existing theory in change prediction research. The research method is divided into three parts: problem formulation, framework development, and validation. In Part 1, a literature review is conducted to identify research gaps. An exploratory case study was conducted across 19 different projects to investigate the existing practice and identify the root causes of changes. A semi-structured interview was conducted with 67 industry experts to understand the problems on managing changes in the entire construction project life cycle. The research problem is formulated by triangulating the findings of the literature review and the exploratory case study. In Part 2, a change prediction framework is developed based on a comprehensive set of requirements which are identified from the literature review and validated from industry experts. Further, case studies of eight different projects were conducted to explore selected matrix-based modeling methods: AD and the MDM. In Part 3, the proposed framework is validated using data from three ongoing construction projects – multi-story residential apartment, underground metro, and hospital building. The validation reveals that the proposed framework is quite useful in minimizing errors during the implementation of changes. Further, a roadmap for implementing the proposed framework is also presented.

Overall, the proposed change prediction framework can aid design and construction stakeholders to identify, schedule and quantify changes proactively across multiple entity types in a construction project.

Keywords: Changes, Change management, Change propagations, Axiomatic design, Multiple domain matrix.

विभिन्न कारणों के कारण एक निर्माण परियोजना में परिवर्तन अटल हैं। इस तरह के परिवर्तन गंभीर व्यवधान पैदा कर सकते हैं, हालांकि, और विशेष रूप से वे एक निर्माण परियोजना के समय, लागत, और अन्य पहलुओं जैसे कि श्रम उत्पादकता, सुरक्षा और कामकाजी संबंधों को प्रभावित कर सकते हैं। निर्माण में परिवर्तन प्रबंधन परियोजना प्रबंधन का एक अनिवार्य पहलू है। परिवर्तन प्रबंधन में एक महत्वपूर्ण चुनौती परिवर्तनों को पहचानने और उनके कार्यान्वयन से पहले उनके प्रभावों की भविष्यवाणी करना है ताकि परिवर्तनों के नकारात्मक प्रभावों को कम से कम किया जा सके। हालांकि, विभिन्न प्रकार की इकाई जैसे कि दल, घटक, डिलिवरेबल्स, गतिविधियाँ और पैरामीटर, साथ ही साथ इन इकाई के बीच मौजूद जटिल अन्योन्याश्रितियाँ, परिवर्तन प्रभावों की भविष्यवाणी करना मुश्किल बनाती हैं। किसी भी प्रकार की इकाई में किए गए परिवर्तन दूसरों के प्रचार की संभावना रखते हैं। न केवल व्यक्तिगत परिवर्तन प्रभावों बल्कि जटिल परिवर्तन प्रसार और उनके प्रकारों पर भी प्रभाव पड़ता है, इसके बारे में जागरूक होना आवश्यक है। इसलिए, अनुसंधान का समग्र उद्देश्य निर्माण परियोजनाओं में कई इकाई प्रकारों में मॉडलिंग परिवर्तन के लिए एक रूपरेखा विकसित करना है।

साहित्य की समीक्षा से पता चलता है कि मौजूदा तरीकों में शुरुआती बदलाव की पहचान के लिए एक संरचित दृष्टिकोण की कमी है और ये विधियाँ केवल एकल इकाई प्रकार में परिवर्तन और उनके प्रभावों की भविष्यवाणी करने तक सीमित हैं। कुछ अध्ययनों ने बहु-इकाई मॉडलिंग की आवश्यकता को मान्यता दी है; हालाँकि, ये अध्ययन प्रसार पथों के वर्गीकरण और पीढ़ी तक सीमित हैं, और उनमें परिवर्तन के प्रसार को निर्धारित करने के लिए मात्रात्मक दृष्टिकोण का अभाव है। इसके अलावा, खोजपूर्ण मामले के अध्ययन से पता चलता है कि व्यवसायी को भी परिवर्तन प्रभावों की भविष्यवाणी करना मुश्किल लगता है क्योंकि परियोजनाओं के डिजाइन और निर्माण की योजना के लिए इस्तेमाल की जाने वाली तकनीक और उपकरण कार्यान्वयन को बदलने से पहले इकाई प्रकारों में परिवर्तन प्रभावों की मात्रा निर्धारित करने की

सुविधा नहीं देते हैं। इसलिए, निश्चित रूप से परिवर्तनों का प्रबंधन करने के लिए एक मॉडलिंग ढांचे की आवश्यकता है।

प्रस्तावित परिवर्तन-भविष्यवाणी ढांचा दो आव्यूह -आधारित मॉडलिंग विधियों को एकीकृत करता है: स्वयंसिद्ध डिजाइन (AD) और एक एकाधिक ज्ञानक्षेत्र आव्यूह (MDM)। रूपरेखा में तीन प्रमुख खंड होते हैं: 1) परिवर्तनों की पहचान, 2) परिवर्तन प्रसार पर नज़र रखना, और 3) परिवर्तन प्रसार प्रभावों का अनुमान। प्रारंभ में, कार्यात्मक आवश्यकताओं और डिज़ाइन मापदंडों के बीच संबंधों को इकाई प्रकारों को अंतिम रूप देने के लिए AD का उपयोग करके मॉडलिंग और विश्लेषण किया जाना चाहिए। जब कार्यात्मक आवश्यकता में कोई परिवर्तन शुरू किया जाता है, तो इकाई प्रकारों में परिवर्तन की पहचान संरचित तरीके से की जा सकती है। अगला, परिवर्तन के प्रसार को ट्रैक करने के लिए इकाई प्रकारों के अंतर्संबंधों को एमडीएम में मॉडल किया जाना चाहिए। एमडीएम में पैरामीटर स्तर पर समय के संदर्भ में परिवर्तन की मात्रा निर्धारित करने के लिए एक मात्रात्मक दृष्टिकोण प्रस्तावित है। इसके अलावा, अन्य इकाइयों के प्रकारों में परिवर्तन का प्रभाव एमडीएम में मापदंडों के संशोधित अवधि से अर्द्ध-स्वचालित रूप से अनुमानित है।

परिवर्तन भविष्यवाणी अनुसंधान में मौजूदा सिद्धांत को विकसित करने के लिए एक अपहरण-आधारित केस स्टडी अनुसंधान विधि को अपनाया गया है। शोध पद्धति को तीन भागों में बांटा गया है: समस्या निर्माण, रूपरेखा विकास और सत्यापन। भाग 1 में, अनुसंधान अंतराल की पहचान करने के लिए एक साहित्य समीक्षा की है। मौजूदा अभ्यास की जांच करने और परिवर्तनों के मूल कारणों की पहचान करने के लिए 19 विभिन्न परियोजनाओं के दौरान एक खोजपूर्ण मामले का अध्ययन किया गया। पूरे निर्माण परियोजना के जीवन चक्र में परिवर्तन के प्रबंधन पर समस्याओं को समझने के लिए 67 उद्योग विशेषज्ञों के साथ एक अर्ध-संरचित साक्षात्कार आयोजित किया गया। शोध समस्या की समीक्षा साहित्य समीक्षा के निष्कर्षों और खोजपूर्ण केस अध्ययन को तैयार करके की है। भाग 2 में, आवश्यकताओं की एक व्यापक

सेट के आधार पर एक परिवर्तन भविष्यवाणी रूपरेखा विकसित की है जिसे साहित्य समीक्षा से पहचाना और उद्योग के विशेषज्ञों से मान्य किया है। इसके अलावा, चयनित आव्यूह -आधारित मॉडलिंग विधियों का पता लगाने के लिए आठ अलग-अलग परियोजनाओं के मामले का अध्ययन किया गया: एडी और एमडीएम। भाग 3 में, प्रस्तावित ढांचे को तीन चल रही निर्माण परियोजनाओं - मल्टी-स्टोरी आवासीय अपार्टमेंट, भूमिगत मेट्रो और अस्पताल भवन से डेटा का उपयोग करके मान्य किया गया है। सत्यापन से पता चलता है कि प्रस्तावित रूपरेखा परिवर्तनों के कार्यान्वयन के दौरान त्रुटियों को कम करने में काफी उपयोगी है। इसके अलावा, प्रस्तावित रूपरेखा को लागू करने का एक रोडमैप भी प्रस्तुत किया गया है।

कुल मिलाकर, प्रस्तावित परिवर्तन भविष्यवाणी रूपरेखा डिजाइन और निर्माण हितधारकों को एक निर्माण परियोजना में कई इकाई प्रकारों में परिवर्तन की पहचान, अनुसूची और मात्रा निर्धारित करने में सहायता कर सकती है।

कुंजी शब्द: परिवर्तन, परिवर्तन प्रबंधन, प्रचार परिवर्तन, स्वयंसिद्ध रचना, एकाधिक ज्ञानक्षेत्र आव्यूह।

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LISTS OF ABBREVIATIONS

AD	Axiomatic Design
ADVICE	Active Distributed Virtual Change Environment
ASM	Affordance Structure Matrix
BIM-CQM	BIM-based change impact quantification model
BIM	Building information modeling
BIM-CTM	BIM-based change tracking model
CAD	Computer-aided design
C-FAR	Change Favorable Representation
CI	Change impact
CL	Change likelihood
CMM	Change Modeling Method
CPL	Change propagation likelihood
CPM	Change prediction method
CPP	Change propagation path
CPR	Cumulative change propagation risk
CPS	Change prediction system
DCR	Direct construction risk
DDR	Direct design risk
DMM	Domain Mapping Matrix
DP	Design parameter
DPCM	Design Process Change Method
DPM	Dynamic Planning and control Methodology
DPR	Detailed project report
DR	Direct risk
DSM	Design Structure Matrix
ECMS	EC management system
EIR	Employer information requirement
FACP	Functional Analysis of Change Propagation

FBS	Function–behaviour–structure linkage method
FR	Functional requirement
GFC	Good for construction
HoQ	House of quality
HVAC	Heat, ventilation, and air conditioning
ICMS	Integrated Change Management System
ICPSM	Integrated change propagation scheduling model
IFR	Intermediate functional requirement
IM	Information Model
IM-2	Information model
IT	Information technology
MDM	Multiple Domain Matrix
MGPS	Medical gas pipeline system
MNM	Multilayer network model
nFR	non-functional requirement
OBS	Organization breakdown structure
ABS	Activity breakdown structure
PCM	Project Connectivity Model
PLN	Parameter linkage network
PR	Propagation risk
RDIT	ReDesignIT
QFD	Quality function deployment
REDM	The Risk in Early Design Method
RRM	Rapid Redesign Methodology
TAD	Total additional duration
TVS	Tunnel ventilation system
STEP	Standard for the Exchange of Product
WBS	Work breakdown structure
WP	Work package