TACIT KNOWLEDGE SHARING IN CONSTRUCTION: A SYSTEM DYNAMICS APPROACH

By

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THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by Mr. Muhammad Bilal Tahir, Registration No. NUST2017MSCE&M0900000205651, of NIT-SCEE has been vetted by undersigned, found complete in all respects as per NUST Statutes / Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfilment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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Date: _______________________________________

This thesis is dedicated to my parents and respected teachers!

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In the name of Almighty Allah, the most Merciful, the Beneficent. All praise is only for Allah who created us and always planned the best for us. I am grateful to the Almighty Allah for His countless blessings and mercy bestowed upon me through the difficulties of life and I seek His guidance, and pray to Him for blessings and ease throughout this life and the life to come. I am in debt of gratitude to my research supervisor Dr.Khurram Iqbal Ahmad khan for his guidance, motivation and constant encouragement throughout this journey. I sincerely appreciate the valuable time and personal support accorded by him. I am also extremely grateful to the committee members, Dr. Abdur Rehman Nasir and Lec. Muhammad Hussnain for their sincere guidance to complete this research work.

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Abstract

Most of the knowledge in construction industry is tacit rather than explicit, and its sharing is imperative for enhanced project performance. Tacit Knowledge Sharing (TKS) is heavily influenced by an array of human factors such as behaviour, attitude, skills, experience, personal contact and interaction. These factors interact in multiple ways resulting in positive as well as negative loops for TKS, leading towards complexity. The purpose of this study is to examine the role of TKS in developing countries and thereafter, develop a System Dynamics (SD) model for addressing aforementioned complexity. The study delineates the interrelations between nineteen shortlisted contributing factors of TKS using systems thinking and causal loop diagram (CLD). In total, CLD encompassed four reinforcing and two balancing loops. Furthermore, CLD was used to develop a SD model that contained four stocks. An additional stock named as TKS was incorporated to visualize the combined effect of all stocks. The model was simulated over a period of five years and results indicated increase in TKS efficiency under the defined system and hence improvement in construction project performance. The resultant CLD and SD model reflect the systems thinking and behaviour over time for TKS in construction. The study adopts a novel methodology in form of SD for holistically addressing the construction culture to be favourable for TKS and thereby improving construction project performance.

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List of Acronyms

- KM Knowledge Management
- EK Explicit Knowledge
- TK Tacit Knowledge
- TKS Tacit Knowledge Sharing
- SD System Dynamics
- CI Construction Industry
- IT Information Technology

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Chapter -1

INTRODUCTION

1.1. Study Background

Construction industry is knowledge intensive and common knowledge can help organizations to gain competitive advantage through integrated knowledge approach. The primary role of organizations is to integrate specialized knowledge of individuals in to goods and services (Grant, 1996).

Significant amount of research has been carried out regarding knowledge management (KM) in developed countries. Research on knowledge management can be divided in to three phases (Yu and Yang, 2018);

1. First stage is from 1995 to 2004 where less than ten papers were published per year. Major topics under discussion were knowledge management system (e.g. knowledge based decision support system for contractors pre-screening (Taha et al., 1995)), KM skills (e.g. productivity adjusted schedule using knowledge based approach (Mohamed, 2001)), knowledge generation and acquisition (e.g. tracing and tracking information for research in construction management (Palaneeswaran and Kumaraswamy, 2003)).

2. Second stage is from 2005 to 2011 where dozens of papers were published per year. Major topics under discussion were ontology (e.g. role of semantic web for knowledge management (Svetel and Pejanović, 2010)), tacit knowledge (e.g. tacit knowledge in construction (Styhre, 2009)), knowledge learning and sharing, safety knowledge management system, KM modelling, value and performance.

3. Third stage started from 2012 where 20 papers were published in 2012 and 2013, 16 were published in 2014. Papers in 2015 were only 9 because data was taken only up till august, 2015. Major topics under discussion were building information modelling (BIM) and big data technology (e.g. BIM based knowledge management (Lin, 2014)), KM processes (e.g. knowledge based simulation of construction processes (Akhavian and Behzadan, 2014)), social techniques and collaborative KM.

Talking specifically about tacit knowledge from 2014 to present, majors topics covered are tacit knowledge sharing and transferring (e.g. model for trust, collaborative and tacit knowledge sharing culture in project management (Kucharska and Kowalczyk, 2016), enterprise tacit knowledge sharing stimulation system (Jin-Feng et al., 2017) and critical factors for tacit knowledge sharing and transferring within lean and agile construction (Saini et al., 2018)).

In this work, we will first determine the contributing factors of tacit knowledge for improved productivity and performance in construction followed by developing systems thinking based upon relative influence/impact of these factors towards productivity and performance in construction. Based upon identified factors and systems thinking, a system dynamics model will be developed.

1.2. Problem Statement

1. Most of the knowledge in construction is tacit rather than explicit (Abu Bakar et al., 2016), and its sharing is imperative for enhanced project performance (Pathirage et al., 2007) whereas companies investment in information technology mainly focuses on explicit knowledge, leaving tacit knowledge behind (Johannessen et al., 2001).
2. Tacit knowledge sharing is influenced by an array of human factors (Hau et al., 2013, Mohajan, 2017, Zhang and He, 2015), which interact in multiple ways, resulting in positive as well as negative loops, leading towards complexity (Yu-Jing, 2012).
3. There is a need to address aforementioned complexity using system dynamics approach, to delineate systems thinking as well behaviour over time of tacit knowledge sharing in construction.

1.3. Research Objectives

1. To identify contributing factors of tacit knowledge sharing in construction.
2. To develop causal loop diagram for tacit knowledge sharing in construction.
3. To develop system dynamics model for addressing complexity associated with tacit knowledge sharing in construction along with its validation.

1.4. Research Significance

There is a need to utilize experience and expertise of construction professionals, and lessons learned from construction projects. However, there is generally lack of effective knowledge management creating complexity. Knowledge management, in particular, tacit knowledge is pivotal for improving project's productivity and performance pertinent to construction sector of developing countries including Pakistan. Good knowledge management improves chances of project success because success of project management is directly linked with it (Levin, 2010).

In construction industry, most of the knowledge is tacit rather than explicit (Abu Bakar et al., 2016). Therefore, it is of ultimate significance to know contributing factors of tacit knowledge leading to improved productivity and performance in construction projects. The idea is to develop a system dynamics model by making use of contributing factors and systems thinking.

System Dynamics (SD) is an approach employed for understanding nonlinear behavior of complex systems over time via internal feedback loops, table functions and time delays (Sapiri et al., 2017). This was proposed in 1956 by professor Forrester of Massachusetts Institute of Technology (MIT) and became a separate subject in late 1950's (Forrester, 2007). The SD method is a simulation method also called SD simulation method which comprises of three elements; system, model and computer (Yu-Jing, 2012).

Construction projects consist of multiple complex interactive elements, nonlinear relationships, multiple positive as well as negative feedback loops and also there is coexistence of both soft (human based) and hard (technical based) data (Yu-Jing, 2012). SD takes all of these complex and nonlinear aspects into consideration (Yu-Jing, 2012) and this was the motivation behind selection of SD approach for this research.

Most of the knowledge is tacit rather than explicit in construction industry (Abu Bakar et al., 2016) so study of tacit knowledge, its contributing factors and corresponding project performance is purely related to construction industry.

1.5. Advantages

1. Success of project management is directly linked with knowledge management, good knowledge management improves chances of project success (Levin, 2010).
2. Projects within an organization can benefit directly from integrated common knowledge approach, the idea is to preserve the knowledge held by individuals (Grant, 1996).
3. Tacit Knowledge is considered to be more important than explicit knowledge (Styhre, 2009), effective knowledge management can help organizations to get benefit from tacit knowledge which is purely individual based knowledge.

1.6. Scope of Research

Knowledge management can be applied at different levels (Levin, 2010), such as;

1. Project level
2. Program level
3. Enterprise project management office (EPMO) level
4. Functional levels of organizations
5. Enterprise level

The idea of knowledge management is to use knowledge through integration which is not common between them (Grant, 1996). Knowledge management as a whole is directly linked with project management and improves chances of project success (Levin, 2010).

The focal point of research is tacit knowledge related to project-based construction industry and main sources of knowledge in construction industry are lessons learned, experiences and interactions alongside recorded documents (Rezgui et al., 2010). Lessons learned, experiences and interactions are all tacit aspects of knowledge which will be addressed by this research.

Chapter – 2

LITERATURE REVIEW

2.1. Introduction

The current chapter provides literature review regarding knowledge management with a specific focus on tacit knowledge. It discusses the research carried out on knowledge management, in particular, tacit knowledge. Moreover, it summarizes earlier efforts carried out on tacit knowledge in construction industry with reference to developing a system dynamics model which is the goal of this research.

2.2. Knowledge Management

2.2.1. Data

Data or more accurately datum is a value which itself has no meaning but when put in a context, it gives meaning (Cooper, 2017).

2.2.2. Information

Information is more refined form of data which has been given meaning and is useful but does not necessarily have to be (Bellinger et al., 2004).

2.2.3. Knowledge

Knowledge can be defined as the relevant and actionable information which is at least partially based on some experience (Leonard and Sensiper, 1998). Knowledge can answer question of "how" (Cooper, 2017) and it is the collection of information which is intended to be useful i.e. deterministic process (Bellinger et al., 2004). Knowledge consists of two major elements; explicit knowledge and tacit knowledge (Styhre, 2009). Knowledge and information are often used interchangeably which is a misconception, knowledge is extracted from information and information is processed from data (Pathirage et al., 2007).

2.2.4. Understanding

It is an interpolative, probabilistic, cognitive and analytical process which allows to take knowledge and synthesize new knowledge from previously knowledge undertaken (Bellinger et al., 2004).

2.2.5. Wisdom

It is a an extrapolative, non-deterministic and non-probabilistic process (Bellinger et al., 2004) which includes knowledge in an ethical and moral way which aims to separate good and bad (Cooper, 2017).

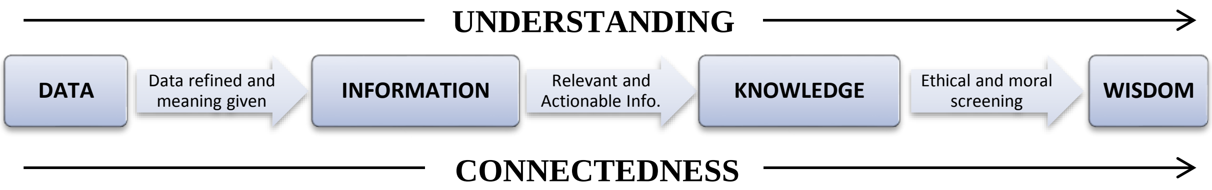

Figure 1: Data, Information, Knowledge, Understanding and Wisdom

Source: (Cooper, 2017, Bellinger et al., 2004)

2.2.6. Knowledge Management

It is a process of developing, storing, retrieving and disseminating the information and the expertise which can be used for improving the efficiency and performance of an organisation (Gupta et al., 2000, Girard, 2015). In developed countries, knowledge management research has significantly blossomed in last more than two decades (Yu and Yang, 2018). Knowledge management is important for knowledge intensive organisations such as construction industry (Gupta et al., 2000). Knowledge management can be broadly classified as objectivist and practice based knowledge management (Addis, 2016).

2.2.7. Explicit Knowledge

Explicit knowledge is available in the documented form such as drawings, specifications and risk analysis etc. (Abu Bakar et al., 2016).

2.2.8. Tacit Knowledge

Tacit knowledge is the knowledge which human beings develop over the period of time through experiences, lessons learned etc. and it lies in the heads of the individuals (Ribeiro, 2013). It is based upon experience and expertise of construction professionals, the company culture, from lessons learned and know how, as well as other abstract sources (Lin et al., 2005). In organizations, the tacit knowledge is considered more valuable than the explicit knowledge (Yu and Yang, 2018). Therefore, most of the knowledge in construction industry is tacit rather than explicit (Abu Bakar et al., 2016).

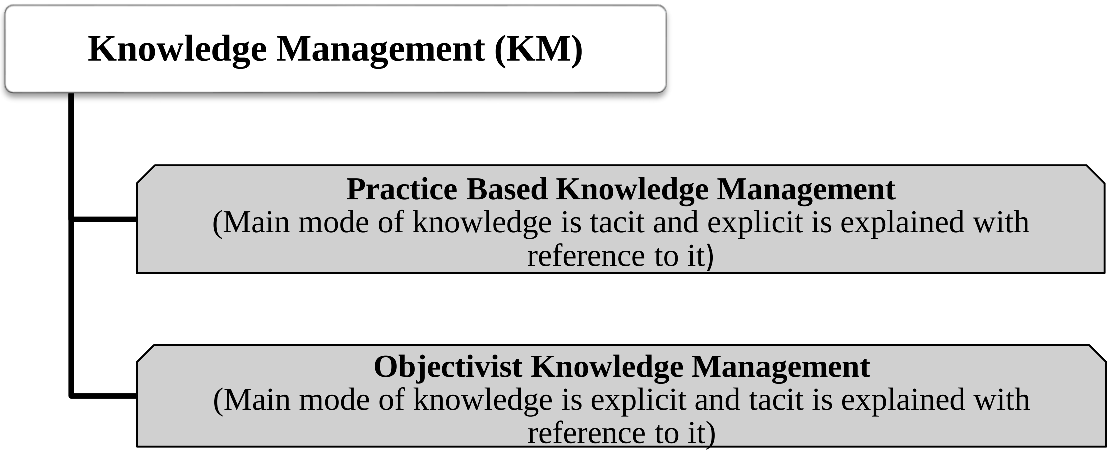

Figure 2: Knowledge Management classification and dominating knowledge types

Source: (Addis, 2016)

2.3. Tacit Knowledge

2.3.1. Overview

Tacit knowledge as compared to explicit knowledge is relatively unexplored and not understood although it is associated with many disciplines by many authors (Pathirage et al., 2007). Explicit knowledge consists of only a small portion of construction knowledge as compared to tacit knowledge (Addis, 2016). Dealing with tacit knowledge management is not easy and it imposes limitations especially on objectivist aspect of knowledge management (Addis, 2016). Furthermore, there is a complexity as well as diversity associated with tacit knowledge and it's a matter of debate in literature that what should be treated as tacit knowledge and the characteristics of the concept behind (Addis, 2016).

There are two schools of thought regarding what is tacit and what is explicit knowledge. First school of thought says that there is a codification or verbalization barrier between tacit and explicit knowledge (Ribeiro, 2013). Second school of thought says that tacit and explicit are two ends of the same coin and explicit knowledge originate from tacit knowledge in terms of understanding and application (Ribeiro, 2013).

2.3.2. Types of Tacit Knowledge

Based upon different roles of human body and brain, Collins divides tacit knowledge into two distinct type i.e. Somatic-limit tacit knowledge and Collective tacit knowledge (Collins, 2007). Somatic-limit tacit knowledge is further classified into somatic and contingent tacit knowledge based upon their nature and ability to be codified (Ribeiro, 2013). Therefore, tacit knowledge can be broadly classified into following three types based upon their nature, ability to be codified and different roles played by human body and brain. These knowledge types do not have entirely different causes but consequences are completely different (Collins, 2007).

1) Somatic Tacit Knowledge
2) Contingent Tacit Knowledge
3) Collective Tacit Knowledge

2.3.2.1. Somatic Tacit Knowledge

Somatic tacit knowledge comes with the interaction with the physical world and the only way to develop such knowledge is through interaction with the subject matter (Ribeiro, 2013). It is limited by capacity as well as capabilities of human brain and body which Collins termed Somatic-limit tacit knowledge (Collins, 2007). Such type of knowledge may or may not be codified (Ribeiro, 2013).

2.3.2.2. Contingent Tacit Knowledge

Contingent tacit knowledge is rooted in the practices of a form of life and is responsive to codification (Ribeiro, 2013). It is a knowledge which people are consciously or unconsciously using which is known to them as something that works (Ribeiro, 2013).

2.3.2.3. Collective Tacit Knowledge

Collective tacit knowledge is purely nonresponsive to codification and is individual based which enables them to make decisions or perform actions through understanding of social context (Ribeiro, 2013, Collins, 2007). Development of such type of knowledge in an individual is directly linked with becoming a member of the given form of life (Ribeiro, 2013).

Collective tacit knowledge can help to perform three types of judgements namely; judgement of similarity/difference, judgement of relevance/irrelevance and judgement of risk (Ribeiro, 2013). A person with the right know how of the social context for a given form of life can perform these judgements correctly.

With reference to projects, somatic and contingent form of tacit knowledge lies in the preoperational phase of the project while collective tacit knowledge lies in execution phase of project (Ribeiro, 2013). Three types of tacit knowledge and their location in vicinity is demonstrated in figure 3.

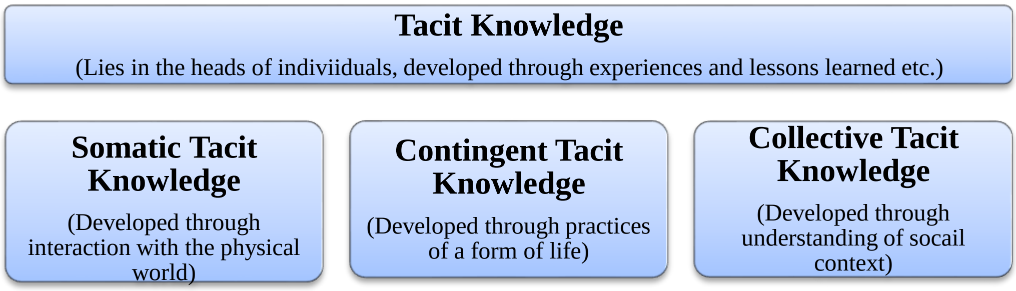

Figure 3: Tacit Knowledge and their types

Source: (Ribeiro, 2013, Collins, 2007)

2.3.3. Knowledge Classification in Construction Domain

As we move from industry level to organisational level and further to project level, the nature of knowledge also shifts from explicit to tacit (Rezgui et al., 2002). Knowledge in construction can be divided into following three forms (Rezgui et al., 2002);

1) Domain Knowledge
2) Organisational Knowledge
3) Project Knowledge

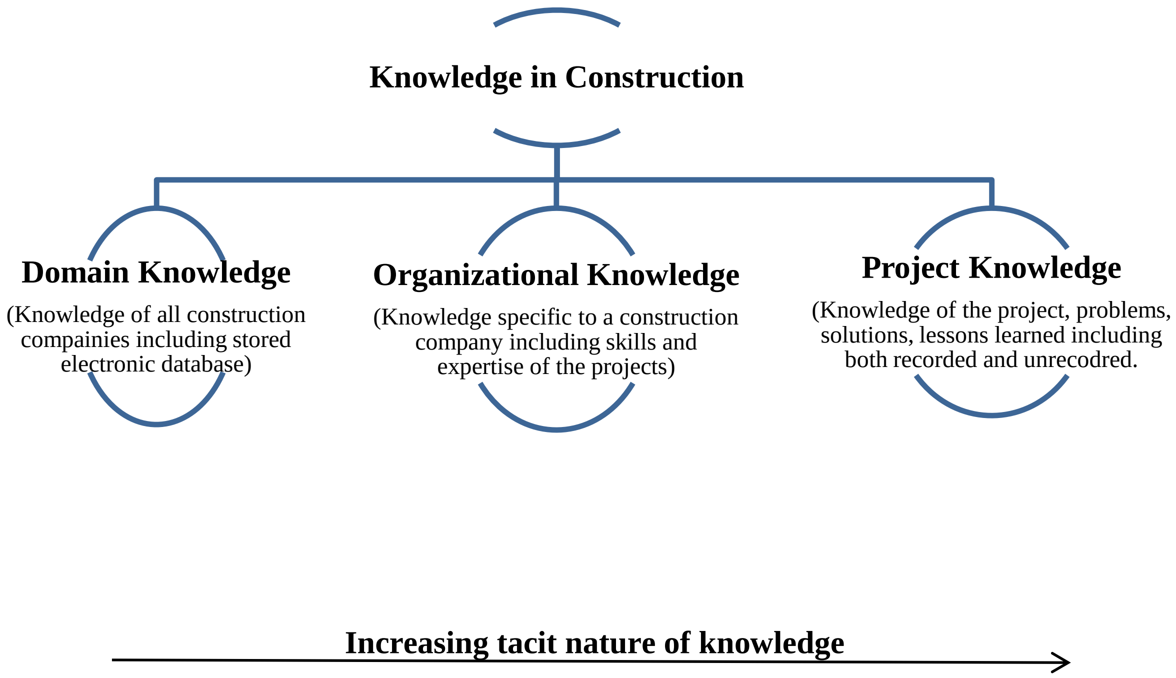

Figure 4: Knowledge Classification in Construction

Source: (Rezgui et al., 2002)

2.3.4. Importance of Tacit Knowledge in Construction

Companies invest in information technology (IT) for preservation of explicit knowledge and less attention is paid to the tacit knowledge which ultimately leads to the mismanagement of tacit knowledge (Johannessen et al., 2001). Tacit knowledge plays a key role in developing sustainable competitive advantage in companies and ignoring it can be self-destructive (Johannessen et al., 2001).

Pertinent to construction industry, following three points highlight the significance of tacit knowledge in a very concise way (Pathirage et al., 2007);

1) Most of knowledge in construction industry rests in the minds of the individuals working on a project.
2) Decisions are made regularly on construction sites but intent behind those decisions is hardly recorded.
3) On a project based construction industry, most of the workforce leaves the project after completion of the project which results in loss of intellectual capital (tacit knowledge).

For labour intensive industries such as construction industry, peoples are always the most important resource and they are difficult to manage too in terms of preservation of their skills and experience (Pathirage et al., 2007). Construction industry relies heavily on skills as well capabilities of individual worker to bring a successful project (Druker et al., 1996). Performance of construction industry greatly is compromised when people factor is ignored (Egan, 1998). Hence the people factor and people cantered approach which is often overlooked is absolutely essential in construction industry as knowledge, skills and behaviour contributes to superior performance (Pathirage et al., 2007).

2.3.5. System Dynamics and TKS Complexity in Construction

System Dynamics (SD) is an approach employed for understanding nonlinear behaviour of complex systems over time via internal feedback loops, table functions and time delays (Sapiri et al., 2017). This approach was proposed in 1950's by Forrester of Massachusetts Institute of Technology (MIT) and has evolved into a subject since then (Forrester, 2007). The SD method, also called SD simulation method, comprises three elements: system, model and computer (Yu-Jing, 2012).

Construction projects consist of multiple complex interactive elements, nonlinear relationships, feedback loops (both positive and negative), and also there is coexistence of soft (human-based) and hard (technical-based) data (Yu-Jing, 2012). The coexistence of hard data (written specifications, plans, drawings etc.) as well as soft data (human emotions, ability, skill etc.) and their interaction amongst them in multiple ways results in complexity. Tacit Knowledge Sharing (TKS) in construction is directly influenced by human factors such as personal contact, interaction, communication, experience, attitude, knowledge and skills (Mohajan, 2017, Nesan, 2012, Zhang and He, 2015). These human factors interact in multiples ways resulting in positive as well as negative loops for TKS and thus leading towards complexity (Yu-Jing, 2012). Hence, due to its utility of undertaking complex, nonlinear aspects and their subsequent interactions into consideration (Yu-Jing, 2012), system dynamics approach was selected for this research.

2.3.6. Contributing Factors of Tacit Knowledge Sharing in Construction

Following are the contributing factors of tacit knowledge sharing which are identified after a detailed literature review. Initially 78 factors were identified which were then shortlisted to 57 based upon their merging and overlapping characteristics. These are the contributing factors of tacit knowledge sharing for organisations and dedicated projects teams which are more relevant to construction industry.

Sr.	Code	Contributing Factors of Tacit Knowledge Sharing	References
1	F1	Trust (social trust between employees)	(Saini et al., 2018, Zhang and He, 2015, Hau et al., 2013, Nesan, 2012, Okyere-Kwakye and Nor, 2011, Joia and Lemos, 2010)
2	F2	Care of employees	(Nesan, 2012)
3	F3	Leadership commitment (credible and inspiring)	(Saini et al., 2018, Zaim et al., 2015, Zhang and He, 2015, Nesan, 2012)
4	F4	Strategic thinking (business strategy, innovative and experimentation)	(Saini et al., 2018, Zaim et al., 2015, Nesan, 2012)
5	F5	Organisation capability	(Saini et al., 2018)
6	F6	Power and sense of ownership of knowledge	(Mohajan, 2017, Garrick and Chan, 2017, Zhang and He, 2015, Hau et al., 2013, Joia and Lemos, 2010)
7	F7	Individual's agreeableness (willingness, personality and temperament)	(Mohajan, 2017, Zhang and He, 2015, Zaim et al., 2015, Hau et al., 2013)
8	F8	Leadership structure (hierarchy of command)	(Mohajan, 2017, Joia and Lemos, 2010)
9	F9	Type of valued knowledge (Vitality, renewal and integrity of knowledge)	(Garrick and Chan, 2017, Joia and Lemos, 2010)
10	F10	Individual Management of time	(Mohajan, 2017, Mohajan, 2016, Zaim et al., 2015, Nesan, 2012, Joia and Lemos, 2010)
11	F11	System of rewards	(Jin-Feng et al., 2017, Zhang and He, 2015, Hau et al., 2013, Nesan, 2012, Zhang et al., 2012, Joia and Lemos, 2010, Saini et al., 2018)
12	F12	Personal contact (employee and management meetings,	(Mohajan, 2017, Jin-Feng et al., 2017, Mohajan, 2016, Zhang and He, 2015,

		participation in a dialogue, social interaction)	Zaim et al., 2015, Hau et al., 2013, Nesan, 2012, Zhang et al., 2012, Chen and Mohamed, 2010)
13	F13	Expertise development (apprenticeship, tailored training and mentoring)	(Mohajan, 2016, Zaim et al., 2015, Nesan, 2012, Zhang et al., 2012, Joia and Lemos, 2010)
14	F14	Personalized strategy in IT (project and individual specific)	(Mohajan, 2016, Zhang and He, 2015, Joia and Lemos, 2010, Chen and Mohamed, 2010)
15	F15	Communication (open, lateral, written, verbal and honest communication)	(Nesan, 2012, Joia and Lemos, 2010, Zaim et al., 2015)
16	F16	Criticism tolerated environment (internal level of questioning)	(Joia and Lemos, 2010)
17	F17	Document upload (skill and experience of employees)	(Jin-Feng et al., 2017)
18	F18	Post project reviews (Lesson's learned)	(Mohajan, 2016, Nesan, 2012, Chen and Mohamed, 2010)
19	F19	Best practices database	(Mohajan, 2016)
20	F20	Rotation of staff	(Mohajan, 2016)
21	F21	Approachable (distance constraints)	(Mohajan, 2017, Mohajan, 2016)
22	F22	Story telling	(Mohajan, 2016)
23	F23	Language and perspective	(Saini et al., 2018, Mohajan, 2017, Mohajan, 2016, Joia and Lemos, 2010)
24	F24	Team culture (supportive work environment)	(Saini et al., 2018, Zhang and He, 2015)
25	F25	Proactive management approach (process improvement, source, type and target of knowledge)	(Saini et al., 2018, Zhang and He, 2015)
26	F26	Team learning	(Zhang and He, 2015)
27	F27	Team composition (job design, enjoyment)	(Zhang and He, 2015, Zaim et al., 2015, Hau et al., 2013, Nesan, 2012, Chen and Mohamed, 2010)
28	F28	Mutual reciprocity	(Zhang and He, 2015, Zaim et al., 2015, Hau et al., 2013, Nesan, 2012, Okyere-Kwakye and Nor, 2011)
29	F29	Understanding of benefits	(Zhang and He, 2015)
30	F30	Interpersonal skills	(Mohajan, 2017, Zaim et al., 2015)
31	F31	Individual reputation	(Zhang and He, 2015)
32	F32	Career development	(Mohajan, 2017, Nesan, 2012, Zhang et al., 2012)
33	F33	Individual knowledge/skills (practical and expertise)	(Saini et al., 2018, Zhang and He, 2015, Zaim et al., 2015, Nesan, 2012)
34	F34	Peer relations (social ties, understanding and emotional bonds)	(Zhang and He, 2015, Zaim et al., 2015, Hau et al., 2013)
35	F35	Teamwork, shared goals (social goals, collaborative relationship, positive outcome expectations)	(Zhang and He, 2015, Zaim et al., 2015, Hau et al., 2013, Nesan, 2012, Zhang et al., 2012)
36	F36	Self-efficacy (belief in ability to achieve goals)	(Zhang and He, 2015, Okyere-Kwakye and Nor, 2011)
37	F37	Conformity to culture and expectations	(Zhang and He, 2015)
38	F38	Listening	(Zaim et al., 2015)
39	F39	Quick decision making	(Nesan, 2012)
40	F40	Professional development	(Zaim et al., 2015)
41	F41	Task responsibility (Obligations and responsibilities)	(Zhang and He, 2015, Chen and Mohamed, 2010)
42	F42	Education level	(Zaim et al., 2015)
43	F43	Self-esteem (confidence in abilities)	(Zaim et al., 2015, Zhang et al., 2012)
44	F44	Peer assist (inviting of members with relevant knowledge)	(Mohajan, 2017, Zaim et al., 2015)
45	F45	Distributive justice (fairness in allocation of goods)	(Zhang and He, 2015)
46	F46	Procedural justice (fairness in resolution of disputes)	(Zhang and He, 2015)
47	F47	Learning capacity	(Zaim et al., 2015, Nesan, 2012)
48	F48	Risk taking	(Zaim et al., 2015)
49	F49	Visionary thinking	(Zaim et al., 2015)
50	F50	Supervisor-subordinate communication	(Zaim et al., 2015)
51	F51	Altruism (socially responsible, welfare)	(Zaim et al., 2015, Nesan, 2012, Okyere-Kwakye and Nor, 2011)
52	F52	Brainstorming (Problem solving)	(Zaim et al., 2015, Nesan, 2012, Chen and Mohamed, 2010)

53	F53	Involvement of each employee during project (employee empowerment)	(Nesan, 2012, Chen and Mohamed, 2010)
54	F54	Project teams continuity	(Nesan, 2012)
55	F55	Repeated owner	(Nesan, 2012)
56	F56	Early involvement of contractor in a project	(Nesan, 2012)
57	F57	Change management (changes in day of work)	(Garrick and Chan, 2017, Nesan, 2012)

Table 1: Contributing factors of tacit knowledge sharing from literature

2.3.6.1. Ranking of factors based upon literature score

Each factor is assigned code of low, medium or high based upon relative importance discussed by the author in their respective papers and hence a literature and normalized score of each factor is developed through analysis. Ranking of factors is made based upon literature score as appended below;

RANKING OF FACTORS BASED UPON LITERATURE SCORE					
Sr.	**Code**	**Contributing Factors of Tacit Knowledge Sharing**	**Literature Score**	**Normalized Score**	**Ranking**
1	F1	Trust (social trust between employees)	0.50	0.0685	Ist
2	F12	Personal contact (employee and management meetings, participation in a dialogue, social interaction)	0.49	0.0668	2nd
3	F27	Team Composition (job design, enjoyment)	0.31	0.0428	3rd
4	F28	Mutual reciprocity (exchange of goods for mutual benefit)	0.31	0.0428	3rd
5	F34	Peer relations (social ties, understanding and emotional bonds)	0.31	0.0428	3rd
6	F11	System of rewards	0.26	0.0360	4th
7	F6	Power and sense of ownership of knowledge	0.23	0.0308	5th
8	F7	Individual's agreeableness (willingness, personality and temperament)	0.23	0.0308	5th
9	F13	Expertise development (apprenticeship, tailored training and mentoring)	0.23	0.0308	5th
10	F33	Individual knowledge/skills (practical and expertise)	0.23	0.0308	5th
11	F35	Teamwork, shared goals (social goals, collaborative relationship, positive outcome expectations)	0.23	0.0308	5th
12	F3	Leadership commitment (credible and inspiring)	0.19	0.0257	6th
13	F4	Strategic thinking (business strategy, innovative and experimentation)	0.19	0.0257	6th
14	F10	Individual Management of time	0.19	0.0257	6th
15	F25	Proactive management approach (process improvement, source, type and target of knowledge)	0.19	0.0257	6th
16	F14	Personalized strategy in IT (project and individual specific)	0.15	0.0205	7th
17	F15	Communication (open, lateral, written, verbal and honest communication)	0.15	0.0205	7th
18	F23	Language and perspective	0.15	0.0205	7th
19	F36	Self-efficacy (belief in ability to achieve goals)	0.13	0.0171	8th

20	F38	Listening	0.13	0.0171	8th
21	F48	Risk taking	0.13	0.0171	8th
22	F49	Visionary thinking	0.13	0.0171	8th
23	F53	Involvement of each employee during project (employee empowerment)	0.13	0.0171	8th
24	F8	Leadership structure (hierarchy of command)	0.11	0.0154	9th
25	F18	Post project reviews (Lesson's learned)	0.11	0.0154	9th
26	F21	Approachable (distance constraints)	0.11	0.0154	9th
27	F30	Interpersonal skills	0.11	0.0154	9th
28	F32	Career development	0.11	0.0154	9th
29	F51	Altruism (socially responsible, welfare)	0.11	0.0154	9th
30	F52	Brainstorming (Problem solving)	0.11	0.0154	9th
31	F2	Care of employees	0.08	0.0103	10th
32	F9	Type of valued knowledge (Vitality, renewal and integrity of knowledge)	0.08	0.0103	10th
33	F22	Story telling	0.08	0.0103	10th
34	F24	Team Culture (supportive work environment)	0.08	0.0103	10th
35	F29	Understanding of benefits	0.08	0.0103	10th
36	F31	Individual reputation	0.08	0.0103	10th
37	F41	Task responsibility (Obligations and responsibilities)	0.08	0.0103	10th
38	F43	Self-esteem (confidence in abilities)	0.08	0.0103	10th
39	F44	Peer assist (inviting of members with relevant knowledge)	0.08	0.0103	10th
40	F47	Learning capacity	0.08	0.0103	10th
41	F57	Change Management (Changes in day of work)	0.08	0.0103	10th
42	F37	Conformity to culture and expectations	0.06	0.0086	11th
43	F42	Education level	0.06	0.0086	11th
44	F5	Organisation capability	0.04	0.0051	12th
45	F16	Criticism tolerated environment (internal level of questioning)	0.04	0.0051	12th
46	F17	Document upload (skill and experience of employees)	0.04	0.0051	12th
47	F19	Best practices database	0.04	0.0051	12th
48	F20	Rotation of staff	0.04	0.0051	12th
49	F39	Quick decision making	0.04	0.0051	12th
50	F40	Professional development	0.04	0.0051	12th
51	F54	Project teams continuity	0.04	0.0051	12th
52	F55	Repeated owner	0.04	0.0051	12th

53	F56	Early involvement of contractor in a project	0.04	0.0051	12th
54	F26	Team Learning	0.01	0.0017	13th
55	F45	Distributive justice (fairness in allocation of goods)	0.01	0.0017	13th
56	F46	Procedural Justice (fairness in resolution of disputes)	0.01	0.0017	13th
57	F50	Supervisor-subordinate communication	0.01	0.0017	13th

Table 2: Ranking of Potential Factors of Tacit Knowledge Sharing via Content Analysis

2.4. Productivity and Performance of Construction Projects

Productivity and performance of construction projects can be measured by making use of following factors (Enshassi et al., 2009);

1. Cost
2. Time
3. Quality
4. Productivity factor
5. Client satisfaction
6. Regular and community satisfaction
7. People factor
8. Health and safety factor
9. Innovation and learning factor
10. Environmental factor

2.5. System Dynamics

2.5.1. Background and Overview

System Dynamics (SD) was founded by professor Forrester of Massachusetts Institute of Technology (MIT) in 1956 and it became separate field in late 1950's (Yu-Jing, 2012). The basic idea of SD is that feedback mechanism and internal dynamic structure is responsible for pattern of behaviour and characteristics of systems (Xie, 2001). It is field used to recognize, explore and comprehensively solve economic, biological and ecologically complex problems as wells as problems related to natural and social sciences (Yu-Jing, 2012).

2.5.2. Definition

"The investigation of information feedback characteristics of systems and use of models for design of improved organizational forms and guiding policy" (Forrester, 1961)

A more comprehensive definition given by Coyle in his book is given below (Coyle, 1996);

System dynamics deals with time dependent behaviour of managed systems with the aim of describing the system and understanding through qualitative and quantitative models, how information feedback govern its behaviour and designing robust feedback structures and control policies through simulation and optimization.

2.5.3. System Dynamics Method

SD method which is also known as SD simulation method comprises of three elements namely: system, computer and SD model in which model is extracted from system (which is the focus of study) and computer runs the model through trial and error (Yu-Jing, 2012).

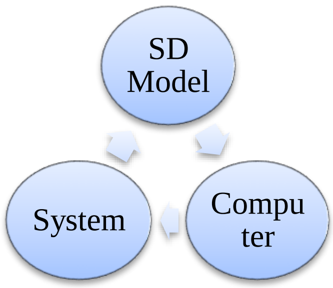

Figure 5: Components of system dynamics model and their relation

Source: (Yu-Jing, 2012)

2.5.4. Application of system dynamics in construction projects

Different kinds of influencing factors make the construction projects complex resulting in big problems which are appended below (Yu-Jing, 2012).

1) There is a causal relationship between different elements in construction projects which are separated over time and space e.g. design changes in one element may lead to changes in other elements as well.

2) Construction projects comprise of multi loops including positive (reinforcing) as well as negative (balancing) loops.

3) Different elements of construction projects has nonlinear behaviour e.g. productivity of a labour over time.

4) In construction projects, there is coexistence of both hard data (written specifications, plans, drawings etc.) as well as soft data (human emotions, ability, skill etc.).

Above mentioned factors as whole lead to complexity in construction projects and that is where SD comes to rescue us to help in recognition, exploring and comprehensively solving the construction related problems.

Chapter – 3

RESEARCH METHODOLOGY

3.1. Introduction

This chapter will discuss research framework in which different steps and stages will be given to accomplish objectives, mentioned in Chapter 1. Research flow chart will also be discussed which represent objectives and their strategies in a systematic way.

3.2. Research Methodology

Research was divided into four phases: initial study, factor analysis, systems thinking and system dynamics model as shown in Figure 6. Methodology of these four phases is explained here one by one.

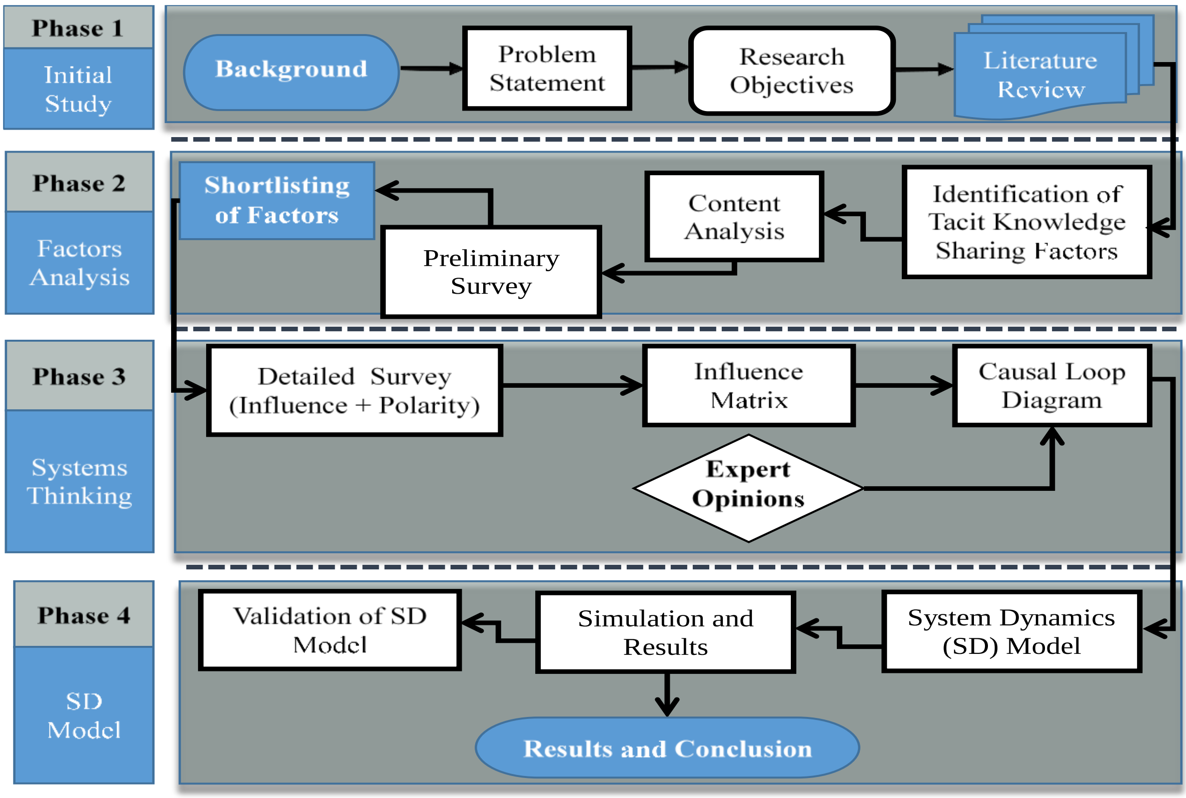

Figure 6: Research Methodology

3.2.1. Initial Study

After identifying research gap, problem statement and research objectives were established (section **1.2** and **1.3**). A detailed literature review was carried out on to recognize amount of work already carried out on knowledge management pertinent to tacit knowledge sharing. Field of system dynamics was also reviewed and understood through literature and its utility is also justified, since system dynamics is used as a methodology in this work.

3.2.2. Factor Analysis

Extensive literature review was carried out to identify potential contributing factors of tacit knowledge sharing via literature. Data from 16 research papers was used to carry out content analysis and a literature score was assigned to each factor. A total of 57 potential contributing factors of tacit knowledge sharing were identified through literature (section **2.3.6** and **2.3.6.1**). A preliminary questionnaire was developed on Likert scale ranging from 1 to 5 to get the field input of already identified factors. Data from total of 37 respondents was collected from developing countries out of which 7 were invalid and 30 were considered for analysis (Chan et al., 2018). Normality and reliability of data were checked by applying basis statistical tests on SPSS ®. Relative importance index of factors was calculated and a field score was assigned to each factor. Literature scores and field scores were normalized, and thereafter merged by 50/50 ratio to avoid unbiased. After arranging factors in descending order with respect to their merged score, factors having cumulative percentage normalized score up to 51 percent were shortlisted for further analysis.

3.2.3. Systems Thinking

A detailed questionnaire survey was carried out to determine polarity as well as causal strength of each factor on the other. Respondents were asked to rank causal strength of each factor on the other as Low (1), Medium (3) and High (5) along with polarity as Direct or Indirect. Data from total of 74 respondents of developing countries was collected out of which 13 were invalid and 61 were considered for further analysis (Dillman et al., 2014, Cochran, 2007). Normality and reliability of data were checked by applying basis statistical tests on SPSS ®. Interrelation having mean value ranging from 4 to 5 were considered for further analysis (Chong et al., 2017). Using this information, systems thinking was developed through causal loop diagrams. Causal loop diagram was developed using VENSIM ® based upon shortlisted interrelation and modified through incorporating expert opinions to make it meaningful and ensure its relevance to construction industry.

3.2.4. System Dynamics Model

Mean score or relative importance index of each interrelation was normalized to be used in system dynamics model. System dynamics model was developed by making use of causal loop diagrams, polarity as well as causal strength of the factors on the other. The model was simulated over the period of five years to observe its behaviour. Validation of the developed model was carried out using two criteria's: internal validity (Qudrat-Ullah and Seong, 2010) and behaviour over time. The developed model addresses tacit knowledge sharing complexity in construction leading to improved productivity and performance in construction.

3.3. Research Flow Chart

A flow chart of research is shown in figure 6 which represents aim and methodology of the work. Firstly, contributing factors of tacit knowledge sharing were identified through content analysis and field survey. Final factors were shortlisted by using 50/50 ratio (50 for field score and 50 for literature score). Secondly, systems thinking was developed through causal loop diagrams. To accomplish this, a detailed questionnaire was circulated to determine the polarity as well as causal strength of each factor on the other. Finally, system dynamics model was developed by making use of systems thinking and causal loop diagrams to address tacit knowledge sharing complexity leading towards improved productivity and performance in construction.

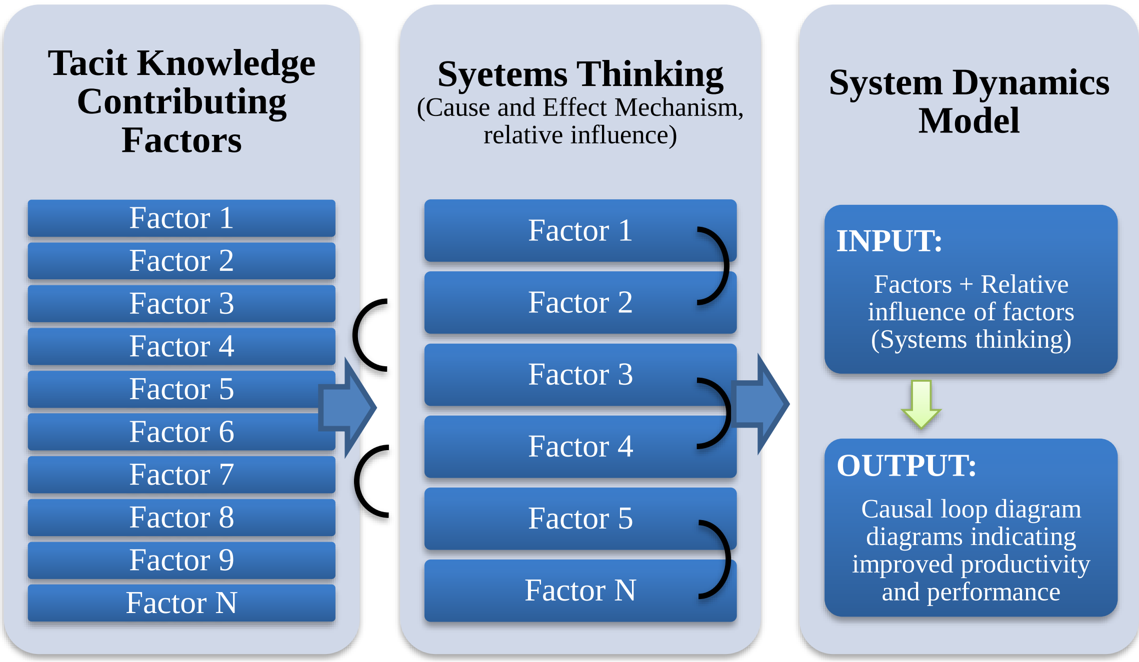

Figure 7: Research Flow Chart

Chapter – 4

RESULTS AND DISCUSSION

4.1. Preliminary Questionnaire Survey (Phase - 1)

In order to shortlist contributing factors of tacit knowledge sharing through factor analysis, a preliminary questionnaire survey was conducted. Data was collected from 30 respondents, which is considered to be a sufficient sample size as per central limit theorem (Chan et al., 2018). Respondents belonged to developing countries including Pakistan, India, Bangladesh, Brazil, Kuwait, Turkey, Morocco, UAE and Qatar. Sources used to collect data were Gmail ®, LinkedIn ® and Facebook ®.

Preliminary questionnaire was developed using Google ™ docs. It contained two sections; first section was related to personal information of the respondent such as name, email id, professional experience, highest academic qualification, region and field of work. Second section was specific to tacit knowledge sharing factors in which respondents were asked to rank factors on a Likert's scale ranging from very low to very high (1 - 5). Numbers of factors captured through a detailed content analysis were 57.

4.1.1. Respondents Detail

Targeted respondents were having civil engineering / architecture background to ensure input which is specific to construction.

4.1.1.1. Highest Academic Qualification

Out of thirty respondents, 40 % of the respondents were BSc civil engineers, while 37 % percent of the respondents had MSc degree. The reaming 23 % of the respondents had doctorate degree.

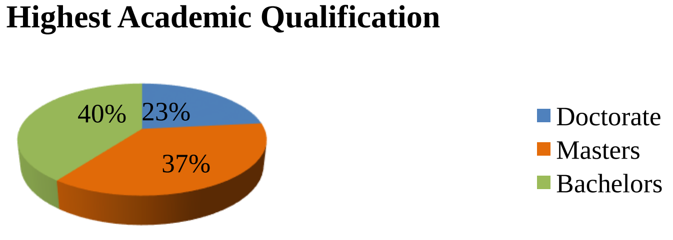

Figure 8: Preliminary Survey - Highest academic qualification

4.1.1.2. Professional Experience

With respect to professional experience, 30 % of the respondents had 1-5 years of experience while 24 % of the respondents had 6 to 10 years of experience. Similarly, 23 % of respondents had 11 to 15 years of experience while 10 % of the respondents had 16 to 20 years of experience. The remaining 13 % of the respondents had professional experience more than 21 years.

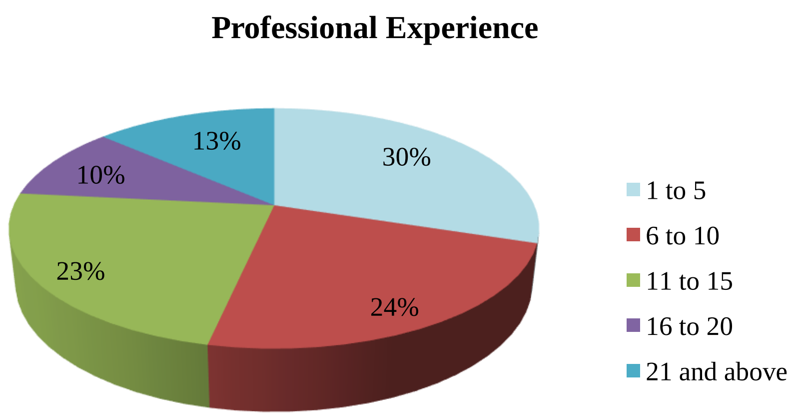

Figure 9: Preliminary Survey - Professional experience

4.1.1.3. Field of Work

With respect to field of work, 24 % of the respondents were from project management while 40 % were from construction management. The remaining were site execution, building information modeling, engineering, building design and infrastructure management.

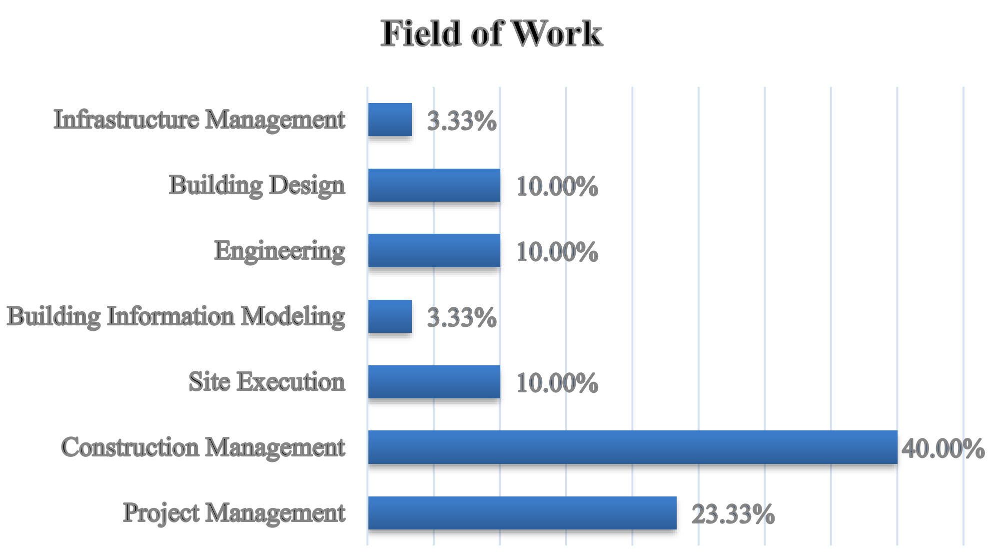

Figure 10: Preliminary Survey - Field of work

4.1.1.4. Organization Type

Regarding organization type, 40 % of the respondents were from contractor organization while 23 % were from client side. Similarly, 23 % of the respondents were from consultant organization while 4 % were from government sector. The remaining 10 % were academician.

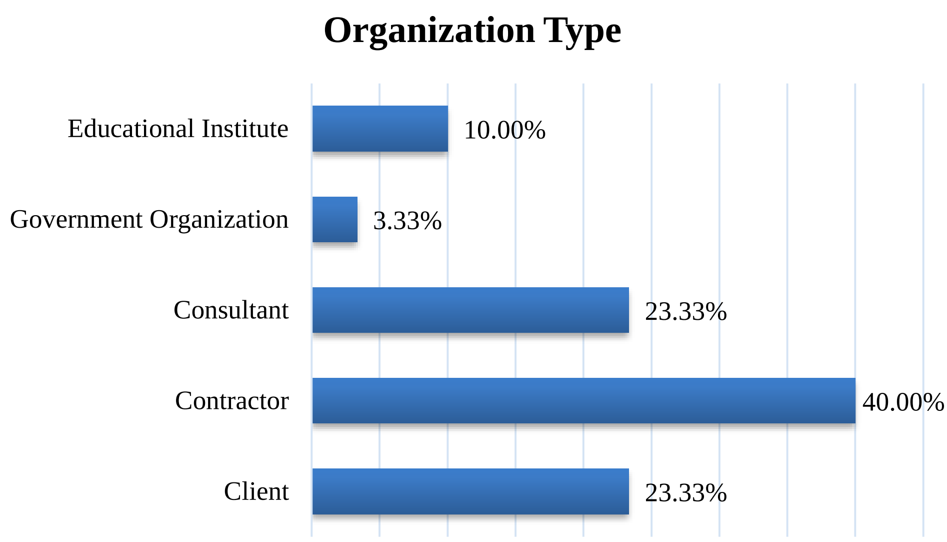

Figure 11: Preliminary Survey - Organization type

4.1.1.5. Region of Respondents

Targeted respondents were from developing countries including Pakistan, India, Bangladesh, Brazil, UAE, Kuwait, Turkey, Morocco and Qatar. In terms of percentage, 30 % of the respondents were from Pakistan, 13.33 % were from India, 10 % from Bangladesh, 3.33 % from Brazil, 23.33 % from UAE, 3.33 % from Kuwait, 3.33 % from Turkey, 3.33 % from Morocco and 10 % from Qatar.

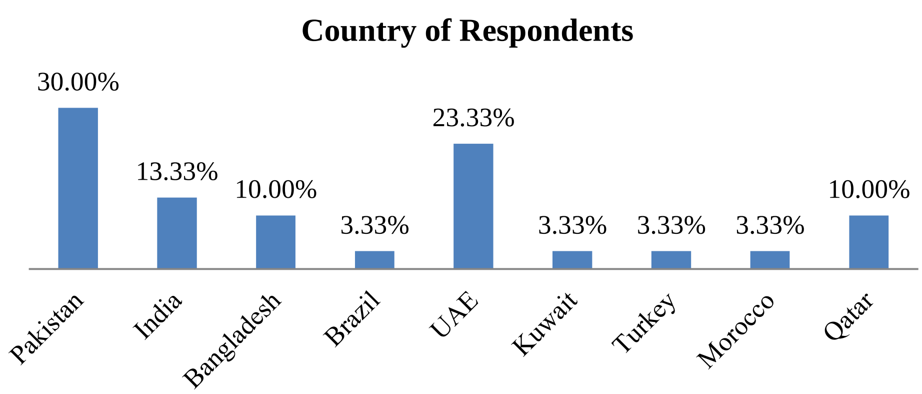

Figure 12: Preliminary Survey - Regions of respondents

4.1.2. Normality and Reliability Check

Shapiro-Wilk test was conducted to check normality of data, significance values came out to be less than 0.05 which indicated that data is not normally distributed and is non-parametric.

To check reliability and internal consistency of data, Cronbach's Alpha test is conducted and it's bench mark value is 0.7 (Polat et al., 2017, Gliem and Gliem, 2003), higher the value, the more data is reliable and internally consistent as shown in Figure 13. Cronbach's Alpha value came out to be 0.957 (Figure 14), which indicated that data is sufficiently reliable and internally consistent (Tavakol and Dennick, 2011).

The relationship between the Cronbach's alpha value and internal consistency.

Cronbach's alpha value (α)	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable

Figure 13: Cronbach's Alpha Benchmark Values

Reliability Statistics

Cronbach's Alpha	N of Items
.957	57

Figure 14: Cronbach's Alpha Value

4.1.3. Ranking of Factors based upon Field Score + Literature Score

Field normalized score was calculated for each factor using field survey data. Field normalized score and literature score were merged to get the final ranking. The ratio used in this regard is 50/50 to avoid any unbiased.

RANKING BASED UPON FIELD NS + LITERATURE NS (50/50 RATIO)					
Sr.	**Code**	**Contributing Factors of Tacit Knowledge Sharing**	**50/50**	**Normalized**	**Ranking**
1	F1	Trust (social trust between employees)	0.044930	0.044930	Ist
2	F12	Personal contact (employee and management meetings, participation in a dialogue, social interaction)	0.044074	0.044074	2nd
3	F27	Team (Composition (job design, enjoyment)	0.032088	0.032088	3rd
4	F28	Mutual reciprocity (exchange of goods for mutual benefit)	0.032088	0.032088	3rd
5	F34	Peer relations (social ties, understanding and emotional bonds)	0.032088	0.032088	3rd
6	F11	System of rewards	0.028663	0.028663	4th
7	F6	Power and sense of ownership of knowledge	0.026095	0.026095	5th
8	F7	Individual's agreeableness (willingness, personality and temperament)	0.026095	0.026095	5th

9	F33	Individual knowledge/skills (practical and expertise)	0.026095	0.026095	5th
10	F35	Teamwork, shared goals (social goals, collaborative relationship, positive outcome expectations)	0.026095	0.026095	5th
11	F13	Expertise development (apprenticeship, tailored training and mentoring)	0.023958	0.023958	6th
12	F3	Leadership commitment (credible and inspiring)	0.023526	0.023526	7th
13	F4	Strategic thinking (business strategy, innovative and experimentation)	0.021389	0.021389	8th
14	F10	Individual Management of time	0.021389	0.021389	8th
15	F25	Proactive management approach (process improvement, source, type and target of knowledge)	0.021389	0.021389	8th
16	F15	Communication (open, lateral, written, verbal and honest communication)	0.018821	0.018821	9th
17	F8	Leadership structure (hierarchy of command)	0.018389	0.018389	10th
18	F30	Interpersonal skills	0.018389	0.018389	10th
19	F36	Self-efficacy (belief in ability to achieve goals)	0.017109	0.017109	11th
20	F38	Listening	0.017109	0.017109	11th
21	F48	Risk taking	0.017109	0.017109	11th
22	F49	Visionary thinking	0.017109	0.017109	11th
23	F53	Involvement of each employee during project (employee empowerment)	0.017109	0.017109	11th
24	F14	Personalized strategy in IT (project and individual specific)	0.016684	0.016684	12th
25	F23	Language and perspective	0.016684	0.016684	12th
26	F18	Post project reviews (Lesson's learned)	0.016252	0.016252	13th
27	F21	Approachable (distance constraints)	0.016252	0.016252	13th
28	F51	Altruism (socially responsible, welfare)	0.016252	0.016252	13th
29	F52	Brainstorming (Problem solving)	0.016252	0.016252	13th
30	F32	Career development	0.014116	0.014116	14th
31	F9	Type of valued knowledge (Vitality, renewal and integrity of knowledge)	0.013684	0.013684	15th
32	F24	Team Culture (supportive work environment)	0.013684	0.013684	15th
33	F29	Understanding of benefits	0.013684	0.013684	15th
34	F31	Individual reputation	0.013684	0.013684	15th
35	F41	Task responsibility (Obligations and responsibilities)	0.013684	0.013684	15th
36	F43	Self-esteem (confidence in abilities)	0.013684	0.013684	15th
37	F44	Peer assist (inviting of members with relevant knowledge)	0.013684	0.013684	15th
38	F47	Learning capacity	0.013684	0.013684	15th
39	F57	Change Management (Changes in day of work)	0.013684	0.013684	15th
40	F5	Organisation capability	0.013252	0.013252	16th
41	F37	Conformity to culture and expectations	0.012828	0.012828	16th
42	F42	Education level	0.012828	0.012828	16th
43	F2	Care of employees	0.011547	0.011547	17th
44	F22	Story telling	0.011547	0.011547	17th
45	F16	Criticism tolerated environment (internal level of questioning)	0.011116	0.011116	18th
46	F19	Best practices database	0.011116	0.011116	18th
47	F20	Rotation of staff	0.011116	0.011116	18th
48	F40	Professional development	0.011116	0.011116	18th
49	F54	Project teams continuity	0.011116	0.011116	18th

50	F55	Repeated owner	0.011116	0.011116	18th
51	F56	Early involvement of contractor in a project	0.011116	0.011116	18th
52	F26	Team Learning	0.009403	0.009403	19th
53	F45	Distributive justice (fairness in allocation of goods)	0.009403	0.009403	19th
54	F50	Supervisor-subordinate communication	0.009403	0.009403	19th
55	F17	Document upload (skill and experience of employees)	0.008979	0.008979	20th
56	F39	Quick decision making	0.008979	0.008979	20th
57	F46	Procedural Justice (fairness in resolution of disputes)	0.007266	0.007266	21th

Table 3: Ranking of Factors based upon Field + Literature Normalized Score (50/50)

4.1.4. Shortlisted Factors - Tacit Knowledge Sharing

Factors are shortlisted based upon 51 percent of the cumulative normalized score as the cutoff point. The number of having cumulative normalized score under 51 came out to be nineteen (Rasul et al., 2019).

Sr.	Code	Shortlisted Factors - Tacit Knowledge Sharing	50/50 Principle	Normalized Score	Cumulative Score
1	F1	Trust (social trust between employees)	0.04493	0.04493	0.04493
2	F12	Personal contact (employee and management meetings, participation in a dialogue, social interaction)	0.04407	0.04407	0.08900
3	F27	Team Composition (job design, enjoyment)	0.03209	0.03209	0.12109
4	F28	Mutual reciprocity (exchange of goods for mutual benefit)	0.03209	0.03209	0.15318
5	F34	Peer relations (social ties, understanding and emotional bonds)	0.03209	0.03209	0.18527
6	F11	System of rewards	0.02866	0.02866	0.21393
7	F6	Power and sense of ownership of knowledge	0.02609	0.02609	0.24003
8	F7	Individual's agreeableness (willingness, personality and temperament)	0.02609	0.02609	0.26612
9	F13	Expertise development (apprenticeship, tailored training and mentoring)	0.02609	0.02609	0.29222
10	F33	Individual knowledge/skills (practical and expertise)	0.02609	0.02609	0.31831
11	F35	Teamwork, shared goals (social goals, collaborative relationship, positive outcome expectations)	0.02396	0.02396	0.34227
12	F3	Leadership commitment (credible and inspiring)	0.02353	0.02353	0.36579
13	F4	Strategic thinking (business strategy, innovative and experimentation)	0.02139	0.02139	0.38718
14	F10	Individual Management of time	0.02139	0.02139	0.40857
15	F25	Proactive management approach (process improvement, source, type and target of knowledge)	0.02139	0.02139	0.42996
16	F15	Communication (open, lateral, written, verbal and honest communication)	0.01882	0.01882	0.44878
17	F8	Leadership structure (hierarchy of command)	0.01839	0.01839	0.46717
18	F30	Interpersonal skills	0.01839	0.01839	0.48556
19	F36	Self-efficacy (belief in ability to achieve goals)	0.01711	0.01711	0.50267

Table 4: Shortlisted Factors Based upon Literature + Field Normalized Score (50/50)

4.2. Detailed Questionnaire Survey (Phase - 2)

After shortlisting a total of 19 contributing factors of tacit knowledge sharing, next stage is to determine the causal relationship along with polarity of each factor upon the other.

A detailed questionnaire was developed for contributing factors tacit knowledge sharing comprising of 342 causal relationships along with their polarities. Respondents were asked to rank the causal relationships of factors as low (1), medium (3) or high (5) and polarity as direct or indirect. Considering the lengthy nature of questionnaire, respondents were asked to give their input in a grid format (combined level of influence and polarity) in order to facilitate their quick response.

4.2.1. Sample Size

Before collection of data, minimum sample size was calculated through a formula provided by Dillman (Dillman et al., 2014);

$$n = \frac{z^2 * p * q}{E^2}$$

Equation 1

Where n = sample size, z = critical value for desired confidence level, p = proportion being tested, q = 1 – p and E = desired margin of sampling error. Considering 80/20 split for the subject data collection (i.e. expectation of getting 80 percent “yes” and 20 percent “no”), 95% confidence level which gives z value to be 1.96 and taking sampling error as 5%, required minimum sample size comes out to be 61 (Dillman et al., 2014). 80/20 split was chosen by bearing in mind the nature of questions asked in the questionnaire regarding polarity and level of influence which points that it’s unlikely that one person assumes direct polarity between two factors while other assumes indirect.

4.2.2. Respondents Detail

Data was collected from total of 74 respondents out of which 13 were invalid and 61 responses were considered for the analysis (Cochran, 2007). Targeted respondents were having civil engineering / architecture background to ensure input which is specific to construction.

4.2.2.1. Highest Academic Qualification

Out of sixty respondents, 36 % of the respondents were BSc civil engineers, while 49 % percent of the respondents had MSc degree. The reaming 15 % of the respondents had doctorate degree.

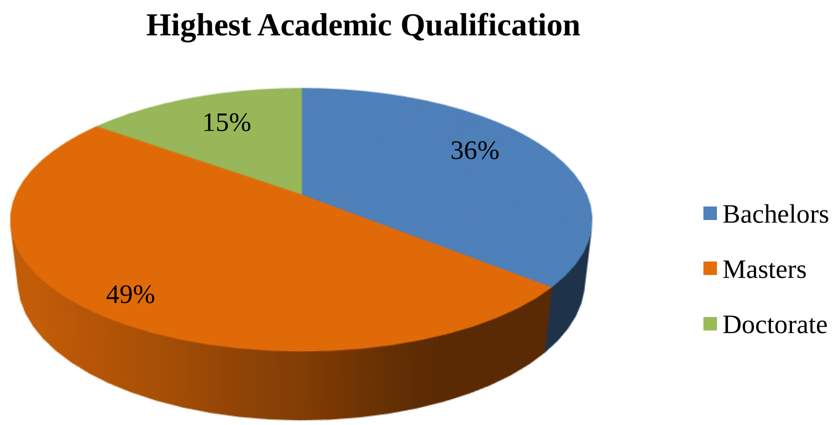

Figure 15: Detailed survey - Highest academic qualification

4.2.2.2. Professional Experience

With respect to professional experience, 39 % of the respondents had 1-5 years of experience while 23 % of the respondents had 6 to 10 years of experience. Similarly, 18 % of respondents had 11 to 15 years of experience while 12 % of the respondents had 16 to 20 years of experience. The remaining 8 % of the respondents had professional experience more than 21 years.

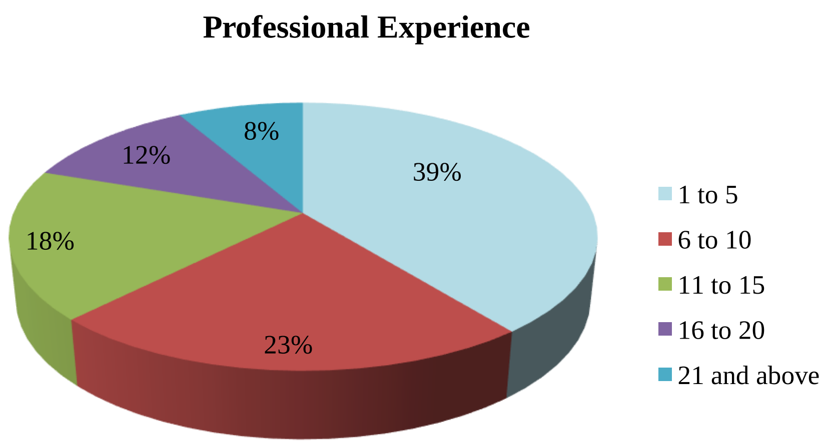

Figure 16: Detailed survey - Professional experience

4.2.2.3. Field of Work

With respect to field of work, 21 % of the respondents were from project management while 34 % were from construction management. The remaining was from site execution, engineering, building design, quantity surveying and engineering.

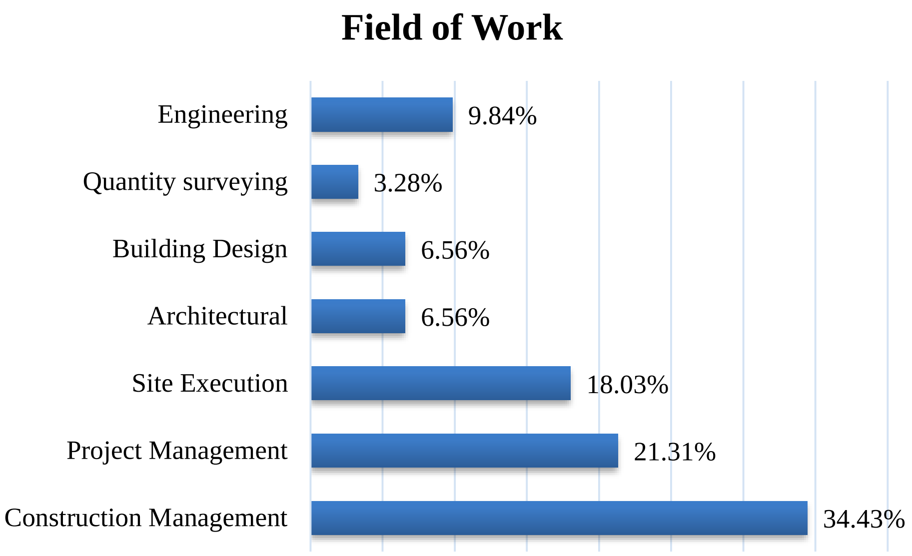

Figure 17: Detailed survey: Field of work

4.2.2.4. Organization Type

Regarding organization type, 43 % of the respondents were from contractor organization while 11 % were from client side. Similarly, 33 % of the respondents were from consultant organization while 2 % were from government organization. The remaining 8 % were from educational institute and 3 % were project manager.

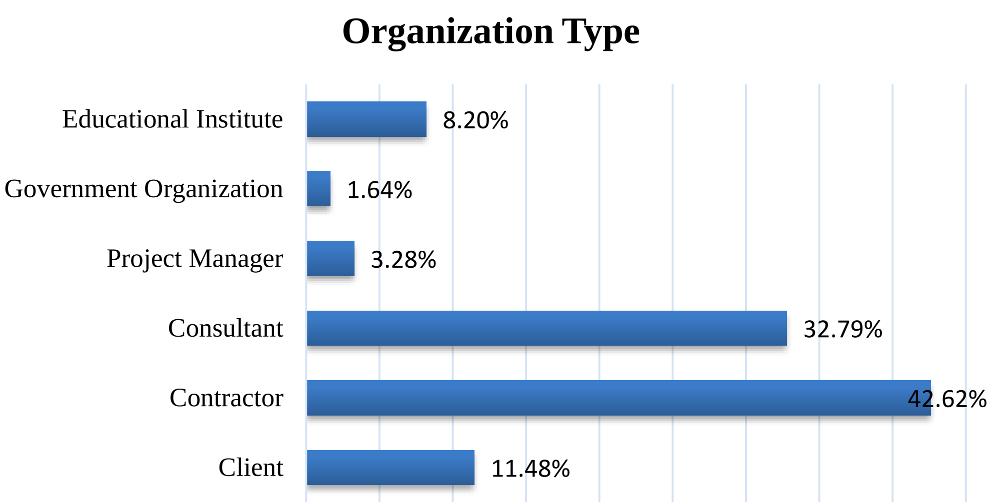

Figure 18: Detailed survey: Organization type

4.2.2.5. Region of Respondents

Targeted respondents were from developing countries including Pakistan, India, Bangladesh, Brazil, UAE, Iran, Nepal, Saudi Arabia, Italy and Turkey. In terms of percentage, 45.90 % of the respondents were from Pakistan, 6.56 % were from India, 9.84 % from Bangladesh, 3.28 % from Brazil, 11.48 % from UAE, 8.20 % from Iran, 3.28 % from Nepal, 3.28 % from Saudi Arabia, 3.28 % from Italy and 4.92 % from Turkey.

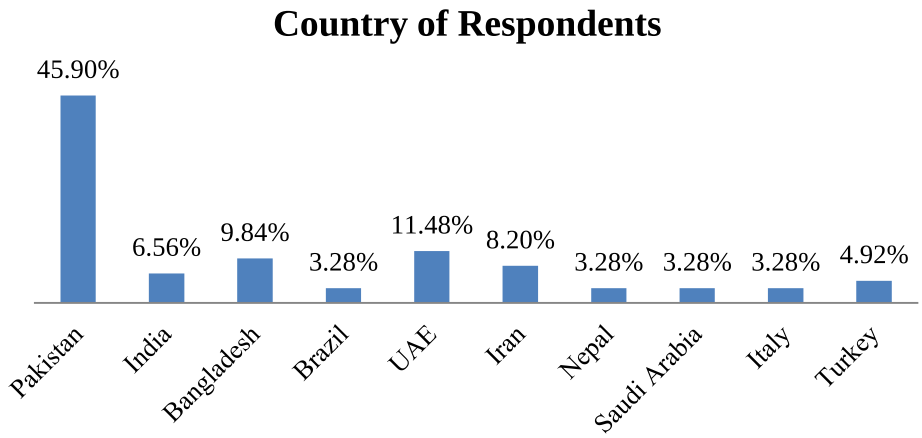

Figure 19: Detailed survey: Regions of respondents

4.2.3. Normality and Reliability Check

Shapiro-Wilk test was conducted to check normality of data, significance values came out to be less than 0.05 which indicated that data is not normally distributed and is non-parametric.

To check reliability and internal consistency of data, Cronbach's Alpha test is conducted and it's bench mark value is 0.7 (Polat et al., 2017, Gliem and Gliem, 2003), higher the value, the more data is reliable and internally consistent as shown in Figure 20. Cronbach's Alpha value came out to be 0.981 (Figure 21), which indicated that data is sufficiently reliable and internally consistent (Tavakol and Dennick, 2011).

The relationship between the Cronbach's alpha value and internal consistency.

Cronbach's alpha value (α)	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable

Figure 20: Cronbach's Alpha Benchmark Values

Reliability Statistics

Cronbach's Alpha	N of Items
.981	342

Figure 21: Cronbach's Alpha Value

4.2.4. Significant Causal Relationships with Polarity

Shortlisting listing of causal relationships for influence matrix and causal loop diagram is done based upon relative importance index. Causal relations having RII value greater then equals to 0.8 or having mean value 4<=m=<5 are considered for the further analysis (Chong et al., 2017). Relative importance index is calculated based upon the mean value, since nature of questions were not unique and standalone hence mean value was preferred over the mode value (Boone and Boone, 2012). A total of 19 causal relationships were shortlisted having RII greater or equals to 0.80.

$$Mean\ value = \frac{(1 * Low + 3 * Medium + 5 * High)}{Number\ of\ respondents}$$

Equation 2

S.	Impacting Factor	Impacted Factor	Mean	Polarity
1	Personal contact and interaction	Trust	4.54	Direct
2	Trust	Power and sense of ownership of knowledge	4.11	Indirect
3	Teamwork and shared goals	Trust	4.38	Direct
4	Trust	Communication	4.37	Direct
5	Power and sense of ownership of knowledge	Personal contact and interaction	4.11	Indirect
6	Communication	Personal contact and interaction	4.51	Direct
7	Personal contact and interaction	Interpersonal skills	4.02	Direct
8	Interpersonal skills	Power and sense of ownership of knowledge	4.15	Indirect
9	Expertise development	Individual knowledge/skills	4.11	Direct
10	Communication	Expertise development	4.05	Direct
11	Individual knowledge/skills	Communication	4.11	Direct
12	Interpersonal skills	Individual knowledge/skills	4.05	Direct
13	Self-efficacy	Individual knowledge/skills	4.15	Direct
14	Peer relations	Communication	4.31	Direct
15	Individual's agreeableness	Communication	4.11	Direct
16	Mutual reciprocity	Communication	4.15	Direct
17	Team composition	Teamwork and shared goals	4.34	Direct
18	Communication	Teamwork and shared goals	4.11	Direct
19	Leadership structure	Leadership commitment	4.21	Direct

Table 5: Interrelations having Mean Influence Value >= 4

4.2.5. Influence Matrix for Causal Loop Diagram

Influence matrix is developed based upon results and analysis of preliminary and detailed questionnaire survey. Values in the lower half of the matrix represent data taken through expert opinions which helped in the modification of causal loop diagram.

Expert opinions were carried out to make the causal loop meaningful and ensure that feedback loops are moving in the same direction. Hence, directions of few interrelations were changed through expert opinions. The interrelation between leadership and leadership commitment was ignored because it was not contributing to the system. Influence matrix after incorporating changes through expert opinions is given below.

	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V13**	**V14**	**V15**	**V16**	**V17**	**V18**	**V19**
V1	**1**						**-0.82**									**0.87**			
V2	**0.91**	**1**																**0.90**	
V3			**1**								**0.87**								
V4				**1**												**0.83**			
V5					**1**											**0.86**			
V6						**1**													
V7		**-0.82**					**1**												
V8								**1**								**0.82**			
V9									**1**	**0.82**									
V10										**1**						**0.82**			
V11	**0.88**										**1**								
V12												**1**							
V13													**1**						
V14														**1**					
V15															**1**				
V16		**0.90**							**0.81**		**0.82**					**1**			
V17												**0.84**					**1**		
V18							**-0.83**			**0.81**								**1**	
V19										**0.83**									**1**

V1: Trust **V2:** Personal contact and interaction **V3:** Team composition **V4:** Mutual reciprocity **V5:** Peer relations **V6:** System of rewards **V7:** Power and sense of ownership of knowledge **V8:** Individual's agreeableness **V9:** Expertise development **V10:** Individual knowledge/skills **V11:** Teamwork and shared goals **V12:** Leadership commitment **V13:** Strategic thinking **V14:** Individual management of time **V15:** Proactive management approach **V16:** Communication **V17:** Leadership structure **V18:** Interpersonal skills **V19:** Self-efficacy

Figure 22: Influence matrix for causal loop diagram

4.3. Causal Loop Diagram

Causal loop diagram (CLD) is developed on VENSIM® based upon interrelationships having mean influence value 4=<m<=5. It consists of 4 reinforcing and two balancing loops. Causal loop diagram is modified based upon expert opinions from construction professional having experience above 15 years to make it simplified and meaningful. CLD is modified to ensure that feedback loops are moving in the same direction and some of the interrelations were ignored which were going away from the system.

CLD is the combination of four reinforcing and two balancing loop, these loops are explained in upcoming sections one by one.

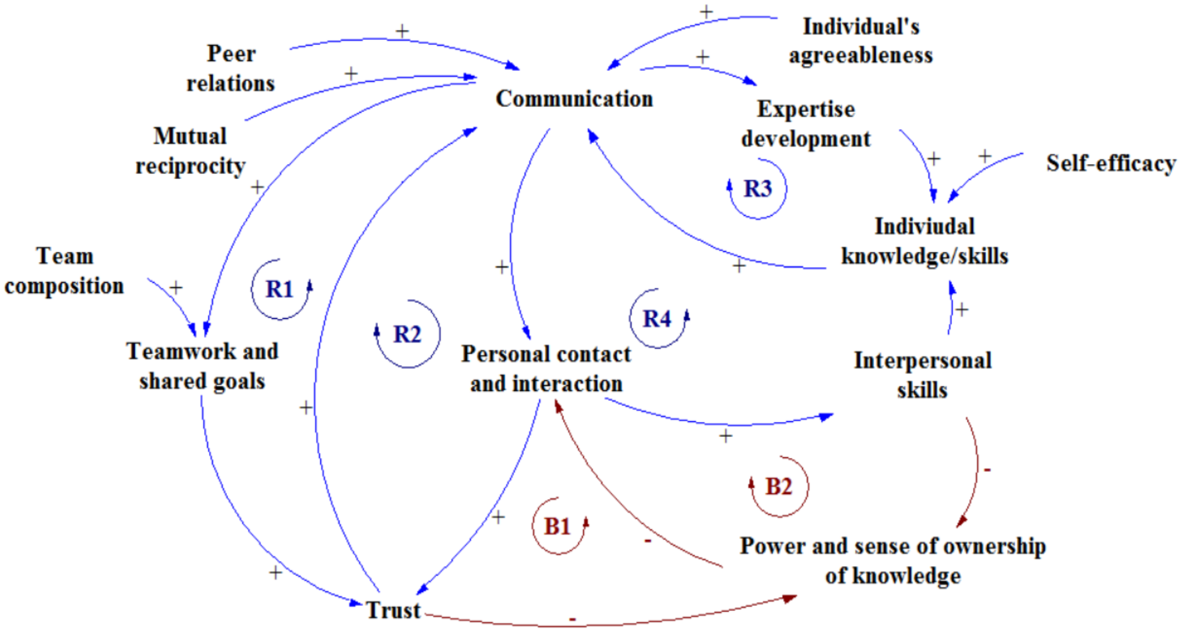

Figure 23: Causal Loop Diagram

4.3.1. Reinforcing Loop R1

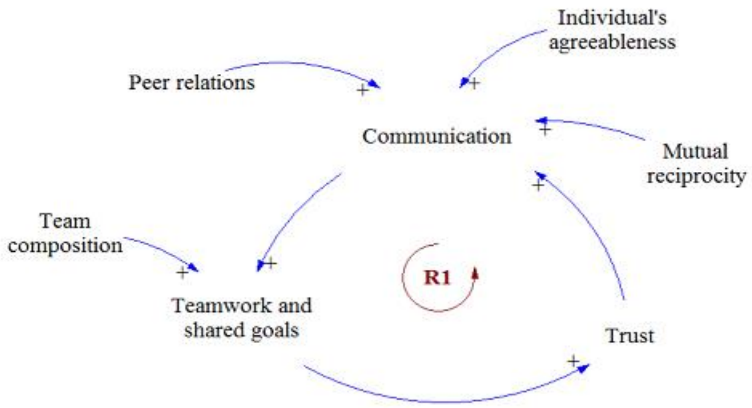

Figure 24: Reinforcing Loop R1

Reinforcing loop R1 implies that as communication increases, it leads towards increase in teamwork and shared goals which as a result increases trust amongst project team members. Communication is externally complemented by mutual reciprocity, peer relation, and individual's agreeableness in a positive way. Similarly, teamwork and shared goals is also externally complemented by team composition positively.

4.3.2. Reinforcing Loop R2

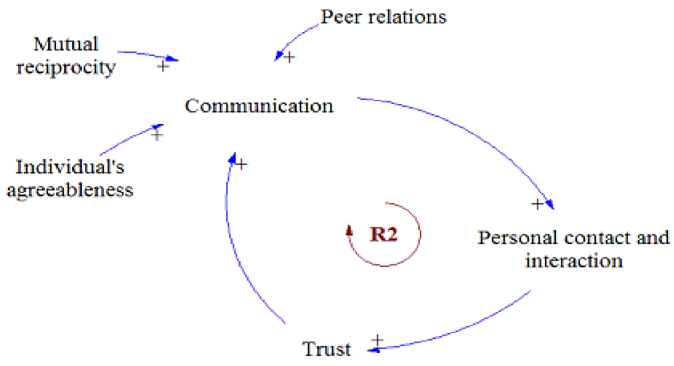

Figure 25: Reinforcing Loop R2

Reinforcing loop R2 implies that increase in communication leads toward increase in personal contact and interaction which as a result increase amongst project team members. Communication is externally complemented by mutual reciprocity, peer relation, and individual's agreeableness in a positive way.

4.3.3. Reinforcing Loop R3

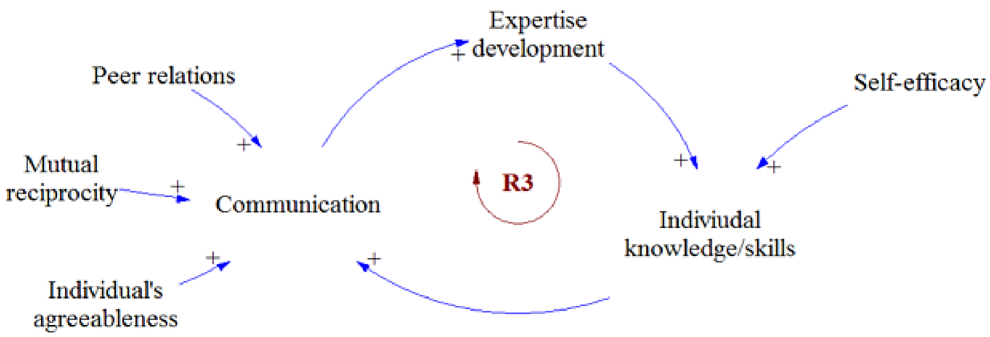

Figure 26: Reinforcing Loop R3

Reinforcing loop R3 implies that increase in communication leads toward increase in expertise development which as a result increases individual knowledge/skills. Self-efficacy is a factor which is externally influencing the individual knowledge/skills. Similarly, communication is externally complemented by mutual reciprocity, peer relation, and individual's agreeableness in a positive way.

4.3.4. Reinforcing Loop R4

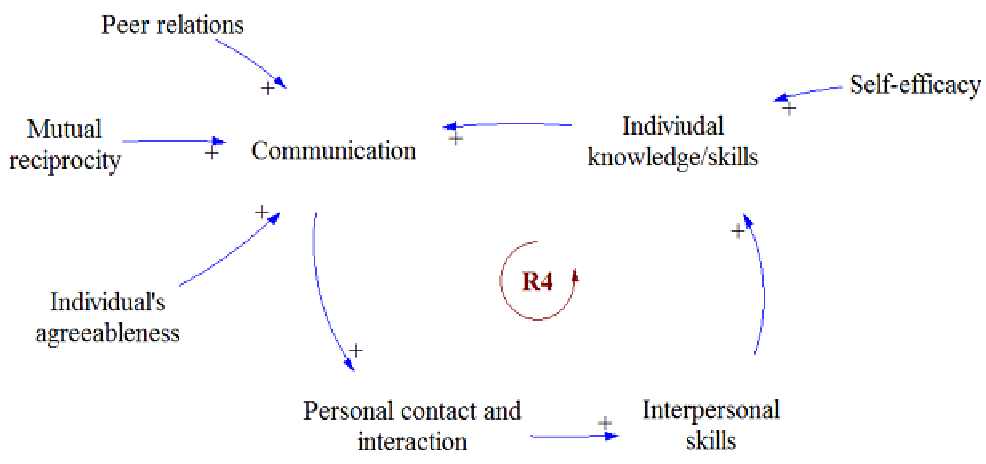

Figure 27: Reinforcing Loop R4

Reinforcing loop R4 implies that increase in communication leads toward increase in personal contact and interaction. Increase in personal contact and interaction increasers interpersonal skills which as a result increase individual knowledge/skills. Self-efficacy is a factor which is externally influencing the individual knowledge/skills. Similarly, communication is externally complemented by mutual reciprocity, peer relation, and individual's agreeableness in a positive way.

4.3.5. Balancing Loop B1

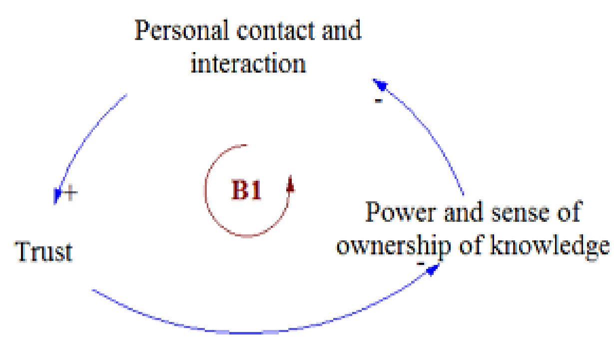

Figure 28: Balancing Loop B1

Balancing loop B1 implies that increase in trust leads toward decrease in power and sense of ownership of knowledge. Decrease in power and sense of ownership of knowledge will increase personal contact and interaction. However, increase in personal contact and interaction will increase trust amongst project team members.

4.3.6. Balancing Loop B2

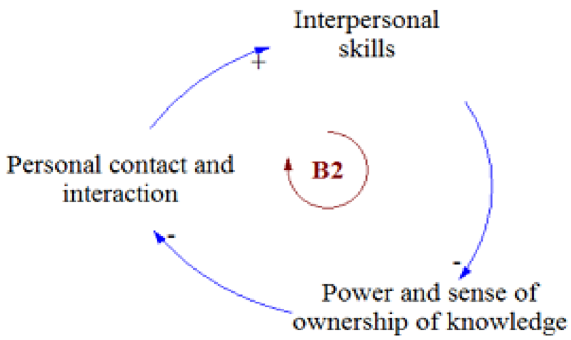

Figure 29: Balancing Loop B2

Balancing loop B2 implies that increase in interpersonal skills leads toward decrease in power and sense of ownership of knowledge. Decrease in power and sense of ownership of knowledge will increase personal contact and interaction. However, increase in personal contact and interaction will increase interpersonal skills amongst project team members.

4.4. Stock and Flow Diagram

Using causal loop diagram, stock and flow diagram was developed. Four stocks were identified named as communication, personal contact and interaction, trust and individual knowledge/skills.

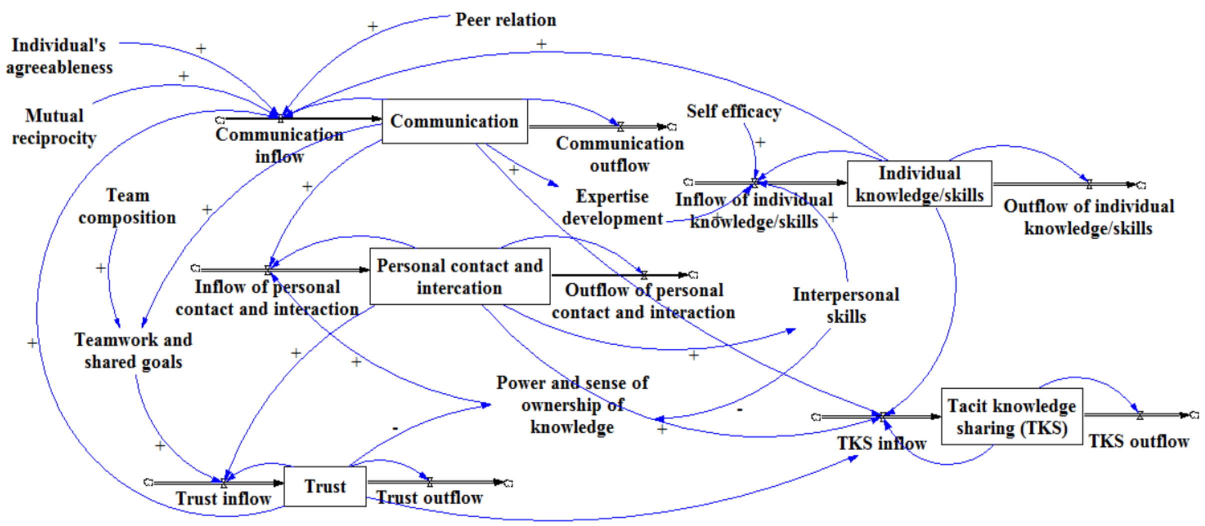

Figure 30: Stock and Flow Diagram

4.5. System Dynamics Model

In order to develop equations for each factor and different flows, mean values of each causal relationship were normalized as given below;

S.	Impacting Factor	Impacted Factor	Mean	N. Mean	Polarity
1	Personal contact and interaction	Trust	4.54	0.060	Direct
2	Trust	Power and sense of ownership of knowledge	4.11	0.054	Indirect
3	Teamwork and shared goals	Trust	4.38	0.058	Direct
4	Trust	Communication	4.37	0.058	Direct
5	Power and sense of ownership of knowledge	Personal contact and interaction	4.11	0.054	Indirect
6	Communication	Personal contact and interaction	4.51	0.060	Direct
7	Personal contact and interaction	Interpersonal skills	4.02	0.053	Direct
8	Interpersonal skills	Power and sense of ownership of knowledge	4.15	0.055	Indirect
9	Expertise development	Individual knowledge/skills	4.11	0.054	Direct
10	Communication	Expertise development	4.05	0.053	Direct
11	Individual knowledge/skills	Communication	4.11	0.054	Direct
12	Interpersonal skills	Individual knowledge/skills	4.05	0.053	Direct
13	Self-efficacy	Individual knowledge/skills	4.15	0.055	Direct
14	Peer relations	Communication	4.31	0.057	Direct
15	Individual's agreeableness	Communication	4.11	0.054	Direct
16	Mutual reciprocity	Communication	4.15	0.055	Direct
17	Team composition	Teamwork and shared goals	4.34	0.057	Direct
18	Communication	Teamwork and shared goals	4.11	0.054	Direct

Table 6: Interrelations for System Dynamics Model with Normalized Influence Mean

Four stocks were identified in the system dynamics model; communication, personal contact and interaction, trust and individual knowledge/skills. An additional stock was introduced in the model named as project performance to observe the convergence of four stocks. Equations developed through normalized mean influence for inflows and outflows of all stocks are given below;

1. Communication inflow = $0.058*V_1 + 0.054*V_{10} + 0.057* V_5 + 0.054* V_8 + 0.055* V_4 + 1.00*V_{16}$

Equation 3

2. Communication outflow = $1.00*V_{16}$

Equation 4

3. Inflow of personal contact and interaction rate = $0.060*V_{16} - 0.054*V_7 + 1.00*V_2$

Equation 5

4. Outflow of personal contact and interaction rate = $1.00*V_2$

Equation 6

5. Trust inflow = $0.058*V_{11} + 0.060*V_2 + 1.00*V_1$

Equation 7

6. Trust outflow = $1.00*V_1$

Equation 8

7. Inflow of Individual knowledge/skills = $0.054*V_9 + 0.053*V_{18} + 0.055*V_{19} + 1.00*V_{10}$

Equation 9

8. Outflow of Individual knowledge/skills = $1.00*V_{10}$

Equation 10

9. TKS inflow = $V_{16} + V_2 + V_1 + V_{10}$ + 1.00*Tacit knowledge sharing

Equation 11

10. TKS outflow = 1.00* Tacit knowledge sharing

Equation 12

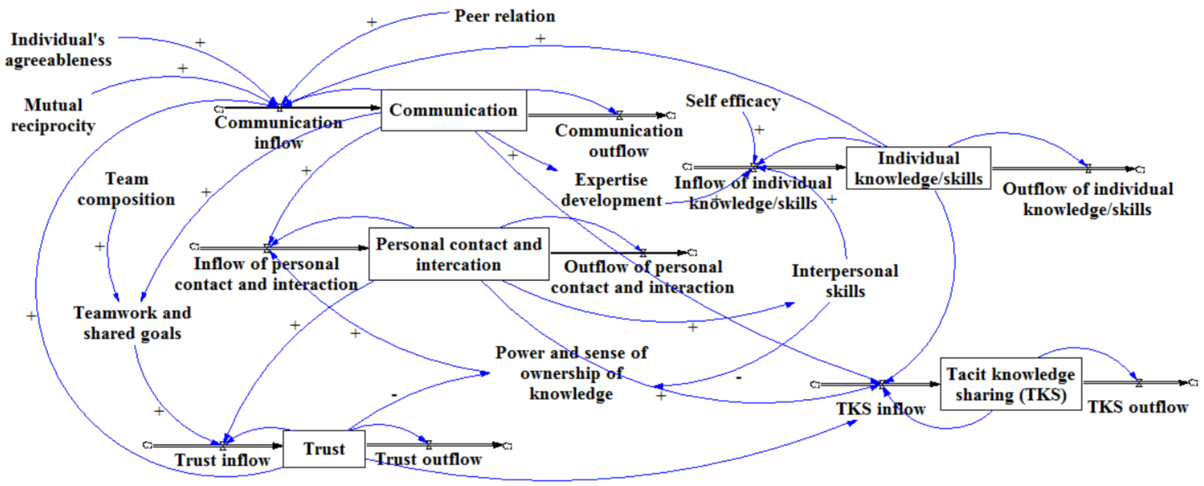

Figure 31: System Dynamics Model

4.5.1. Simulation and Results

Simulation represents the behaviour of the system over 5 year's period. The values of exogenous variables peer relations, individual's agreeableness, mutual reciprocity, team composition and self-efficacy were kept constant i.e. one throughout the simulation. Four stocks named as *communication, personal contact and interaction*, *trust* and *individual knowledge/skills* were simulated separately over the period of five years and results are explained one by one. Simulation graph of power and sense of ownership of knowledge was also shown to express decreasing behaviour. At the end, additional stock named as *Tacit*

Knowledge Sharing was also simulated to observe the impact of all these four stocks which were converged on it.

By keeping values of exogenous variables to unity, *communication* gradually increased in a linear way over the period of five years. This was because of the reinforcing loop in which factors like *trust* and *individual knowledge/skills* were positively complementing the *communication*.

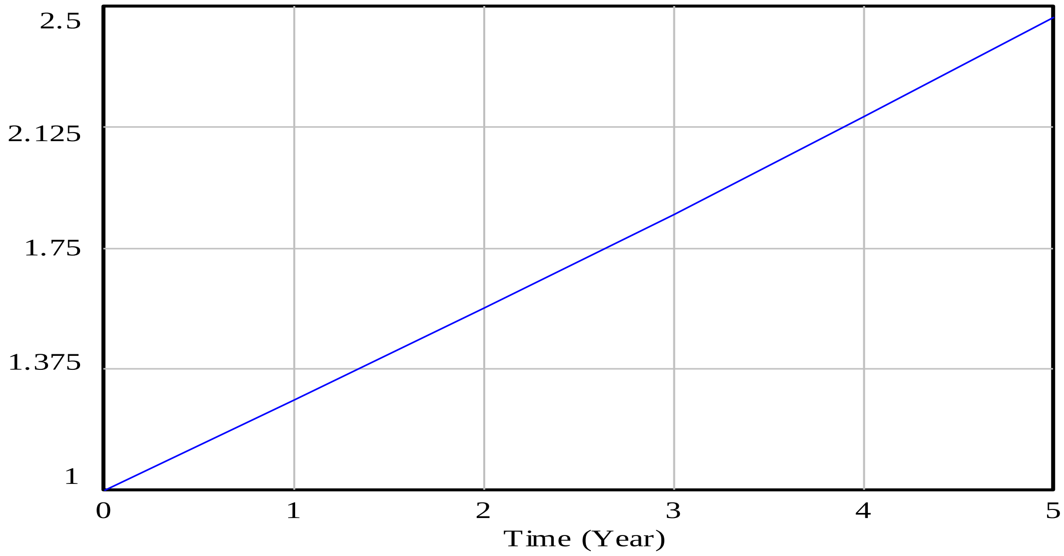

Figure 32: Simulation Graph (Communication)

Similarly, *personal contact and interaction* also gradually increased over the period of five years. This was also because of the reinforcement on the communication factor, although *power and sense of ownership* of knowledge was negatively complementing the *personal contact and interaction* but still cumulative impact of positive influence was higher which was causing *personal contact and interaction* to increase over the period of time.

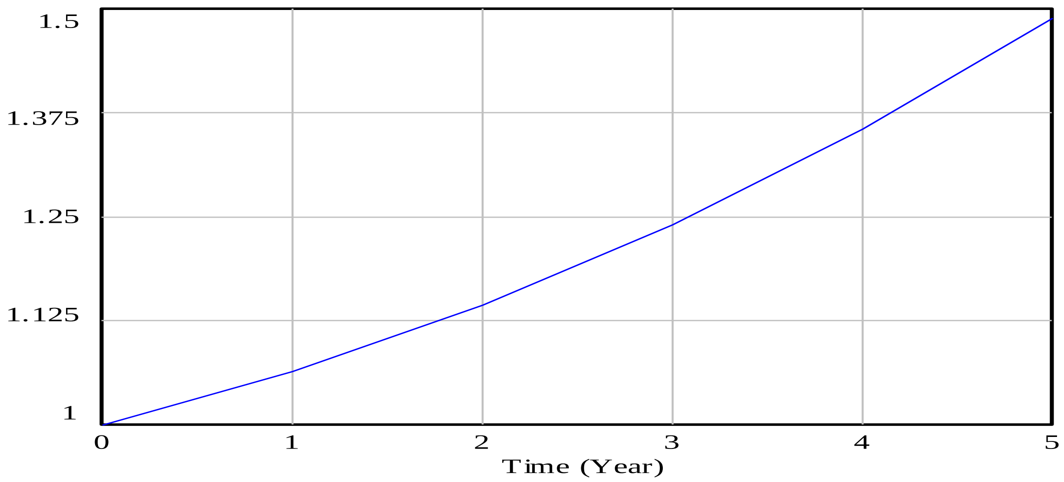

Figure 33: Simulation Graph (Personal contact and interaction)

Likewise, *trust* also increased in almost a linear way. This was also because of factors like *personal contact and interaction* and also *teamwork and shared goals* which were complementing the trust positively.

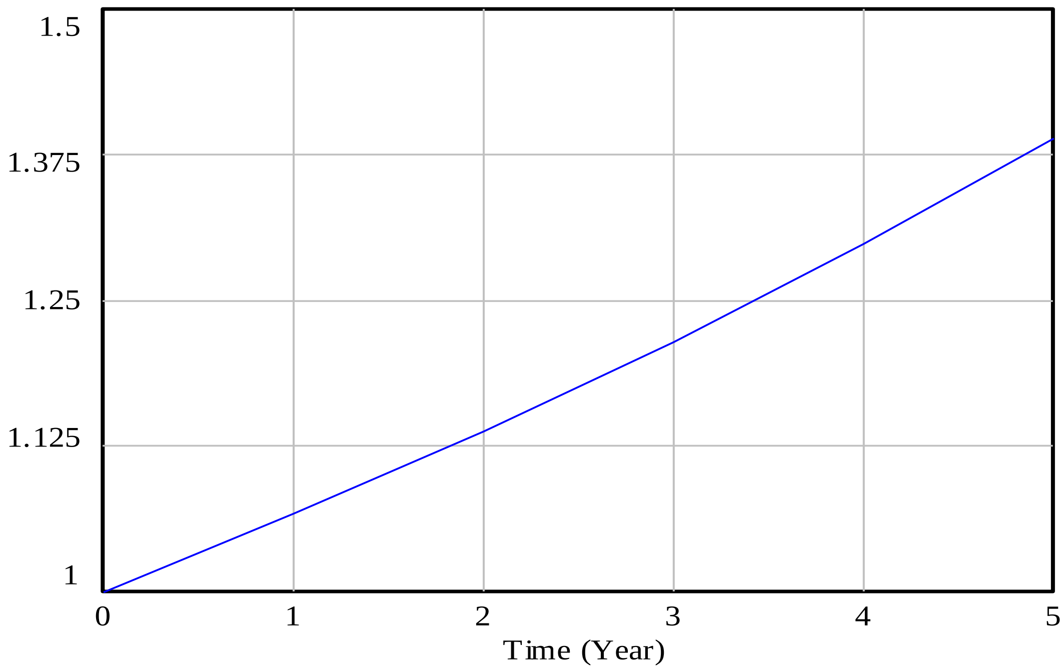

Figure 34: Simulation Graph (Trust)

Furthermore, *individual knowledge/skills* also increased in an almost linear way because three factors *self-efficacy*, *expertise development* and *interpersonal skills* are complementing the individual knowledge/skills positively. The value of *self-efficacy* was kept constant throughout the simulation i.e. unity.

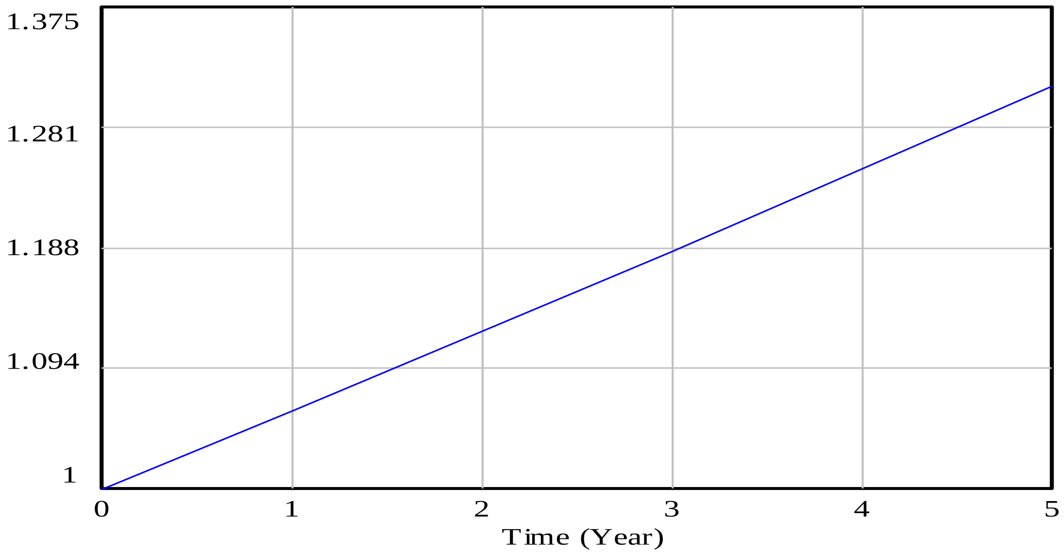

Figure 35: Simulation Graph (Individual knowledge/skills)

Simulation graph of *power and sense of ownership of knowledge* suggested that it's decreasing over the period of time because factors like *interpersonal skills* and *trust* were complementing it negatively.

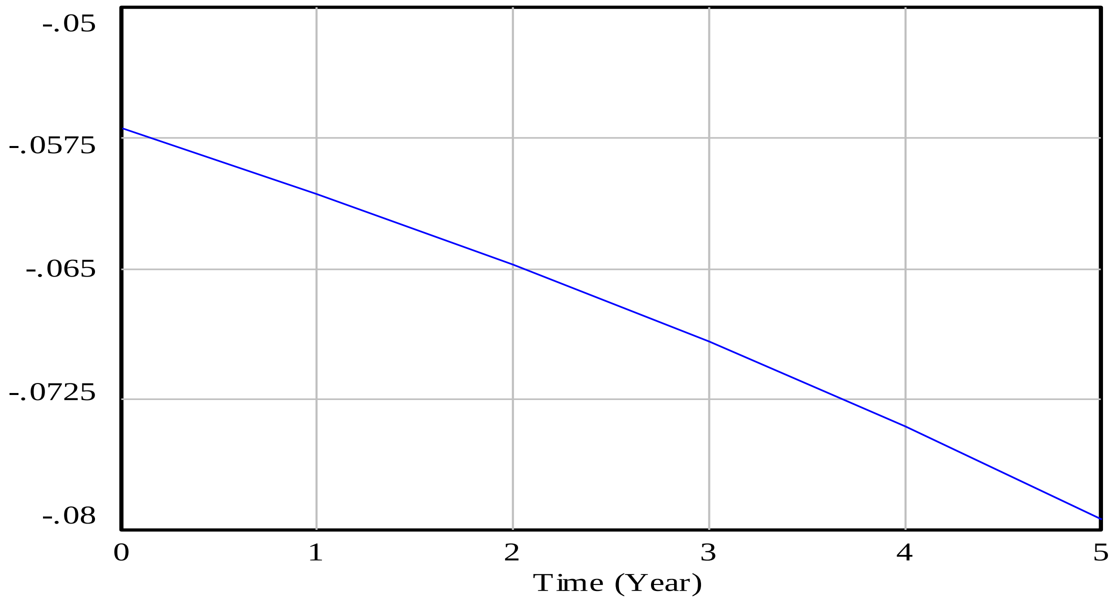

Figure 36: Simulation Graph (Power and sense of ownership of knowledge)

Lastly, simulation graph of *Tacit Knowledge Sharing* which took input from all the four stocks also showed an increasing curve over period of time which was very logical understandable since all the four stocks were increasing under the influence of reinforcing loops/interrelationships. The model directed that *Tacit Knowledge Sharing* increased with the passage of time under the given system and hence project performance.

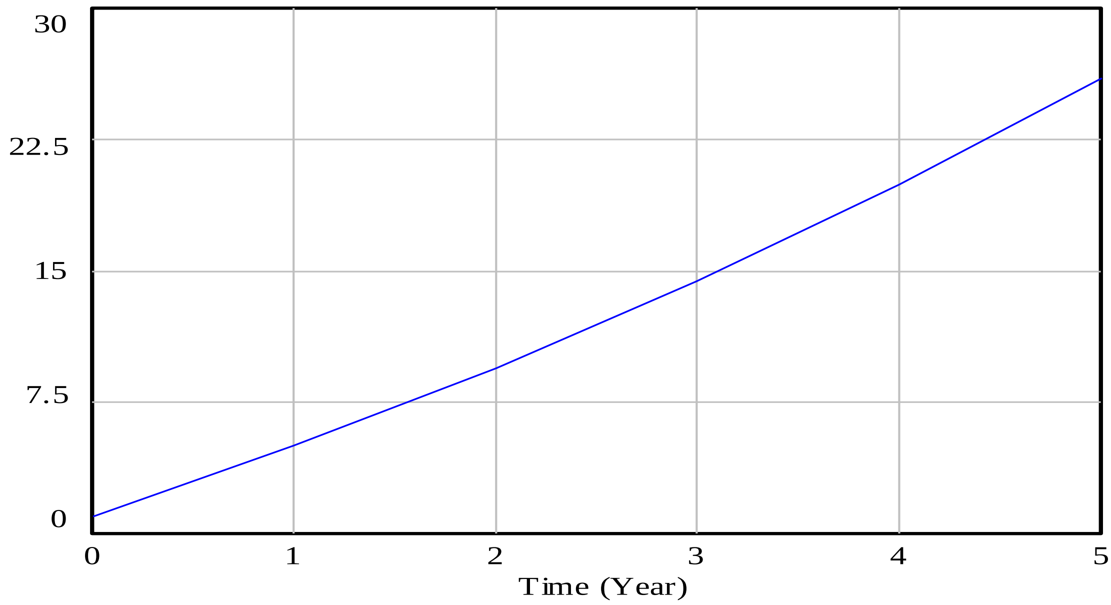

Figure 37: Simulation Graph (Tacit knowledge sharing)

4.5.2. Model Validation

System dynamics model addresses a specific problem and the confidence with which it can be applied does not depend upon whether it can address other problems or not (Richardson and Pugh, 1981). As described by (Sterman, 2002), validation of a system dynamics (SD) model depends upon the purpose for which it was developed. The objective of this system dynamics model was to address complexity resulting from tacit knowledge sharing and to observe the role of tacit knowledge sharing in construction. The first step in validation is to validate the model structure and following four tests are used to validate the model structure (Qudrat-Ullah and Seong, 2010).

a. Boundary-adequacy test
b. Structure verification test
c. Parameter verification
d. Extreme condition test

Apart from validating the model structure, model behaviour verification test is also employed to verify behaviour of the model.

4.5.2.1. Boundary-adequacy test

The purpose of this test is to verify three things; whether all the important concepts are endogenous to the structure or not, whether behaviour of the model change significantly when boundary conditions are change and whether policy recommendations change when boundary is extended (Sterman, 2002).

In the current system dynamics (SD) model, all the variables are found through a thorough literature review and counter validated by respondents of construction industry. All the variables in the SD model are endogenous such as expertise development and interpersonal skills except five which are exogenous such as self-efficacy and team composition. Under simulation, the behaviour of the does not change significantly when boundary conditions are changed and same goes with policy recommendations.

4.5.2.2. Structure verification test

The objective of this test is to verify that the structure of the model is consistent and logical; hence this step is of significant importance in terms of verification of the system dynamics model.

In the current SD model, all the variables are identified through a thorough literature review and counter verified by experts of construction industry. Causal loop diagram is developed by determining influence and relationship of each factor on the other from expert construction professionals, the resulting CLD was further modified through construction experts to make it meaningful. Hence, the SD model is cognisant, logical and closely representing the actual construction industry system. This methodology is in conformance to as followed by (Qudrat-Ullah and Seong, 2010).

4.5.2.3. Parameter verification

The mathematical functions used in the system dynamics model were developed based upon two things; influence of factor on the other and polarity. Both the influence and polarity of each factor on the other were determined through field construction experts.

4.5.2.4. Extreme condition test

The current system dynamics was already simulated under extreme conditions since all the exogenous variables were given unity values i.e. 100%. The results showed that model behaviour is still meaningful as "Tacit knowledge sharing" (the convergence point of all the four stocks in the model) increased under the given system and hence project performance.

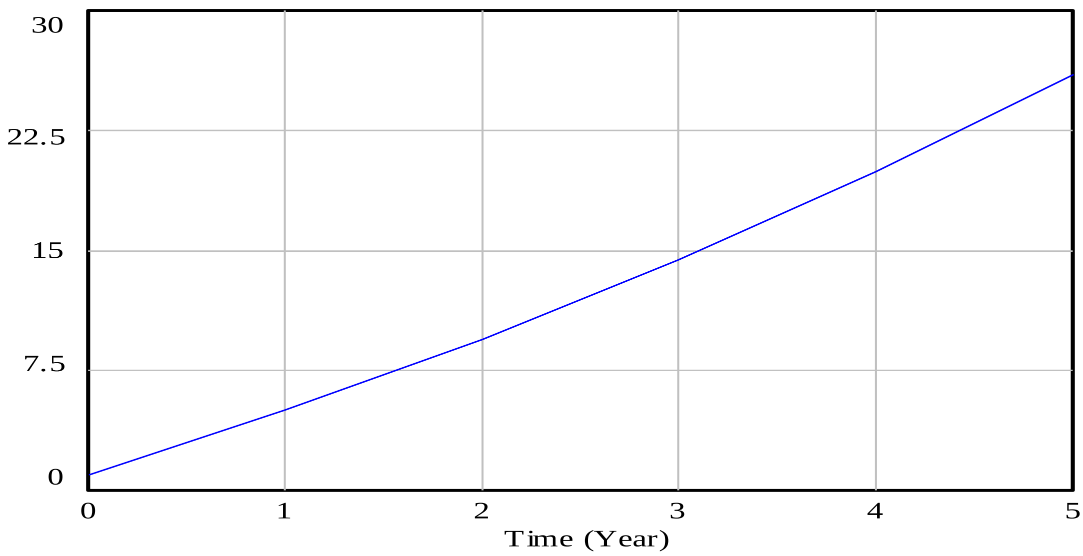

Figure 38: SD model behaviour under extreme conditions

4.5.2.5. Model behaviour verification test

This test is employed to observe whether the behaviour of the model is in line with the previous similar models. Since, no previous such studies have been conducted which resulted in a system dynamics model for tacit knowledge sharing so the comparison was not possible. However, the behaviour of the model system is very logical which showed increase in tacit knowledge sharing (project performance) over time. This is because the contributing factors of tacit knowledge sharing were identified through a thorough literature review and counter verified by construction professionals, and most of the interrelations between factors were reinforcing with direct influence so it's logical to expect increase in tacit knowledge sharing over time and hence project performance (Pathirage et al., 2007).

Chapter 5

CONCLUSION AND RECOMMENDATIONS

Most of the knowledge in construction is tacit rather than explicit so aim of this study was to address tacit knowledge sharing complexity which leads towards improved project performance in construction. System dynamics was used as a tool to reflect systems thinking and subsequently develop a model to address complexity resulting from tacit knowledge sharing.

Data was collected in two stages named as preliminary survey and detailed survey. Preliminary survey was carried out to shortlist contributing factors of tacit knowledge sharing and detailed survey was carried out to shortlist most influential interrelationships between the factors along with their polarities. Expert opinions were also carried out in order to make causal loop diagram meaningful and ensure its relevance to construction industry.

The study started from identifying contributing factors of TKS from literature. A total of 57 contributing factors of TKS were identified from literature. A preliminary questionnaire was developed based upon these 57 contributing factors of TKS in which respondents were asked to rank contributing factors of TKS on Likert scale ranging from 1 to 5. Normalized score for literature as well as respondents was developed for contributing factors of TKS and then merged using 50/50 ratio. A total of 19 contributing factors of TKS were shortlisted having cumulative normalized score ranging up to 50 percent. Trust, personal contact and interaction, team composition, mutual reciprocity and peer relations were identified as top 5 contributing factors of TKS.

In order to develop systems thinking and causal loop diagram (CLD), a detailed questionnaire was developed in which respondents were asked to mark causal strength (low, medium or high) as well as causal relationship (direct or indirect) of each contributing factor of TKS on the other. Causal loop diagram was developed based upon interrelations having mean influence value 4<=m<=5. The causal loop diagram was modified based upon expert opinions of construction professionals in order to make it meaningful and ensure its relevance to construction industry. Causal loop diagram consists of four reinforcing and two balancing loops.

Lastly, based upon modified systems thinking and CLD, a system dynamics model was developed using VENSIM®. Shortlisted causal influence scores were normalized to be used in the system dynamics model and hence stock and flow diagram resulting in a SD model was developed through simulation. Model consists of four stocks; **communication**, **personal contact and interaction**, **trust** and **individual knowledge/skills**. One more stock was added in form of **tacit knowledge sharing** and all the four stocks are merged on it in order to see their combined effect.

The model was simulated over five years' time period. The values of exogenous variables peer relations, individual's agreeableness, mutual reciprocity, team composition and self-efficacy were kept constant i.e. one throughout the simulation. All the four stocks under the influence of reinforcing interrelationships showed increasing behavior over the period of time. Simulation graph of the factor power and sense of ownership of knowledge decrees over the period of time because it's been negatively complemented by trust and interpersonal skills of the project team members. Subsequently, "Tacit knowledge sharing" graph also showed an increasing curve because it's the convergence point of all the four stocks. This basically reflects upon the point that tacit knowledge sharing increase over the period of time under the defined system and so as the project performance.

The findings of this study provide a path to the construction companies for developing a culture/strategy which is more favourable for tacit knowledge sharing and thereby improving construction project performance. CLD and SD model holistically explains tacit knowledge sharing culture through systems thinking and behaviour over time. Future research may be directed towards application of the developed model in the construction industry.

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APPENDICES

Appendix 1: Preliminary Questionnaire

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Appendix 2: Detailed Questionnaire

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