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USING SYSTEM DYNAMICS MODELLING PRINCIPLES TO RESOLVE PROBLEMS OF REWORK IN CONSTRUCTION PROJECTS IN NIGERIA

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ABSTRACT

Rework in construction projects has brought in two major challenges: cost overruns and delay. In this regards a study was conducted by considering various construction projects in the South West part of Nigeria to understand the causes of rework and the interventions to mitigate it. Survey research methodologies followed by the conceptual system dynamics (SD) modelling were used in the analysis. This study identified the sources of rework in construction projects from the design related, the client related and the contractor related issues and attempted to derive policy/strategic interventions to limit or eliminate rework on construction projects and its delivery by using conceptual SD models based on the influence of the variables on rework. The findings include that inappropriate scheduling for time pressure or delay at the planning stage, lack of adherence to the specifications, and non-availability of skilled human resource are the major causes of rework. However, rework in construction projects would be reduced or eliminated through policy interventions, such as, achieving client satisfaction with scheduling for time pressure or delay at the planning stage, adherence to specifications ensuring quality of work resulting in client satisfaction, and the availability of skilled manpower ensuring quality management.

Keywords: Rework; Construction projects; System dynamics modelling; Client satisfaction; Cost and delay

1. INTRODUCTION

Construction projects particularly large public projects all over the world involve many challenges. The tasks and activities in the Construction Industry relative to the projects are complex and dynamic in nature. The productivity of these projects or the Construction Industry is usually associated with a number of variables e.g. dealing with diverse interests of multiple stakeholders and resultant changes/variations, rework and wastages among others (Alwi 2002; Josephson 2002). These challenges also affect the delivery of the projects which have specified deadlines and fixed budgets (Alwi et al. 1999). However, rework is considered as one of the major non-value adding endemic symptoms that seriously affect the performance and productivity in construction projects delivery. Specifically, it has been established as a primary cause of both cost and schedule overruns in construction (Love, Mandal et al. 2000).

Although rework has not been uniquely and explicitly defined, yet it constitutes several aspects depending upon the context and nature. According to Ashford (1992), it is a process by which an item in the construction project is made to conform to the original requirement by completion or correction. However, the Australian Construction Industry Development Agency (CIDA), defined rework as ‘‘doing something at least one extra time due to non-conformance to requirements’’ (CIDA 2001). Similarly, Rogge (2001) interpreted it as activities in the field, which are required to be done more than once or activities that remove work previously installed as part of the project. Besides, according to Love et al. (2000) it is said to be the unnecessary effort of redoing a process or activity that was incorrectly implemented in the first time. However, rework has various definitions and interpretations within the construction management literature (Love 2002b; Hwang et al. 2009), terms for it includes “quality deviations (Burati et al. 1992), nonconformance (Abdul-Rahman 1995), defects (Josephson and Hammarlund, 1999) and quality failures (Barber et al. 2000). Scholars like Ashford (1992) also argues that repair can be included as rework, as it is a process of restoring a nonconforming characteristic to an acceptable condition even though the item may not still conform to the original requirement. Therefore, rework essentially occurs when a product or service does not meet the requirements of the customer in the form of quality or function. Consequently, the product is altered in accordance with customer’s requirements and specification of the engineers (Alwi et al. 1999).

Rework can also be treated as both positive and negative. While the positive rework adds value to the project, such as, design reworked for a better understanding of client requirement. The negative rework extends projects schedules and the total cost increases (Ballard, 2001). However, despite its positive aspects reduction of rework is crucial for achieving reduced wastages, good performance and enhanced productivity in construction project systems (Love et al. 2000; Fayek et al. 2004; Palaneeswaran et al. 2005a).

However, rework is found to be a menace in Nigerian construction industry (Oyewobi and Ogunsemi 2010). An analysis of 31 projects executed during 2009-2011 in Lagos and Ondo state of the country revealed that due to rework, time overruns can go up to additional 245% of the initial time schedule. Similarly, cost overruns amount up to 11.00% of the initial cost estimate (Appendix 1). According to Oyewobi and Ogunsemi (2010), the critical variables influencing rework are sub-standard services rendered by professionals and defects in the construction work. Besides, improper site management, lack of team work, lack of trust and commitment on the part of the professionals and workers, lead to failure of quality management, which cause rework significantly. Improper planning of human resources is also a significant factor observed to have adverse impact on construction resulting into rework (Oyewobi and Ogunsemi 2010). Concurrently, the causes of rework as observed from these projects are found to vary from collapse of structural elements, poor workmanship, poor finishing, use of poor quality materials, to failure of mechanical and electrical installations and so on (Appendix 1). There is no congruity among the factors observed by the professionals causing rework in construction projects in Nigeria.

Therefore, the objective of this paper is to investigate the causes of rework in a structural way in construction projects and identify mechanisms for developing plausible strategic interventions, which would enable reduction in the rework and improve performance of construction projects. This investigation was conducted by considering construction projects concentrated in the South West part of Nigeria. Survey research methodology was employed to collect primary data from the various stakeholders on construction projects. The data was analysed by using Likert scale (Gravetter and Wallnau 2008) followed by the development of conceptual models by using system dynamics modelling principles based on the systems thinking process.

The merit of the paper lies in applying the systems thinking archetypes and using system dynamics modelling principles to develop conceptual models to understand the causal feedback relationships among the various variables, which cause rework and derive mechanisms for strategic interventions to enable the construction project managers and leaders to take appropriate decisions to reduce or mitigate the impact of rework in construction projects.

2. LITERATURE REVIEW

2.1 Origin and Implication of Rework in Construction Projects

Rework in construction generally originates from the identification of defects. It can also result from changes in the requirements and or when the implemented design lacks required standard of quality, needing some of the implemented design to be scrapped and reworked, and so the term originated (BRE 1981; and Love and Edwards 2004).

Rework has different impacts on project performance depending on the time when it occurs in a construction process. Since rework is the act of performing a task more than once, it can occur at different stages throughout the project life cycle.

Fayek et al. (2004) observed that rework clearly has a huge impact on project performance whether or not projects can be completed within time and cost constraints. Rework also has a large general impact on the industry as a whole; the impact of rework can be direct or indirect. Although rework has some positive aspects, such as, improved quality, fulfilling of client requirements yet, it is a significant factor that contributes negatively to the construction process and can lead to time overruns, inflation, cost overrun, client dissatisfaction, contractor's financial difficulties, contractor dissatisfaction, design team dissatisfaction, and reduces profitability. Besides, there are other likely consequences of rework, such as, end user dissatisfaction, inter-organisational conflict and litigation, stress and fatigue among the stakeholder and workers, work inactivity, de-motivation, and damages to professional image (Ballard 2001; Love and Edwards 2004).

Causes of Rework

Construction process is very complex. Significant attention and supervision is required to avoid mistakes. Bon-Gang (2009) corroborated the findings of other scholars like Ashford (1992), Love et al. (2000), Rogge (2001) and others and suggested that rework can arise from a number of sources such as changes, non-conformances (e.g. quality deviations), and defects. However, Love and Edwards (2004) classified the root causes of rework into three aggregate factors such as design-related factors, client-related factors, and contractor related factors. Besides, Fayek et al. (2004) identified five major causes of rework, which are related to lack in human resource capability, lack of leadership and communications, inefficient engineering and reviews, inappropriate construction planning and scheduling, and inadequate materials and equipment supply. Causes of rework also differ from one country to another and from one project type to another. Therefore, it should not be relied upon its literal meanings but simply can be treated as suggestive, as levels and interpretations of quality will differ. Local practices, industry culture, and contractual agreements may also have a significant influence on the incidence of the work (Love et al. 1999). However, looking at the amorphous perception of the professional towards the causes of rework in Nigerian Construction industry, it was felt relevant to investigate the causes of rework under three aggregate factors such as, design-related, client-related, and contractor related factors as suggested by Love and Edwards (2004), which have significant influence on rework that this study focuses on.

2.1.1 Design-related factors

A number of findings have emphasized the fact that most reworks originate at the design stage than in the construction stage (BRE 1981; Palaneeswaran 2006; Peter and Li, 2000; Trigunarsyah 2004). According to Palaneeswaran (2006) ineffective use of quality management practices, ineffective use of information technologies, lack of manpower to complete the required tasks, insufficient time to prepare the contract documentation, incomplete design at the time of tender, poor conditions between different design team are some causes of rework.

On the other hand another important study by Trigunarsyah (2004) attributed detailing (inaccurate or inadequate detail), specification (incorrectly specified or inappropriate materials and components), legislation (inadequate knowledge of or disregard for legislation or guidelines), co-ordination (inadequate coordination between client / designer, designers, and designers / contractors), communication (poor interaction between client / designer, and designers /contractors), supervision (inadequate supervision by designers), and constructability (lack of design empathy for construction) are the design related problems causing rework (Love 2005). However, under the pressure to improve project cost and schedule performance, many companies have accepted the fast-tracking approach under which the design phase and the construction phase overlap (Peña-Mora and Li 2001; Fazio et al. 1988). Because of this overlap the contractor can start the construction phase with flawed plans that have undiscovered errors, which can cause rework in the later stages of the project (Li and Taylor 2012).

2.1.2 Contractor-related factors

Faniran et al, (1999); Love et al. (2004); Love (2005), and Palaneeswaran et al. (2005b) identified some contributions to rework from the contractors. The most important factors include poor planning and coordination of resources; ineffective use of information technologies; setting-out errors; ineffective use of quality management practices; staff turnover or reallocation to other projects, and failure to provide protection to constructed works. Similarly, Fayek et al. (2003) observed that insufficient skill level, constructability problems, and poor communications. Investment in the placement of a number of on-site planning personnel for each work task on each discipline, and material and equipment supply particularly prefabrication and construction not to project requirements have a larger contribution to rework. Besides, according to Palaneeswaran et al. (2007) poor managerial practices and inadequate quality management in the part of the contractor and non-detection of the errors for rectification during the construction work also lead to rework in the later stages of construction.

2.1.3 Client-related factors

The client contributions to rework in the delivery of projects can be categorised in two forms: (a) from the design related sources, such as, the design changes made at the request of clients; and (b) from the construction related sources, such as, changes initiated by the clients (Fayek et al 2004; Love and Edwards 2004). These changes can however happen both after some work have been undertaken on-site, and when the product / process had been completed. The major contributing factors could be lack of experience and knowledge of the design and construction process, lack of funding allocated for site investigations, lack of client involvement in the project, inadequate time and funds attributed to the briefing process, poor communication with the design consultants, payment of low fees for preparing contract documentation, ineffective use of information technology (e.g., visualization), and inadequacies in contract documentation (Cnudde 1991; Abdul-Rahman 1993; Josephson and Hammarlund, 1999; Love, Li, and Mandal, 1999; Love, Mandal and Li, 1999; Barber et al. 2000).

2.2 System Dynamics Modelling Approaches to Rework

A system constitutes a set of components, which are interlinked and interdependent on each other to perform a function as a whole (Von Bertalanffy 1974; Forrester 1968). In a system, if a subsystem performs at a higher efficiency than others or becomes defunct then the effect is felt on the whole system. As a result, the whole system may perform at a lesser efficiency or even may become paralysed. In order for the system to perform at a higher efficiency all the subsystems of the system are to work in a coordinated manner. A construction project is a system having a complex set of subsystems, which needs to perform in a coordinated manner to achieve the desired outcome, avoid delay, ensure quality, and more so avoid rework. Thus, in a construction project environment systems thinking process would enable a detailed operational thinking process to have a view of the project in a holistic manner and consequently provide insights to avoid rework.

Investigation regarding various aspects of rework and application of SD in evolving solutions has been taken up by several scholars over the last four decades. The initial instances of SD application in rework was seen from the works of Cooper (1980, 1993) followed by important works of scholars like Abdel-Hamid (1984); Ford and Sterman (1998a, 2003b); Rahmandad and Hu (2010); Owens et al. (2011) and Parvan et al. (2012, 2013) to name a few. However, Lyneis and Ford (2007) provide a detailed discussion regarding SD application on various aspects of rework in his review work "System Dynamics Applied to Project Management". The strength of SD model in rework is that it allows estimating the impact of undiscovered design changes on construction phase quality (Parvan et al. 2012, 2013). Further, Rahmandad and Hu (2010) declare that the quantitative analysis of SD allows for capturing significant schedule over-runs due to a few tasks, with multiple defects, that may cycle through rework process multiple times with robustness in the context of multiple project parameters. Recently, Han et al. (2013) used SD to examine how design errors that lead to rework and/or design changes contribute to schedule delays and cost overruns. While design errors are deemed prevalent, most design and construction firms do not measure the number of errors they create, thereby having limited knowledge regarding their mechanism to undermine project performance. Han et al. (2013) concluded based on their case study that as construction projects are known to involve complex, inter-dependent, uncertain and labour-intensive work, the developed model can assist project managers to understand the dynamics of design errors and recovering delays better, particularly when confronted with schedule pressure. Similarly, Gilkinson and Dangerfield (2013) developed a dynamic model of a typical contracting firm and construct a competitive index to model contract allocation in a stylized market. The simulated scenarios from the model offer insights about how endogenous behaviour can shape the future of the enterprise and minimize unexpected behaviour.

Although, both the works provided new paradigm to the operational thinking of the construction industry, they are case studies and need generalisation particularly with respect to rework. Besides, Han et al. (2013) confined their work to examine how design errors that lead to rework and/or design changes contribute to schedule delays and cost overruns. As the construction projects are getting increasingly complex and dynamic and there are three factors- design, client and contractor related factors overwhelmingly influence rework, there is still a need to look into the rework aspect in a more holistic way, understand the system conceptually and derive principles in order to develop policy interventions before developing generalised quantifiable models.

2.3 Justification of the Use of Conceptual Modelling Based on SD Paradigm

A conceptual model provides a consistent and unifying premise of behaviour taken from bits of information about the real world (Wolstenholme 1992; Robinson 2008). The rigorous structural framework offered by SD assists in eliciting and displaying information used to build a conceptual model (Forrester 1994; Lane and Oliva 1998), which allows to understand how and why the dynamics of concern are generated and enable policy and strategic interventions based on causal feedback relations to improve the situation (Forrester, (1968, 1969); Lee, Choi and Park 2005; Montibeller and Belton 2006; Park et al. 2013). Besides, unlike many mechanistic systems or physical modelling, SD is based on the principle of operation thinking with a feedback mechanism of information-decision-action and influence on the environment. This feedback mechanism provides the dynamic hypotheses with distinctive explanatory power to diagnose the problems and visualise the behaviour of the system under different scenarios (Forester 2003, Olaya 2012; Sterman 2000).

The analysis of the literature reveals that there is no unanimity among the scholars on causes of rework although there is agreement on various factors causing rework across various aspects relating to construction projects. Further, the studies on the inter-linkage and causal relations among these factors causing rework are found to be limited (Lyneis and Ford 2007) although it is acknowledged that a few investigations have been attempted in this direction. Therefore, this study focuses on the delineation of the variables causing rework in the construction project environment and their causal relationships by the application of systems thinking and the conceptual SD modelling so that it would enable reduction or mitigation of rework, the problem can be diagnosed, when the need arise and necessary strategic interventions can be at any stage of construction.

3. MATERAIL AND METHODS

3.1 Projects and Professionals Surveyed

Table 1 presents the characteristics of the projects and professionals surveyed. The study was conducted in the South-Western part of Nigeria and confined to Lagos- a high construction activity area and Ondo being the proxy.

The organisations surveyed were distributed over both private and public sectors and include contracting, consulting, private developers, Federal ministry and State ministry. Professionals such as architects, engineers, project managers and quantity surveyors having experience more than five years and professional qualifications have been consulted and surveyed. The projects from which the professionals were chosen for the survey include both medium and large scale construction projects, such as building of hospitals, office complexes, schools and commercial buildings.

Table 1. Background Information of Respondents

Category	Classification	Number	%
Location	Lagos	71	59
	Ondo	49	41
Nature of Organization	Contracting	69	58
	Consulting	17	14
	Federal Ministry	6	5
	State Ministry	12	10
	Developer	16	13
Profession of the respondents	Architecture	32	27
	Engineering	12	10
	Quantity Surveying	15	13
	Builder-Project management	61	51
Academic Qualification	OND/HND	14	12
	BSC/BTECH	84	70
	MSC/MTECH	16	13
	PHD	6	5
Professional Qualification	Graduate Member	68	57
	Corporate Member	10	8
	Fellow	0	0
	Non-member	42	35
Experience of Respondent	5 – 10	32	27
	11 – 20	65	54

21 − 30	13	11
31 – 40	6	5
Above 40	4	3

3.2 Methodology- Data Collection and Analysis

Survey research methodology was employed to collect primary data from the various stakeholders in the construction projects considered for the study. A total of 145 questionnaires were administered, of which 120 were returned (approximately 83% response rate). The simple random sampling technique was used in the selection of samples for the survey. Samples were drawn from the Nigerian Institute of Quantity Surveyors, Federation of Contractor Institution, Nigerian Institute of Architects, and Nigerian Institute of Engineers (Structures).

The sample size and response rate was considered fairly adequate for the statistical analysis because of two main reasons. First, the professionals concerned are from the middle and higher level in the hierarchy in the projects and they are limited in numbers. Second, the result of the survey would be considered biased and of little value if the return rate is lower than 40% (Kothari, 2004) and in this case the response rate is quite significant. Further, the diverse and varied characteristics of the respondents (Table 1) implied that the information provided by the respondents can be relied upon for the purposes of the analyses.

Quantitative descriptive statistics analysis and Cronbach's alpha test of the data collected were conducted to observe the reliability of the data. Likert scale (Gravetter and Wallnau 2008) was employed to measure the relative influence of the variables (as obtained from the surveyed data) on the most important parameters (such as client, design and contractor) causing rework. The influential variables, their positive and negative influences on the related variables and the causal relationships among them were used to develop conceptual models by using system dynamics modelling principles based on the systems thinking process (Von Bertalanffy 1974 and Forrester 1968, 1969). The causal relationships among the variables within and across the major parameters were developed based on the discussions and experiences of the professionals surveyed.

While developing the causal relationships, initially the variables such as information, decision and action and environment (system) variables (Olaya 2012) were identified. The variables are then connected with simple one way causality in terms of one way linkages of information – decisions – actions – impact on the environment (i.e., information assisting in evolving decisions (policy interventions), decisions leading to appropriate actions, and actions influencing the environment (system)) and (Veniix 1996 and El Halabi et al. 2012) with their influence (Fig. 1).

Once the one way causality is established the feedback relationships are checked and established. The constructed causal feedback relations were then discussed with the professional and experts in the field to check the veracity of the causal diagrams and relevant modifications with respect to the variable names, their polarity and causal relations as need be are made. The valid causal feedback diagrams (causal loop diagrams) were then employed to develop the conceptual SD models.

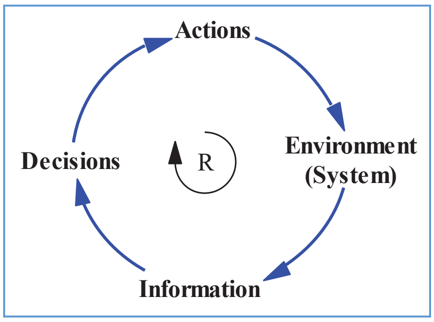

Fig. 1. Methods adopted for construction of causal feedback relations

3.3 Understanding the Causes of Rework and Conceptual Modelling: Findings and Discussions

Rework is a very crucial issue to watch against during construction. As suggested in many previous studies (Ashford 1992; Fazio et al, 1988 Love et al. 2000, 2004; Palaneeswaran et al. 2007, Peña-Mora and Li 2001; Rogge 2001) several factors contribute to rework in a project. However, in this investigation three most important parameters namely, client, contractor, and design related functions are considered as the main controlling parameters, which influence rework. Fig. 2 presents the aggregate causal feedback relationships among these three important parameters and rework. It illustrates that each of the three controlling parameters contributes to rework in three different forms, viz., independently, in combination and in terms of the influence of multiplying effect among the factors of the main parameters.

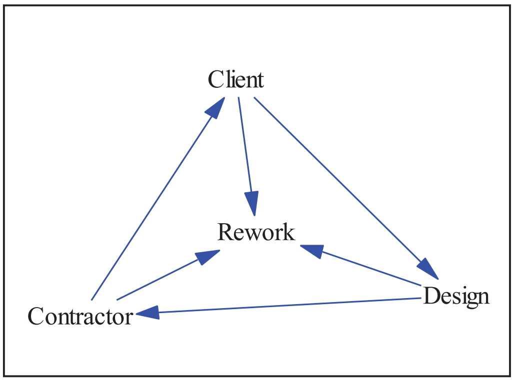

Fig. 2. Aggregate causal feedback model for rework

3.3.1 Design Related Factors Contributing to Rework

Table 2 presents the various factors and their relative influence on rework. There are a subset of 11 design related factors found more influential, from a set of total 30 parameters, which are ranked according to their level of influence based on the mean score in the Likert scale and standard deviation. The outcome of construction activities lies mostly in the quality of design. It is observed that non-adherence to specification, complex design, time pressure / delay and poor communication, lack of understanding and correct interpretation of customer requirements, constraint in carrying out activities, inexperience of personnel, poor technology application, poor quality contract documentation, and lack of information technology use, and design changes are the major factors which influence rework. However, from the expert discussion and established literature (Han et al. 2013; Love, Lopez, Edwards, Goh 2011; Love, Edwards, Han, Goh 2011; Love, Edwards, Irani, Walker 2009; Love, Edwards, Irani 2008; Love and Edwards 2004) non-adherence to specification, complex design, time pressure / delay and poor communication are the four main parameters, which influence rework, and are thus considered in the development of conceptual model.

Table 2. Design-Related Factors Relative to the Causes of Rework

S/N	Design-Related Factors	Not Severe	Less Severe	Severe	More Severe	Most Severe	Mean Score	Standard Deviation
1	Lack of understanding and correct interpretation of customer requirements	4	5	17	36	58	4.16	1.037
2	Constraint in carrying out activities	5	10	20	33	50	3.91	1.250
3	Inexperience of personnel	2	15	24	32	47	3.89	1.113
4	Poor communication	10	6	39	34	31	3.88	0.707
5	Poor technology application	8	17	24	33	38	3.63	0.648
6	Time pressure delay	2	11	30	45	32	3.78	0.997
7	Poor quality contract documentation	23	13	13	23	48	3.51	1.561
8	Lack of information technology use	24	13	14	24	45	3.44	1.560
9	Design changes	6	34	21	19	40	3.44	1.340
10	Non-compliance to standards / specification	11	23	36	12	38	3.36	1.346
11	Complex details	26	6	29	34	25	3.22	1.415
	Cronbach's alpha		0.954					

Source: Field survey

Fig. 2 presents the causal feedback SD model indicating interrelationships among the various variables influencing rework. It is observed that if the quality specification is adhered to, then it will improve standards and afford quality work in construction and in turn will reduce or avoid rework through a reinforcing loop R1. However, on the other hand if specifications are not adhered to, which may happen because of poor communication, poor documentation, lack of proper interpretation of client requirement in a negative feedback mechanism (balancing loop B2), will lead to fall in quality standards and quality in work causing rework (balancing loop B1). Non adherence of specification may also happen because of complex design which could occur because of two feedback mechanisms (1) as lack of expert personals who are not able to cope up with design changes (loop B3) and (2) lack of expert personnel with knowledge and competency in use of computing technology and use of application of technology (loop B4). Thus, while loops B3 and B4 go together to complement loop B2 and B1. Besides the effect of time pressure and delay it enhances the effects of these mechanisms and the chances of rework in construction.

Therefore, adherence for quality specification becomes inevitable. If adherence to quality specification is observed, it will lead to quality standards and products, thereby reducing / eliminating rework. It does mean that if the feedback mechanism R1 is observed in the construction process, it will balance out the feedback mechanism B1, B2, B3, B4 and rework in construction will be avoided. However, the causes of non-adherence to specifications, such as, lack of expert personnel to deal with complex design and design changes, competent use of computing technology, and poor communication among the stakeholders like clients, contractors, and designers need to be addressed at the planning, and design stages. Time pressure on the work and or delay also needs to be envisioned and addressed adequately during the scheduling of the project.

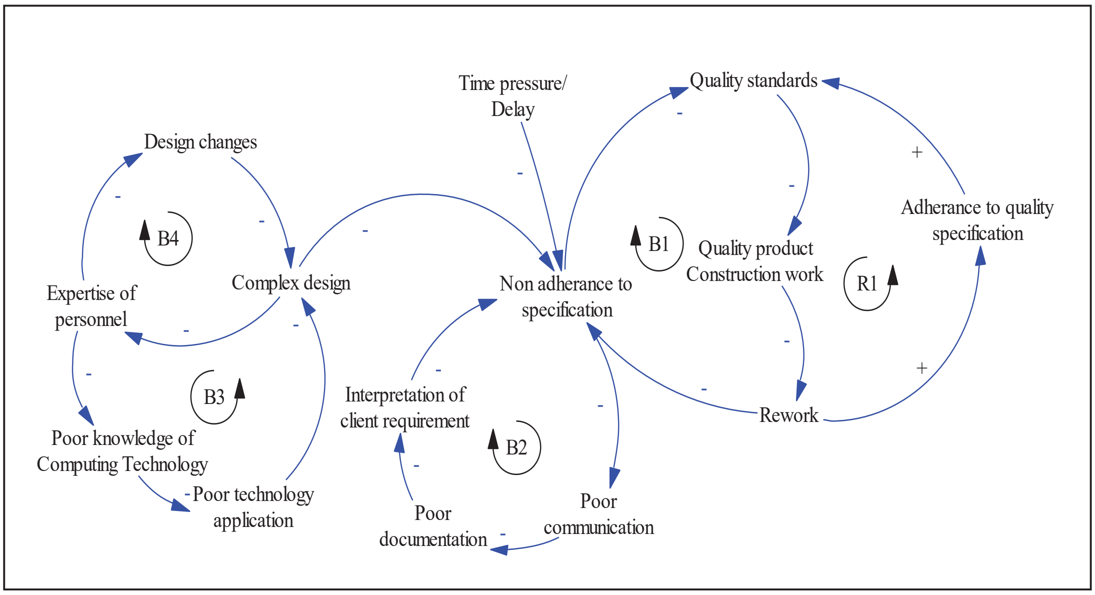

Fig. 2. Conceptual SD modeling showing causal feedback relationships influencing rework due to design related factors.

3.3.2 Client Related Factors Contributing to Rework

Table 3 presents a subset of variables which are more influential in the project environment investigated. According to the evaluation by Likert scale and standard deviation the client related factors, which mostly influence rework are poor communication (instruction), inadequate construction planning, poor management practices, change in plan and scope by client, inaccurate information, inaccurate information, lack of quality management system, unrealistic program, poor information flow, ineffective coordination and integration of project participants, poor contractual relationship, inadequate resources, conflicting information, and change in specification by client (Table 3). The variables having lesser influence have been ignored.

Table 3. Client-Related Factors Contributing to the Causes of Rework

S/N	Design-Related Factors	Not Severe	Less Severe	Severe	More Severe	Most Severe	Mean Score	Standard Deviation
1	Poor communication (instruction)	20	41	20	19	20	3.98	1.365

2	Inadequate construction planning	6	30	7	58	19	3.95	1.173
3	Poor management practices	8	14	28	21	49	3.83	2.539
4	Change in plan and scope by client	9	16	15	32	48	3.78	1.005
5	Inaccurate information	13	21	15	26	45	3.58	1.408
6	Lack of Quality management system	9	18	33	28	32	3.47	2.619
7	Unrealistic program	10	2	60	19	29	3.46	1.131
8	Poor information flow	11	14	25	52	18	3.43	2.532
9	Poor instructions	14	33	12	19	42	3.35	1.482
10	Cost pressure	1	12	44	47	16	3.38	0.777
11	Ineffective coordination and integration of project participants	4	25	47	12	32	3.36	1.377
12	Poor contractual relationship	6	11	36	47	20	3.21	1.257
13	Inadequate resources	15	18	39	27	21	3.18	1.248
14	Conflicting information	27	12	27	22	32	3.17	1.500
15	Incomplete information	13	14	52	30	11	3.10	1.080
16	Change in specification by client	17	21	36	29	17	3.07	1.250
	Cronbach's alpha 0.953							

Fig. 3 shows the causal feedback SD model showing interrelationships among the various variables influencing the rework due to client related factors. It is observed that most of the factors mentioned in Table 3 lead to client dissatisfaction, which inevitably becomes the most important reason for rework in construction along with inadequate planning. In the first place if the client is dissatisfied because of the quality of work or inadequate planning, which would cause addition/ removal/ modifications then there will be a need for rework (balancing loop B1). Further, addition/ removal/ modifications in the construction work can happen because of inadequate construction planning, leading to unrealistic programmes as a result there will be change in plan and scope (loop B1A). It is observed that loop B1A is a subset of loop B1, which enhances the chances of rework. Similarly, quality of work is affected if there is poor communication (instructions) as well as lack of quality management system through a causal feedback system (loop B2). Here it can be noted that poor communication (instructions) happens because of poor information flow which is generally caused by conflicting and inaccurate information (loop B2A). Thus, feedback mechanism formed by loop B2A strengthens the feedback mechanism B2; consequently they influence the quality of rework negatively resulting into rework. Further, inadequate resources availability at the disposal of the client or at the project level would cause ineffective coordination and integration of the project, which with the aid of poor management practices will lead to a poor quality management system that will evidently cause client dissatisfaction (loop B3). Thus, causal feedback mechanisms through loop B2 and B3 complement the loop B1 and enhance the possibility of rework. However, on the other hand if the quality of work is ascertained, the client becomes satisfied or less dissatisfied and obviously there will be reduction or elimination of rework through a reinforcing effect from the feedback mechanism (loop) R1. Therefore, in the project planning there is a need to reinforce the feedback mechanism provided by the loop R1, which essentially will balance out the negative effects of all the balancing loops B1 (B1A), B2 (B2A), and B3. Thus policy or strategic interventions are required at all the feedback mechanisms provided by the balancing loops.

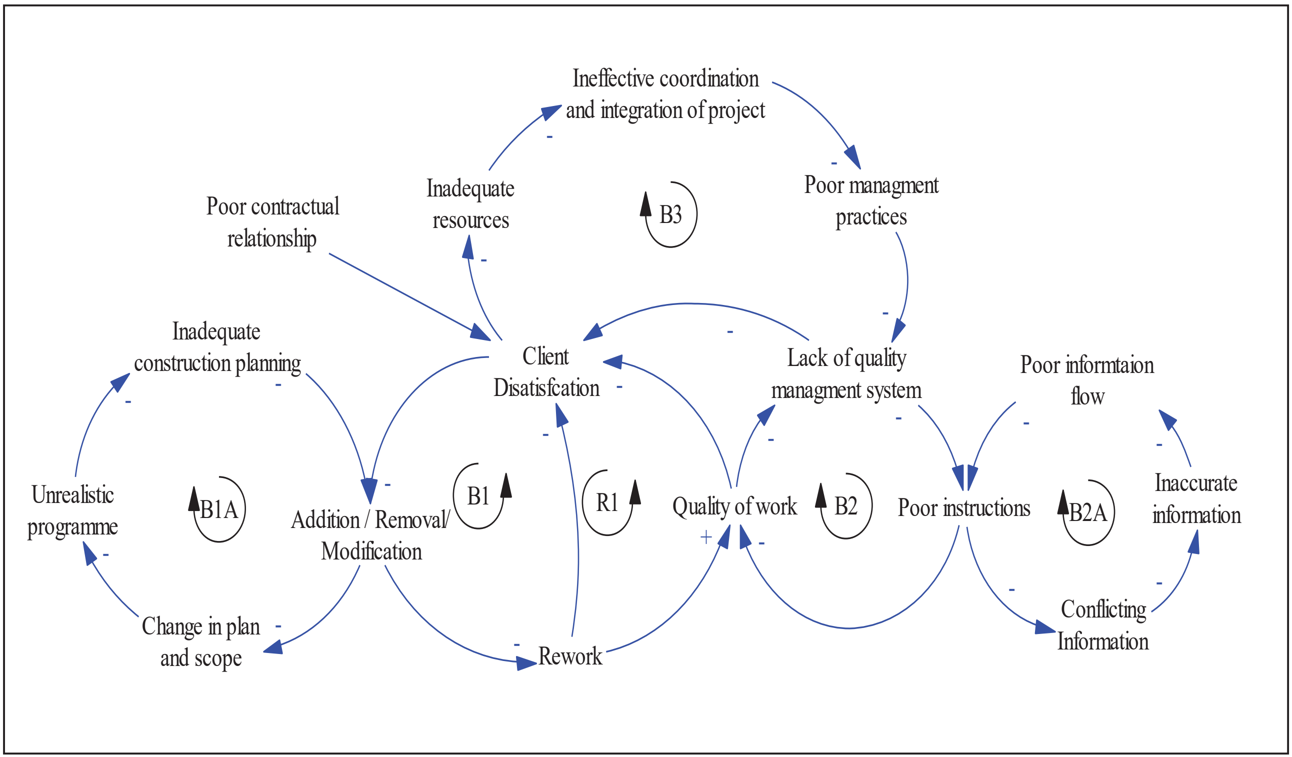

Fig. 3. Conceptual SD modeling showing causal feedback relationships influencing rework due to client related factors

3.3.3 Contractor Related Factors Contributing to Rework

Contractors are essentially critical for the execution of the work. The quality of work depends on the competency of their quality management system and adherence to best practices in the construction work. As it is obvious that quality failure leads to rework, contractor related factors influencing rework become more important both in planning and execution stages of the project to avoid rework. The main contractor related factors, as obtained from the evaluation of the surveyed data, which influence rework are found to be quality failure, lack of quality management, poor workmanship, unavailability of skilled human resources, use of poor construction materials, ineffective site management, lack of coordination, use of poor construction techniques and methods, inadequate procurement of quality materials, defective materials because of poor handling, and lack of safety practices (Table 4). The factors having lesser influence have been ignored.

Table 4. Contractor-Related Factors Relative to the Causes of Rework

S/N	Contractor Related Factors	Not Severe	Less Severe	Severe	More Severe	Most Severe	Mean Score	Standard Deviation
1	Poor workmanship	3	21	12	42	78	4.33	0.950
2	Deflection of part of slab (poor design)	2	15	24	41	38	3.82	1.069
3	Lack of attention to quality	2	11	30	45	32	3.78	0.997
4	Ineffective coordination and integration of components	4	25	12	32	47	3.75	1.550
5	Use of poor materials in sand	11	10	40	17	42	3.58	1.294
6	Defective materials as a result of handling	12	11	40	18	39	3.51	1.194
7	Consultant initiated changes	7	14	31	52	16	3.47	1.053
8	Use of poor materials in Steel	14	6	48	18	34	3.85	1.275
9	Construction error during excavation	4	30	28	31	27	3.39	1.183
10	Poor Safety considerations	15	34	12	19	40	3.29	1.486
11	Quality failure	11	19	29	52	9	3.24	1.100
12	Lack of proper monitoring and evaluation	13	21	26	45	15	3.23	1.200
13	Errors during construction	13	19	38	27	23	3.23	1.268
	Cronbach's alpha	0.951						

Source: Field survey

Based on the interaction of these factors a conceptual SD model indicating the causal feedback relationships has been developed and presented in the Fig. 4. Like in the other two aspects, such as, design and client related factors, in this case also quality failure is the major reason for rework. Rework occurs because of the lack of quality management leading to quality failure (loop B1). However, poor workmanship due to the unavailability of skilled manpower in the possession of the contractor also causes rework (loop B2). Similarly, contractor/client initiated changes because of the architectural design deficiency also cause rework (loop B3). Thus, feedback mechanisms provided by loop B2 and loop B3 strengthens loop B1, and consequently enhance the chances of rework. Besides, lack of quality management, which is the essential cause of quality failure leading to rework is influenced by a causal feedback mechanism constituting lack of coordination, lack of proper site management and lack of monitoring and evaluation (loop B4), and in turn complement loop B1 to enhance rework. Similarly, quality failure occurs because of poor workmanship leading to poor construction (loop B5), deficiency in design (loop B6), and use of poor quality materials (loop B7) respectively. However, while poor construction is caused by the use of poor construction techniques and methods and lack of safety practices; the deficiency in design is caused due to structural design deficiency (both at substructure and super structure stages). These could be due to a lack of coordination between the designer and the contractor. Likewise, the use of poor quality materials is caused by non-procurement of adequate quality materials, as well as, the defects that occur due to poor handling of materials. Therefore, from the causal feedback mechanisms of the model, it is observed that rework is an outcome of both independent and aggregate effects of the various above discussed contractor related factors. It implies that the appropriate selection of the contactors with requisite capability to handle the challenges is of paramount importance. As shown in the loop R1, quality failure will be avoided if a contactor with the right ability is selected through following the best practices, and he could ensure quality management, then quality failure will be eliminated leading to reduction in rework (loop R1). Thus, loop R1 can balance out most of the negative factors and their causal feedback relationships provided by the loops B1, B2, B3, B4, B5, B6, and B7.

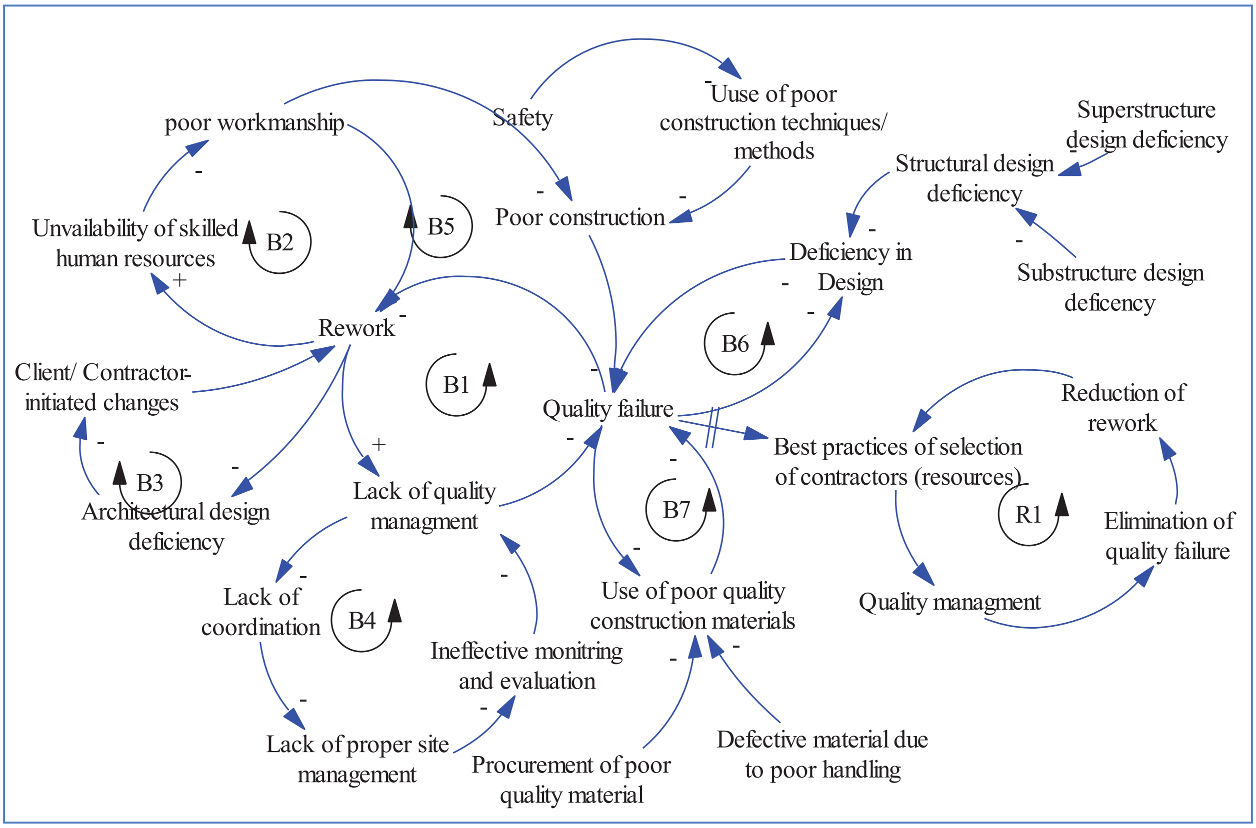

Fig. 4. Conceptual SD modeling showing causal feedback relationships influencing rework due to contractor related factors

3.4 Integrated SD Model for Developing Policy/Strategic Interventions

It was felt necessary to build an integrated model by synthesizing the above three discussed models in order to derive policy interventions to reduce or eliminate rework in construction projects. However, it was also necessary to validate the models for their veracity and their applicability in the real system. Therefore, the models were discussed with the experts in the construction industry and project managers involved in the construction projects. According to their judgment and suggestions the models were modified and causal feedback loops were adjusted and their veracity were tested qualitatively. Further, a synthesis of the causal feedback relationships of rework from the above discussed three models has been done to derive a conceptual integrated SD model (causal feedback system) (Fig. 5) and again validated qualitatively with the help of expert judgment and used for developing policy interventions. The synthesis of the various causal feedback relations of the three prime aspects (design, client and contractor related) revealed that there are three primary causal feedback mechanisms, which essentially influence the rework and can aid to reduce or eliminate rework in any construction projects, if addressed properly. The causal feedback mechanisms are (1) achieving client satisfaction with scheduling for time pressure or delay at the planning stage (loop ER1); (2) adherence to specifications ensuring quality of work resulting in client satisfaction (loop ER2) and (3) availability of skilled manpower ensuring quality management leading to quality work and consequent client satisfaction (loop ER3), through the use of proper construction techniques and methods (loop ER3A), and the use of proper construction materials (loop ER3B).

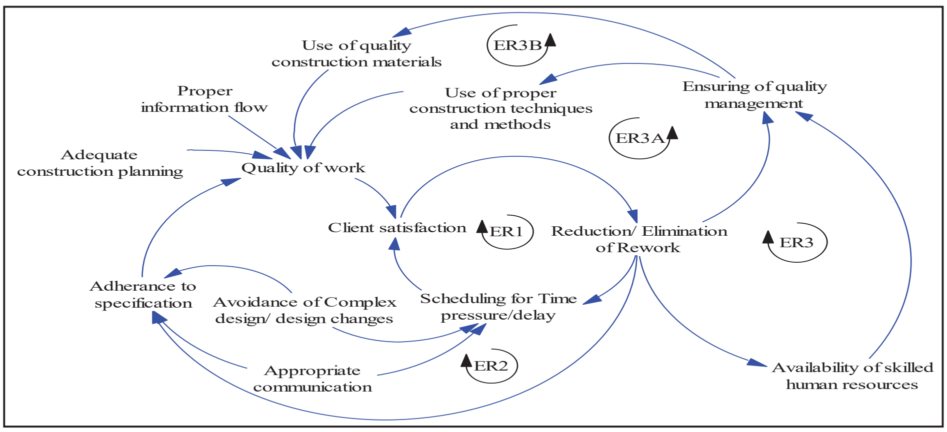

Fig. 5. Conceptual SD modeling showing causal feedback relationships to reduce or eliminate rework

3.5 Validation of the Causal Relationships

After the development of the causal relations, they were discussed with a different set of professionals and experts, than those who have been consulted during the survey from the construction industry, for the validation of the causal relationships used in the models. The feedbacks were checked with the constructed causal relations and adjusted accordingly. Besides, the veracity of the causal relationships was tested qualitatively through structure verification test so as they depict the real world behaviour in the construction project environment.

3.6 Mechanism for Policy Interventions

Fig. 6(a-e) presents the cause and use trees of these feedback mechanisms based on which policy interventions can be derived. Fig. 6a shows how rework is influenced by various factors. Quality of work- adherence to specifications, client satisfaction-scheduling for delay/ time pressure, ensuring quality management and availability of skilled human resources would able to reduce or mitigate rework. Adequate construction planning, adherence to specifications (avoidance of complex design), proper information flow, use of proper construction materials, and application of construction techniques and methods will ensure quality of work (Fig. 6b). Proper communication and information flow can help scheduling for time pressure and delay, which will address the issues of the problems related to complex design or design changes. Adherence to specifications can be achieved through appropriate communication, avoidance or limiting complex design or design changes (Fig. 6c). Ensuring of quality management, which is a function of skilled manpower can lead to the use of proper construction techniques and methods, and use of quality construction materials (Fig. 6d)). Further, ensuring quality of work and scheduling to absorb the time pressure or delay will lead to client satisfaction, which in turn will lead to reduction or elimination of rework in construction projects (Fig. 6e).

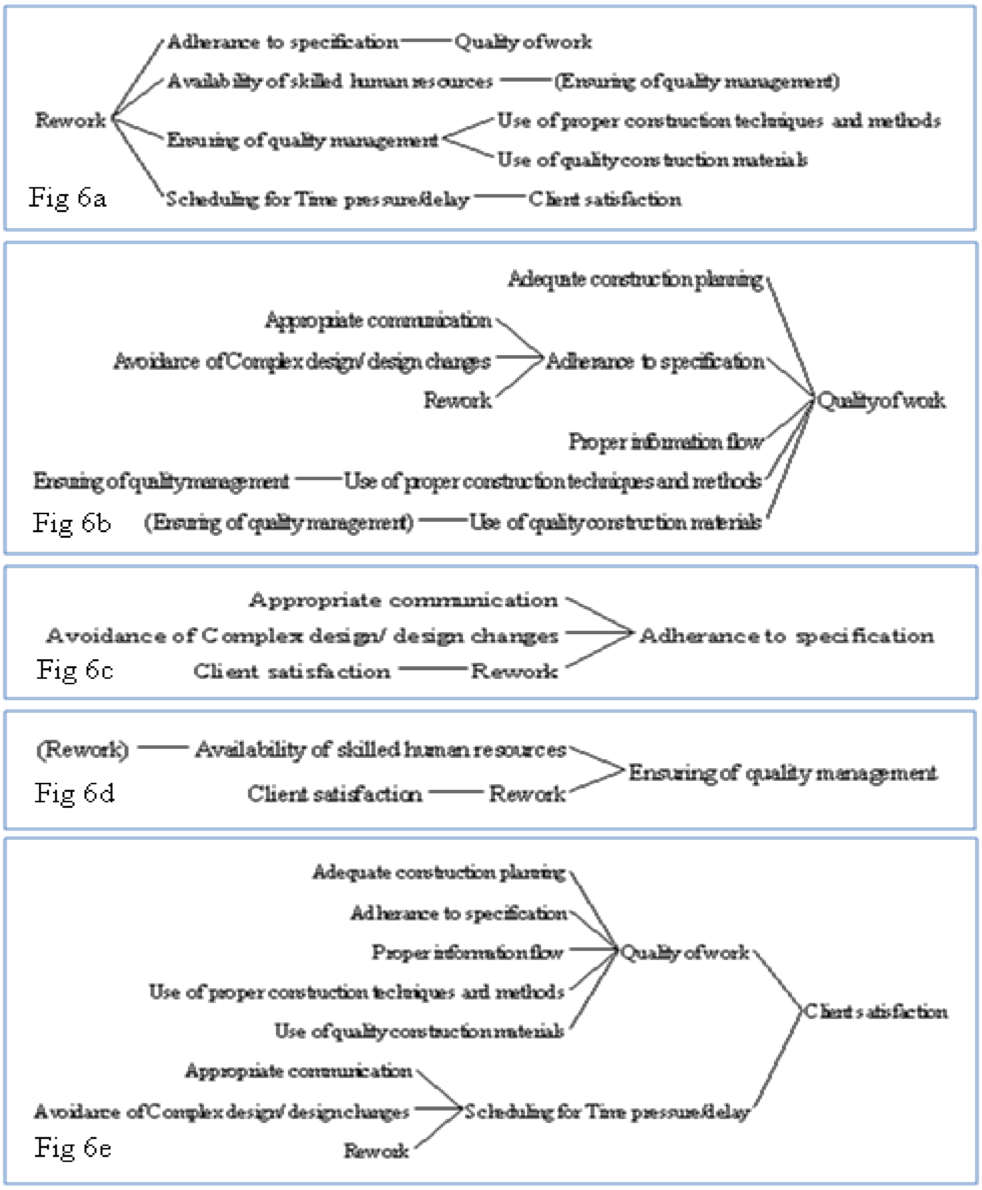

Fig. 6 (a-e). Cause and use trees to develop policy interventions reduce or eliminate rework in construction projects

The cause and use trees as presented in the Fig.6 (a-e) also indicate that all the parameters are linked to each other through feedback mechanisms and influence each other. If any link in the mechanisms fail or work at a reduced efficiency then it will hinder the functions of the other mechanisms. However, it also clearly provides how the mechanisms work and how they influence each other.

So, if any problem occurs at any stage or any link is broken at the various stages of construction work, it can be diagnosed easily and appropriate interventions can be taken to address the problem.

3. CONCLUSION AND RECOMMENDATION

Rework in construction projects is a concern both from the cost and time point of view. Its influence has been explicitly in many projects in Nigeria in terms of both cost and time over runs. Many scholars like Fayek et al. (2003), Han et al. (2013), Love et al. (2000), Love and Edward (2004), (Oyewobi and Ogunsemi 2010) and Palneeswaran (2006) have attributed various reasons for rework and also have recommended interventions to reduce rework, including zero rework strategy. However, rework still remained an unwarranted concern for various stakeholders of the construction projects including clients, contractors and more specifically project managers in general and specifically in Nigeria. Therefore, this investigation examined the causes of rework from the three most important aspects, such as, design, client and contractor related factors point of view. Also, it explored the degree of the influence of the factors of these three aspects on rework; the systems thinking approach, and SD principles were applied to analyse the causal feedback relationships among the various factors causing rework and develop mechanisms to derive policy interventions.

The study revealed that the design related factors which influence rework are non-adherence to specification, complex design, time pressure / delay and poor communication, lack of understanding and correct interpretation of customer requirements, constraint in carrying out activities, inexperience of personnel, poor technology application, poor quality contract documentation, and lack of information technology use, and design changes. Similarly, poor communication (instruction), inadequate construction planning, poor management practices, change in plan and scope by client, inaccurate information, inaccurate information, lack of quality management system, unrealistic program, poor information flow, ineffective coordination and integration of project participants, poor contractual relationship, inadequate resources, conflicting information, and change in specification by client are the client related factors which influence rework. Besides, quality failure, lack of quality management, poor workmanship, unavailability of skilled human resources, use of poor construction materials, ineffective site management, lack of coordination, use of poor construction techniques and methods, inadequate procurement of quality materials, defective materials because of poor handling, and lack of safety practices are the major contractor related factors causing rework.

However, from the causal feedback relationships in the conceptual SD models it was observed that many of the factors are directly or indirectly interrelated through feedback mechanisms and influence one another based on their interactions. The synthesis of the causal feedback relationships in the integrated model revealed that adherence to specifications, scheduling for time pressure and delay, avoiding/limiting complex design/design changes, and ensuring quality management are the major factors along with the variables linked to them (as mentioned in Fig. 6 (a-e), will bring in quality work and consequent client satisfaction, which in turn will lead to reduction or elimination of rework. Further, the cause and effect linkages developed through the systems analysis (cause and use trees) also are able to diagnose the problems adequately enabling appropriate interventions to limit or eliminate problems which will help to avoid rework.

The study has its limitations. The major limitation is that the modelling was done conceptually, although the basic premise behind it was to see the problem of rework in a more holistic way. However, there is a need for the quantitative modelling to examine the extent to which rework can be reduced or eliminated under different scenarios of strategic/policy interventions. Although, scholars like Gilkinson and Dangerfield (2013) and Han et al. (2013) in their recent case study works have attempted to resolve the challenges of rework by applying SD modelling principles quantitatively, there is still a need to investigate it in a more generalised and holistic way, which provides the further scope to this research. However, despite its limitations this study can assist construction project managers and leaders to analyse and diagnose the problems of rework in their projects and enable them to make strategic/policy interventions to reduce or eliminate rework in construction projects.

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