Using system dynamics principles for conceptual modelling to resolve causes of rework in construction projects

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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 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.

Key words: 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 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 the construction projects. Specifically, it has been established as a primary cause of both cost and schedule overruns in construction (Love, Mandal, Smith, & Li, 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 *et al*. (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. 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). According to scholars rework creates problematic behaviors, which extend projects schedules and cause cost overruns (Ballard, 2001) and are the source of many project management challenges (Cooper 1980, 1993; Lyneis and Ford: 2007). Thus, the objective of the paper is to investigate the causes of rework in construction projects from three perspectives such as design, client and contractor related factors and identify plausible strategic interventions, which would enable reduction in the rework and improve performance. The merit of the paper lies in applying the systems thinking archetypes and using SD modelling principles to develop conceptual models to understand the causal feedback relationships among the various variables, which cause rework; and develop a mechanism for deriving strategic interventions that will enable the construction project managers and leaders to take appropriate decisions to reduce or mitigate rework in construction projects.

2. Materials and methods

2.1 Projects and professionals surveyed

The study was conducted in the South-Western part of Nigeria. Professionals, such as architects, engineers, consultants, contractors, developers, project managers, and quantity surveyors from a number of medium and large construction projects, which include hospitals, office complexes, schools and commercial buildings were consulted and surveyed. The selection of the professionals for survey was predicated on, professional qualification, experience and involvement in the construction industry.

2.2 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 investigation. A total of 145 questionnaires were administered, of which 120 were returned (approximately 83% response rate). 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 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 major variables and their influences were then used to develop conceptual models by using systems thinking and SD principles, which were employed to develop policy interventions.

2.2.1 System Dynamics modelling approach

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) and 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, according to Rahmandad and Hu (2010), 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, Lov, Peña-Mora (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. As the construction projects are getting increasingly complex and dynamic, and there are three factors - design, client and contractor related factors overwhelmingly influencing 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. Thus, this study confined its focus to the application of systems thinking and the conceptual SD modelling to understand the causes of rework and causal feedback relationships among the various variables influencing rework.

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.

In this study a conceptual model over and above the results of the statistical analysis was resorted to, because a conceptual model, which essentially is a consistent and unifying theory of behaviour taken from bits of information about the real world (Wolstenholme, 1992 and Robinson, 2008) can able to elicit the perceptive behaviour of the system under various policy interventions.

While developing the causal relationships, initially the variables and their influences observed from the survey were identified as information, decision and action variables. The causal relationships in terms of one way linkages of information – decisions – actions – impact on the environment (i.e., information assisting in decisions (policy interventions), decisions leading to appropriate actions and actions influencing the environment (system)) are mapped; and then their feedback relations were checked. The valid causal feedback diagrams (causal loop diagrams) were then employed to develop the conceptual SD models.

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, several factors contribute to rework in a project (Ashford, 1992; Love *et al.*, 2000; Rogge *et al.*, 2001). 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. Figure 1 presents the aggregate feedback relationships among the three parameters and the rework. It illustrates that each of the three controlling parameter 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.

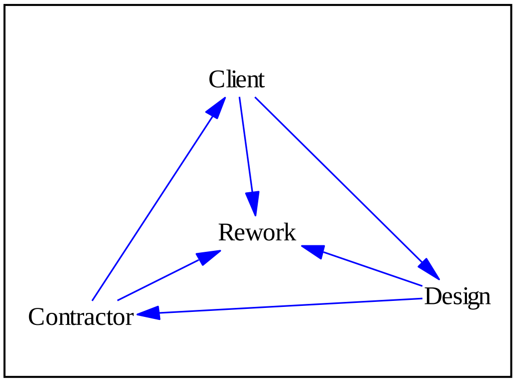

Fig: 1 Aggregate causal feedback model for rework

3.1 Design related factors contributing to rework

Table 1 presents the subset of the various factors and their relative influence on rework. There are 11 design related factors which are ranked according to their level of influence based on the mean score in the Likert scale (the variables having lesser significance have been ignored). Base on the interrelationship of the eleven variables influencing conceptual SD model (Fig 2) was developed.

Table 1: 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	Poor interpretation of client 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	Lack of expertise 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	Poor technology application	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 design	26	6	29	34	25	3.22	1.415

Source: Field survey (Cronobach's α = 0.954)

It is observed that if the quality specification is adhered to, then it will improve standards and bring in 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, poor 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 adequate 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 enhances the effects of these mechanisms enhances 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, contactors, 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.

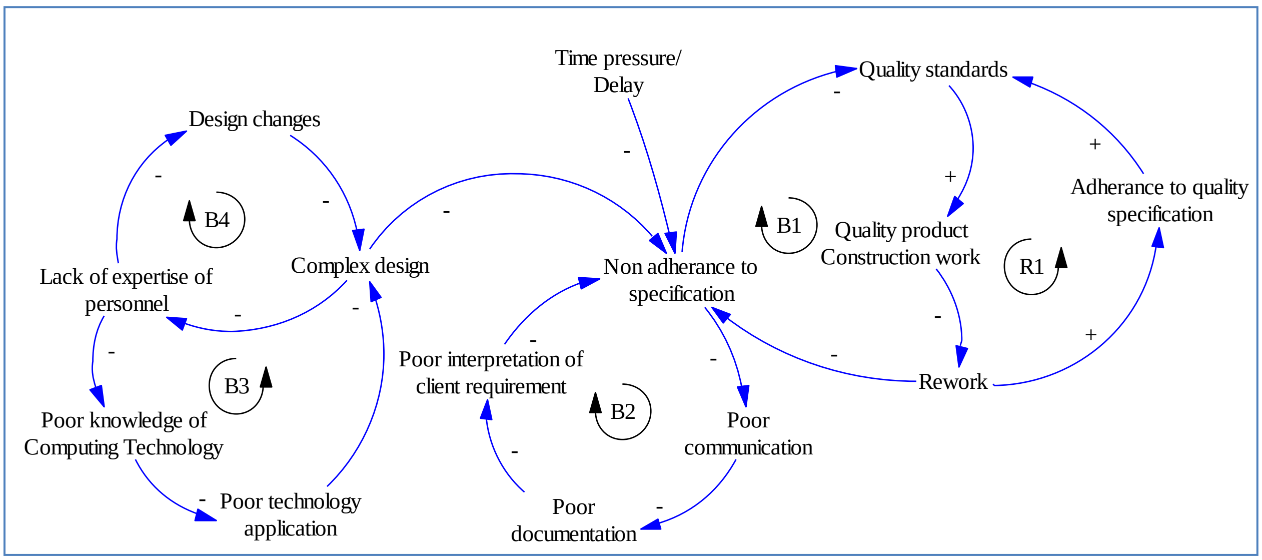

Fig: 2 Conceptual SD modeling showing causal feedback relationships influencing rework due to design related factors.

3.2 Client related factors contributing to rework

The client related factors which mostly influence rework are presented in Table 2. The conceptual SD model (Fig 3) was developed based on these client related variables influencing rework. It is observed that most of the important client related factors 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 shall 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 inaccurate information transfer occurs 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 project level would cause ineffective coordination and integration of the project participants (stakeholders), 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, at the project planning stage 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.

Table2: **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	Inaccurate information	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	Addition/removal/modification	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 (stakeholders)	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 plan and scope	17	21	36	29	17	3.07	1.250

Source: Field survey (Cronobach's α = 0.952)

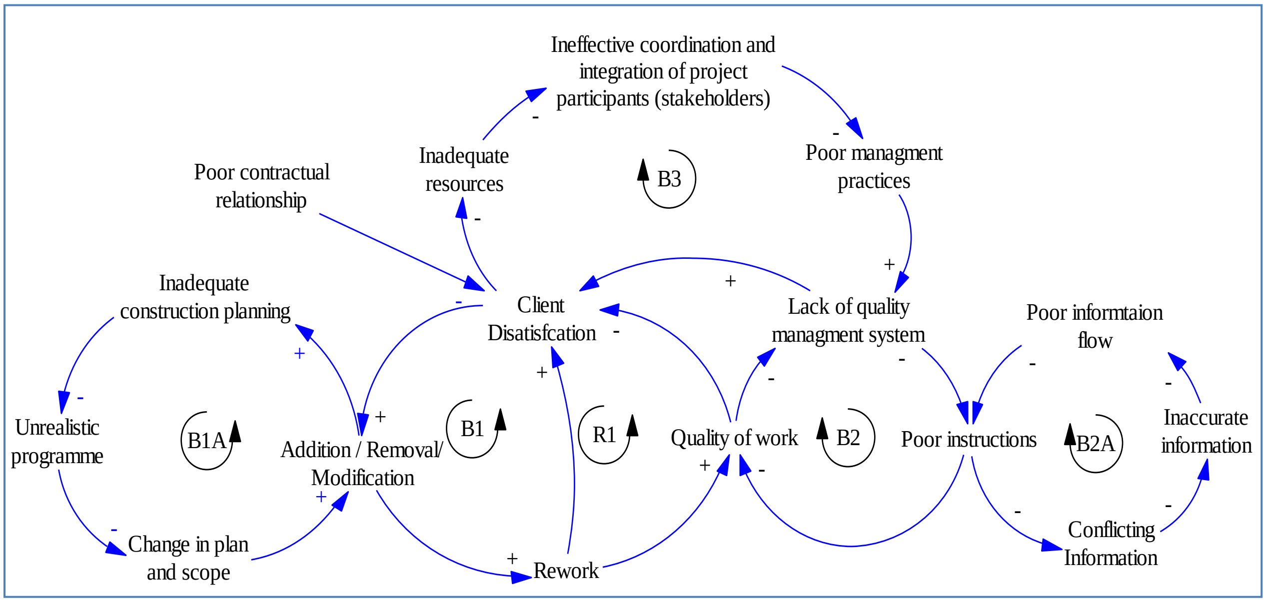

Fig: 3 Conceptual SD modeling showing causal feedback relationships influencing rework due to client related factors

3.3 Contractor related factors contributing to rework

Contractors are essentially critical for the execution of the work. Table 3 reveals the important contractor related factors, which influence rework.

Table 3: 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 quality management	2	11	30	45	32	3.78	0.997
4	Lack of coordination and integration	4	25	12	32	47	3.75	1.550
5	Use of poor quality construction materials (sand)	11	10	40	17	42	3.58	1.294
6	Defective materials due to poor 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 quality construction materials (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	Inefficient monitoring and evaluation	13	21	26	45	15	3.23	1.200
13	Poor construction	13	19	38	27	23	3.23	1.268

Source: Field survey (Cronobach's $\alpha = 0.951$)

Based on the interaction of these factors a conceptual SD model indicating the causal feedback relationships has been developed and presented in the Figure 4. Like in the other two aspects - design and client related factors; in this case too, 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 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 the lack of poor workmanship leading to poor construction (loop B5), design deficiency (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 by the structural design deficiency (both at substructure and super structure stages), which could happen because of the 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 the most of the negative factors and their causal feedback relationships provided by the loops B1, B2, B3, B4, B5, B6, and B7.

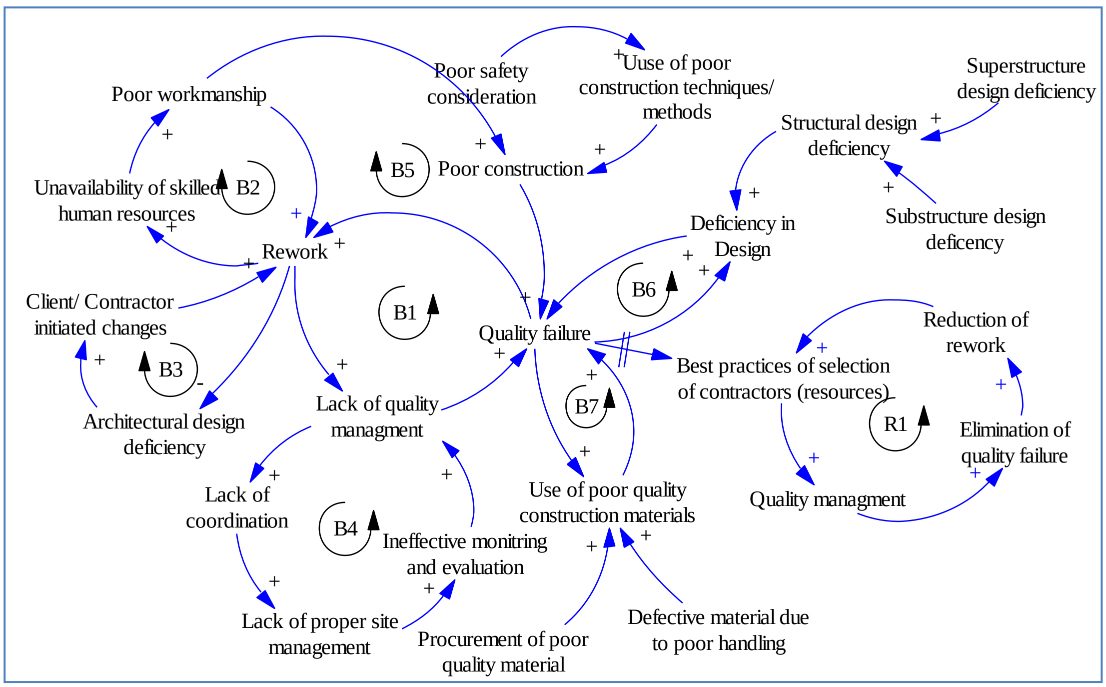

Fig: 4 Conceptual SD modeling showing causal feedback relationships influencing rework due to contractor related factors

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 was tested qualitatively. Further, a synthesis of the causal feedback relationships of the 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 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).

Figure 6(a-e) presents the cause and use trees of these feedback mechanisms based on which policy interventions can be derived. Figure 6(a) 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 6(b)). 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 6(e)).

The cause and use trees as presented in the Figure 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.

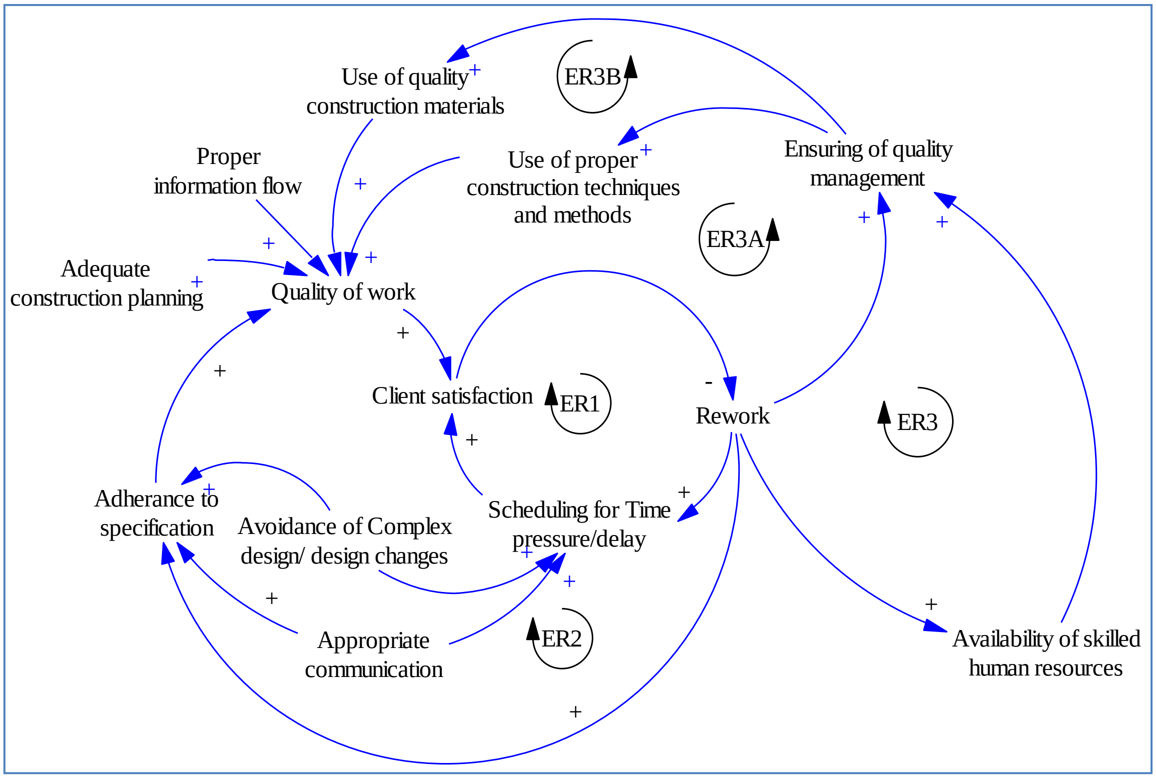

Fig: 5 Conceptual SD modeling showing causal feedback relationships to reduce or eliminate rework

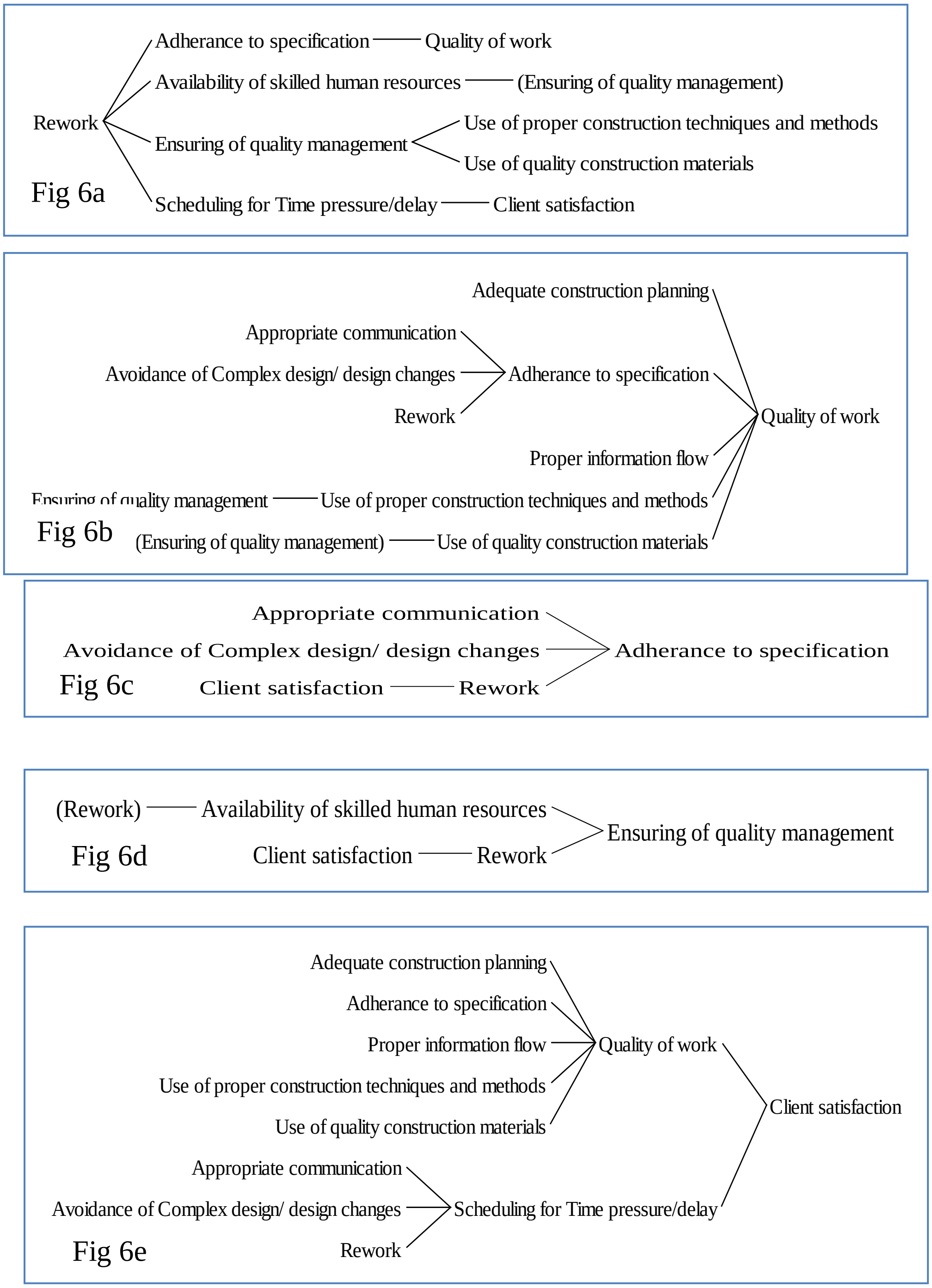

Fig 6 (a-e): Cause and use trees to develop policy interventions reduce or eliminate rework in construction projects

4 Conclusion

Rework in construction projects is a concern both from the cost and time point of view. Many scholars like Fayek et al (2003), Han *et a.,* (2013), Love *et al.* (2000), Love and Edward (2004), 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. 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 the rework; and 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 6a-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 the 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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