University of Twente

CME/ Construction Management and engineering department

Graduation thesis for the partial fulfillment of the master's degree in construction management and engineering Purpose

Understanding and reduction of cross-party conflicts in housing development projects from systems engineering perspective Title

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Ir. K.Th. Veenvliet
Graduation committee

Definitive Version

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Enschede - The Netherlands

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Praise to God, the almighty.

Enschede, the Netherlands (June 10, 2009)

Zinaw Tezera Wodajo

Abstract

In housing projects where many parties are involved, it is common to observe reduction of project success in the form of cost overrun and schedule overrun. In most literatures, such adverse effects are partly attributed to requirement incompleteness, misinterpretation and misunderstanding. However, there isn't enough information on the mechanisms between requirement conflicts and adverse effects. There is also lack of specific remedies for the reduction of such conflicts.

In this research project, general theories of such mechanisms were tested on the Dutch housing development sector. Furthermore, the applicability of systems engineering remedies in the reduction of requirement conflicts was checked. The research accounts for a broad theoretical review of literature materials around the topic and a single case study as a source of empirical input. Pattern matching was used for the analysis process.

The result of this research shows that the propositions that relate requirement conflicts with adverse effects partially hold. Nevertheless, they require refinement and further empirical support for better generalization. The findings also support the capability of systems engineering remedies in the reduction of requirement conflicts.

Contents

Introduction

In housing projects where civil engineers have to work with professionals from other parties like mechanical engineering or housing development firms, there are always conflicts which result in drawbacks on project success.

Generally, such projects follow a traditional approach which is the Design-Bid-Build process. These sequential process starts with client requirement specification, then design development, followed by tendering and finally the erection of the building.

Basically such traditional procedures are typified by skepticism, suspicion and contempt. As a result there is a lot of adversarial attitude and often projects are forced into cost and time overrun from initial budget and schedule (Thomas *et al.* 2002). Such trends lead to long term effects like bad professional image, less profit and poor competitiveness.

In this research project, the issue of cross-party conflicts which lead to adverse effects in housing development projects is taken as a focal point of discussion. The paper accounts for a broad theoretical review of literature materials around the topic and a single case study as a source of empirical input.

The case study considers a housing development project which started on January, 2009. In the project, a housing developer (Beter Wonen), a general contractor (Dura Vermeer) and an installations contractor (Loohuis) work together. The project started with the usual traditional procurement procedure but recently it is changed to a systems engineering project.

The following sub-sections present a clear and precise description of the research problem. In the next section, the research methodology that is applied in handling the theoretical study and the case project is described. Following that, the theoretical propositions section incorporates a detailed literature review about adverse effects, their causes, mechanisms and possible remedies. The fourth section presents the findings of the case study. After that, the conclusion and recommendation of the research project follow. Following the reference section, the appendix part presents the interview database and the condensed form of the thesis report which is meant for publication on the journal of construction management and economics.

Problem definition

Problem description: The existing housing construction process has dysfunctional aspects with respect to cross-party relations among involved parties. As a result, projects face problems of rework, variation and failure. In consequence, it is a common trend to see cost and schedule overruns. And in serious and repeated situations, involved parties would end up losing their competitiveness and reputation. This is broadly presented in the theoretical propositions section with sufficient literature support.

Based on the further research done on the sources of such problems like rework, variations and failures, most authors suggest the following five events as major causes.

- Requirement conflicts in the requirement development stage as well as in design development stage,
- documentation problems which account for design errors and mismatches between architectural, structural and installation designs
- poor coordination and integration which comes about due to communication failure
- poor quality management with respect to supervision and inspection
- poor standard of workmanship which results in mistakes during implementation of documented plans, designs and specifications into final products

Such events that create tension between the different parties involved could have both negative and positive effects. The positive effect is the opportunity they give for revision of the construction process and increase of knowledge for future projects. On the other hand, negative effects are also manifested in the form of rework, variations and failure.

Based on the above information, this research makes its concern on the understanding and reduction of cross-party conflicts which lead to adverse effects in housing development projects from the system engineering perspective. To achieve this, first a detailed theoretical investigation is done on the sources of cross-party conflicts in traditional housing projects. Then propositions developed from theory are tested against the experiences of the professionals involved in the case project. And finally theoretically proposed system engineering based remedies for the reduction of such conflicts are tested for their applicability in the case project.

Among the five causes listed above, requirement conflicts are rated as leading causes of rework. Hence the scope of the research had been limited to requirement problems of the conception and design phases of the construction process. The rest of the conflicts presented in the theoretical study part are left for future research.

Research Goal:

- To test the capability of system engineering in the reduction of cross-party conflicts which lead to adverse effects in housing development projects

Research objectives:

- Find out the sources of conflicts between different parties that work on traditional housing projects.
- Test the applicability of theoretically proposed system engineering based remedies for the reduction of cross-party conflicts in housing projects.

Research questions

The research question is divided into three sub-questions as follows.

Sub-Question 1: Find out the sources of cross-party conflicts among different parties which involve in traditional housing development projects.

Sub-Question 2: Test the propositions developed from sub-question 1 against the experiences of the professionals involved in the case project.

Sub-Question 3: Test the applicability of theoretically proposed system engineering based remedies for the reduction of cross-party conflicts.

Research significance

The research will contribute to the better understanding of the current situation of housing development process by testing it against generic sources and mechanisms of adverse effects that are prescribed for the general construction industry. Furthermore, it is targeted to reinforce the low level of knowledge about mechanisms that lead to adverse effects in traditional housing projects. It also helps to test the applicability of systems engineering approach which is new for the Dutch housing development sector.

Research delimitations

First, due to time limitation, the conflicting issues presented in this research are only from the conception and design phases of the construction process. Moreover, these are the theoretically suggested phases which are the major contributors to overall conflicts in construction processes.

The other limitation is the use of a single case project as a source of empirical data. Furthermore, there is accessibility limitation of data for the reason that most of the available materials are in Dutch.

Research assumptions

To proceed with the research, it is assumed that the case project is a unique housing development project which made it a possible candidate for a case study. Another starting assumption is that data collected by interviews is sufficient, as the other forms of data are difficult to obtain due to language barriers. Lastly, the respondents are assumed to be cooperative and truthful as this research has no other intention than academic purpose.

Research methodology

For this research, the framework of Checkland *et al.* (1998) is used to relate theory with practice. The following figure presents the important items of a research and their interrelationship.

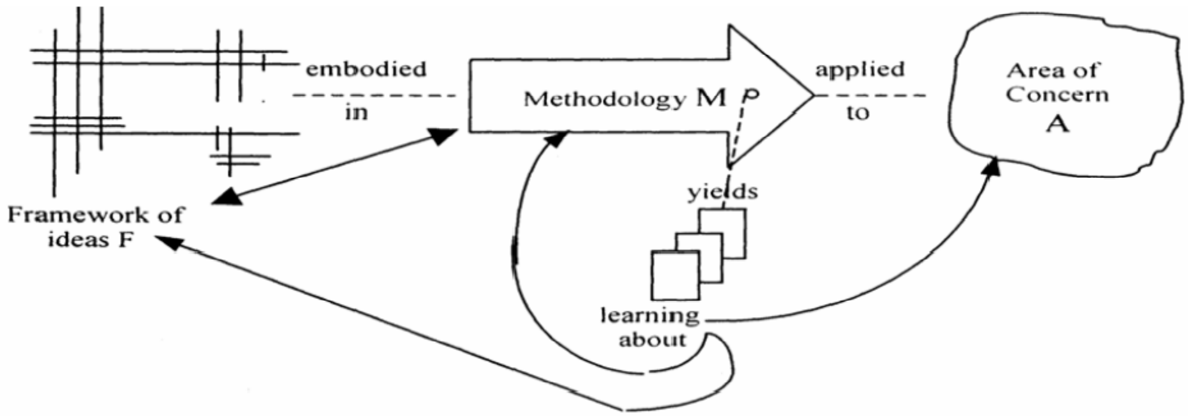

Figure 1: Elements relevant to any piece of research (Checkland and Holwell 1998)

According to the framework, a research should initially have an area of concern (A) on a particular problem in a given field of study or the surrounding environment. The second item is a set of theories and bodies of knowledge which form the framework of ideas (F). Finally, there should be a methodology which incorporates the concepts of this framework and which can be applied to the area of concern.

The area of concern (A) and the frame work of ideas (F) are presented on the theoretical propositions section. In this section, the research methodology (M) that was applied in handling the theoretical study and the case project is presented.

A research design (methodology) is by definition a logical plan that helps to reach from the research questions to the final conclusions. It is a means by which the evidence collected is aligned with the research questions. For the development of the strategy in this research, the book of Yin (2003) is used as a guide.

The choice of the research approach is majorly based on the type of research questions and the possibilities for empirical data. As can be observed from the research questions presented in the introduction, the research starts with an explanatory approach answering ‘why adverse effects occur among projects which involve multiple parties’. Then a search for remedy of the identified problem is carried out by answering the question ‘How to reduce the cross-party conflicts’.

When considering the possibilities of empirical data, there are two criteria to be considered. The first is the possibility to have a control over the behavior of the events to be studied. In this research, there is a single project to be considered as an empirical data source, and there is no chance of manipulation of the project characteristics as the study is done only by external observation.

The second criterion is whether the focus of the study is on contemporary events or historical events. For this case, it is clear that the focus is on contemporary events as the project was started in January, 2009, and was going on during the thesis period.

Hence base on Yin (2003), for a research with a 'why' and 'how' questions, with no control on behavior of events to be studied and with a focus on contemporary events, the recommended research approach is **the case study approach**.

Goal of a case study is the generalization of the evidence collected to theoretical propositions developed beforehand. The form of generalization is more of analytical rather than statistical; meaning it entails the expansion and generalization of a given theory instead of particularizing it.

Now that the case study approach is chosen, there is a need to justify if a single case study is acceptable. This is so because there is only one case project for this research. To qualify as a single case, according to Yin (2003), a case has to satisfy one of the following rationales: criticality, extremeness (uniqueness), representativeness (typicality), being a revelatory case or being a longitudinal case.

Our case project is a unique one for it applies the system engineering approach. All previous housing development projects followed traditional procurement approaches. But this project by Beter Wonen is the first of its kind for adapting system engineering process. Hence by taking it up as a unique case, it is possible to satisfy the objective of capturing the circumstances and conditions of a new and unexplored situation in the housing development projects of the Netherlands.

According to Yin (2003), there are two ways of single case study designs. The first is the holistic design approach which is favored in situations where there are no logical subunits of the case that can be identified and the theory underlying the case study is by itself with a holistic nature. Such a design is disadvantageous for it is at a higher abstraction level and with no clear data of specific events. Furthermore it could result in uncontrolled and unnoticed changes in the course of the study.

But for the case study in this research, the holistic approach is less favored as there are detailed logical subunits of the case that can be observed as presented in the theoretical propositions section. Hence, for this project the embedded design approach is adopted. The embedded design approach is advantageous for it helps to gain a good focus on the case study inquiry, gives more sensitivity to slippage in due course of the study, enables the use of multiple unit of analysis, adds opportunities for extensive analysis and enhances the insight into the single case.

On the other hand, using embedded design approach could result in being trapped at the study of a subunit level and not being able to generalize for the larger unit of analysis (the case itself). In other words, there is a risk of the case being only context instead of being the target of study. For instance, a good example is a situation in which the final conclusions are on the conception stage but not on the whole of the case project. Hence care should be taken in order to avoid this entrapment.

Components of the research design

Based on Yin (2003), a research design should incorporate the following components.

Study questions: The study questions of the research are clearly presented on the introduction part. The first two sub-questions address the reason why adverse effects occur among multiple-party projects, the first from theoretical point of view and the second from the empirical side. The third sub-question addresses the remedies by which the causes to adverse effects can be reduced.

Study prepositions: For the case study to start, the study questions are not enough in directing the way. Development of theoretical propositions is necessary in guiding where to look for evidence during the case study. For this research, a detailed literature review is provided in theoretical propositions section, which is used in the development of interviews for the case study.

Unit of analysis: The unit of analysis is based on the accurate specification of the primary research questions. In this research, the high level unit of analysis is the housing project itself. But at a lower level, it incorporates cross-party conflicts which result in adverse effects as embedded units of analysis.

Linking data to proposition: This is done by pattern matching between evidence (responses of interviews) and nonequivalent dependent variables (the theoretical propositions).

Criteria for interpreting a study's findings: This addresses the issue of justifying if the data is good enough to make the final conclusions. As the number of respondents is too small to make statistical evaluation, a theoretical proposition holds if only all the respondents agree to the proposed outcome. On the other hand, if there is even one response, the proposition will be questioned and be open for refinement.

Data treatment for each sub-question

Case studies could have a wide range of sources of data. These include direct observation of events, interviews of the persons involved in the events, documents, artifacts, participant observations and informal manipulations. But for this research, the data sources are limited to academic articles and direct interviews only due to language restrictions. Below, a detailed description is presented in to how the data for each sub-question was treated.

<u>Sub-question 1:</u> *Find out the sources of cross-party conflicts among different parties which involve in traditional housing development projects.*

Data needed: A broad variety of literature about cross-party conflicts, extent of adverse effects (quantified values), causes of adverse effects and their mechanisms

Data treatment: A condensed literature review of the above issues is made and finally a check list of causes, effects and mechanisms is produced in order to be tested empirically. Based on the framework of literature study described in figure 2, the theoretical study started with the search of information about the dependent variable 'B' then the independent variable 'A' is covered. Consequently, part 'C' is covered in order to form the link between 'A' and 'B'. Part 'B' in figure 2 refers to the area of concern in the Checkland *et al.* (1998) framework(figure 1); whereas Part 'A', 'C' and 'D' of figure 2 refer to the framework of ideas of figure 1.

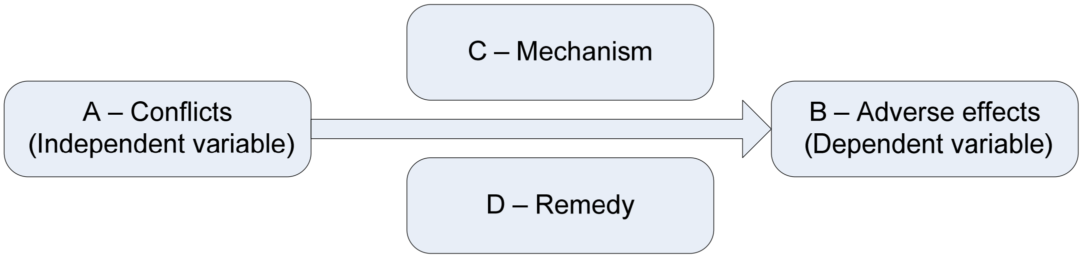

Figure 2: Framework for literature study

<u>Sub-question 2:</u> *Test the propositions developed from sub-question 1 against the experiences of the professionals involved in the case project.*

Data needed: Interview about weakest spots of traditional housing projects from the experience of the professionals involved in the case project.

Data treatment: The analytical strategy applied here is the reliance on theoretical propositions which were previously made. This helped to properly guide the interviews and isolate the important type of data. Hence, the collected data at this stage was filtered and categorized based on the propositions produced during the first question of the research. In order to achieve a proper evaluation process, the technique of pattern matching of nonequivalent dependent variables was applied.

<u>Sub-question 3:</u> *Test the applicability of theoretically proposed system engineering based remedies for the reduction of cross-party conflicts.*

Data needed: Broad study of literature of system engineering approach as a possible source of remedy, specifically in the area of tools and methods which can assist cross-party interactions. This refers to part 'D' of figure 2. In addition to this, interview of the perception of the professionals with respect to the theoretically proposed remedies is required.

Data treatment: The analytical strategy applied here is the reliance on theoretical propositions which were made from the literature study. This helped to properly guide the interviews and isolate the important type of data. Hence, the collected data at this stage was filtered and categorized based on the check list of remedies. In order to achieve a proper evaluation process, the technique of pattern matching was applied.

Research qualification

The research can be qualified by applying the following tests as a judging mechanism of the quality.

Construct Validity: This test is to check the establishment of correct operational measures. This corresponds to the existence of a choice of a specific item of study and whether the collected data is related to the specific chosen item. To achieve this, multiple sources of evidence are considered. For instance, a wide range of publications were studied in order to achieve good theoretical propositions, where as the empirical data collection considered sufficient number of respondents from the case project in order to cover the issue from all sides. The other tactic applied to achieve construct validity is by creating a chain of evidence between the research questions, the case study protocol, the case study database and the final report. Last but not least, draft review of the interview responses were done by the respondents or translators.

Internal Validity: This test is important for causal or explanatory studies. Hence it is applicable for this research. It is dedicated to the evaluation of inferences of interviews for correctness and the convergence of the collected evidence. Internal validity in this research is achieved by proper pattern-matching of the responses collected and the theoretical propositions made.

External Validity: This test is about establishing the domain to which the study's findings can be generalized to. And in this single case study, the domain is the Dutch housing development sector as the respondents are all professionals from this domain.

Reliability: This test is to demonstrate the repeatability of the operations of the study with the same results. The operations could be like the data collection or data analysis procedure. To achieve this, a proper case study protocol and database system was developed in order to properly document all procedures applied during the study.

Theoretical propositions

In this section, first the four parts of figure 2 are broadly presented with sufficient literature support, followed by the list of the propositions which are empirically tested later on.

Area of concern: Adverse effects

In this sub-section a more broad description of the problem environment is given based on the literature review undertaken. The area of concern represents the dependent variable on figure 2 (Part 'B').

The starting point for the problem under consideration is the traditional approach, the Design-Bid-Build system. Such an approach is typified by skepticism, suspicion and contempt. As a result there is a lot of adversarial attitude, loss of productivity and increase in costs. Furthermore, efforts of partnering are usually unsuccessful because of the individualistic culture of involved parties. This often works against open relationships (Thomas *et al.* 2002).

But there is a need to be cautious as such a perspective is one sided. In other words, conflicts due to cross-party relations could have both positive and negative sides (Vaaland 2004). The effect of conflicts depends on the situation and parties under consideration. When there is an addition of motivation due to presence of necessary tension, conflicts are constructive. But when there is tiredness and lack of efficiency due to excessive conflict, then it rather becomes more dysfunctional.

Hence, this research targets to differentiate and present the dysfunctional aspects of cross-party relations in traditional housing development. And for this reason, a detailed study of published materials was done in order to identify such aspects, their mechanisms and resulting adverse effects.

In most materials studied, such dysfunctional aspects are presented under the issues of rework, variations and failure cost. This is so because such effects are visible and can be quantified easily. According to Josephson *et al.* (2002), rework is any unnecessary effort applied for rectifying construction errors and by errors it is meant by failures in conformance to requirements.

The quantification of rework comes about with its manifestation in the form of cost overrun and schedule overrun. Schedule overrun is easily measureable as it is the measure of the extra time any project took with respect to its planned schedule. On the other hand, cost overrun measurement needs a more systematic approach. Josephson *et al.* (2002), Hall *et al.* (2001) and Kazaz *et al.* (2005) present the cost of rework as the combination of the costs of failure, appraisal, prevention and intangible costs.

Failure costs account for rectification processes applied for tasks which lack the quality level required. Failure costs could be in two categories, internal and external. Internal ones account for activities like scrap, rework and delay done before delivery of product to the client. On the other hand, external failure cost is incurred after delivery of product and it could include repairs, complaints and compensations.

The other parts of rework costs which are less avoidable are appraisal costs and prevention costs. Appraisal costs refer to costs incurred during the checking process of conformance, whereas prevention costs are costs of actions taken in order to avoid failures.

All the above costs are direct rework costs which can be easily measured. Nevertheless, there are intangible costs which cannot be associated with any of the above costs. These are for instance costs due to excess inventory, unnecessary procedures, equipment failure or natural disasters.

In the articles considered here, not all the above costs were determined by the authors. Most studies done concentrated on the measurement of direct rework costs only and avoided the indirect ones. This is because of the difficulty of the identification and quantification process of such indirect costs. For instance, Love *et al.* (2000b) suggests that direct costs of rework are about to 10 – 15% of the contract value of projects and it would be higher if latent and indirect costs like schedule delays, litigation costs and poor quality effects were to be included. In table 1, a summary of the articles studied is presented with respect to the extent of rework costs.

Table 1: Summary of previous studies (adapted from Josephson *et al.* (2002) and modified)

Previous study	Subject of study	Rework costs and schedule overruns	Pre-construction phase contribution to rework
(Cnuddle 1991)	-	10 - 20% of total project cost	46%
(Burati *et al.* 1992)	9 fast-track industrial construction projects	12.4% of total project cost	79%
(Haamarlund *et al.* 1990)	-	4% of total project cost	51%
(Josephson *et al.* 1996)	-	2.3 – 9.4% of contract value of project	32%
(Love *et al.* 2000b)	-	10 – 15% of contract value of projects	-
(Love *et al.* 2005)	Australian construction projects	6.4% of contract values (direct costs) 5.9% of contract values (indirect costs)	-
	Singapore	5 – 10% of contract values of projects	-
	United Kingdom	-	50%
(Josephson *et al.* 2002)	Seven case projects	4.4% of contract values of projects and 7.1% schedule delay	57%
	In housing projects	-	50%
(Love *et al.* 2003) & (Love *et al.* 2000a)	A case study of a residential project in Australia	3.15% cost overrun and 11.6% time overrun	73.1% for cost overrun and 57% for time overrun
(Mills *et al.* 2009)	10,548 residential properties in Australia between 1983 & 1997	4% cost overrun	-
(Love 2002)	161 Australian construction projects	12.6% cost overrun and 20.7% schedule overrun	-
(Hwang *et al.* 2009)	Information on 359 projects from Construction Industry Institute	5% cost overrun	-

Table 1 clearly depicts that most projects face high rework costs and schedule overrun irrespective to the very small profit margins that are apparent in the construction industry. Furthermore, rework has now become so common that parties involved in projects are most of the time preset to pay the cost than to try to prevent it (Josephson *et al.* 2002).

Hence the area of concern of this research is the cost and schedule overrun encountered in most traditional housing projects. The research tries to find out the relationships such adverse effects have with cross-party conflicts that occur in the pre-construction phases of a project life cycle.

Framework of ideas

In order to tackle the research problem, based on the three sub-questions and the area of concern described above, a broad theoretical study was done in the following three areas. The first area covers the literature review done about main causes of rework. This refers to the independent variable on figure 2 (Part 'A'). The second area in this subsection addresses the mechanisms that link the identified causes to the final adverse effects (Part 'C' on figure 2). Finally, part 'D', which refers to possible system engineering based remedies for the reduction of causes of adverse effects is presented.

Causes of rework

Basically rework, variation and failure generate mostly from conception (need specification and requirement development) and design phases (Love *et al.* 2002). As can be seen on table 1 above, the contribution of pre-construction phases to rework is significant. These phases are the phases were a temporary multi-organization is formed from members of different organizations. On the other hand, each member has its own function, interest and most often has a specific engagement point in the project lifecycle.

Based on the materials studied, especially Love *et al.* (2002), Hall *et al.* (2001), Burati *et al.* (1992), Hwang *et al.* (2009) and Love *et al.* (2004), the following five issues are found to be the main causes of rework, variations and failure.

Requirement conflicts: This refers to lack of understanding and incorrect interpretation of client and end-user requirements. This goes hand in hand with communication problems especially in feedback processes (Hall *et al.* 2001). It is furthermore aggravated by the incompleteness of initially provided client requirements which eventually leads to requirement changes at a later stage. Hwang *et al.* (2009) puts client requirement changes as the number one source of rework.

Documentation problem: It could be in the form of inaccurate designs, conflict between different designs or incompleteness in general. Such errors and omissions in designs are ranked as second major cause of rework on Hwang *et al.* (2009). Love *et al.* (2000b) also support this and suggest that time limitations on projects, ways of inducting (recruiting) design staff, parallelism between tasks, underestimation of design hours needed, and lack of sufficient resources to complete documentation aggravate the problem. And as a very basic source to the above factors, low design fees and concept briefing based design planning are given as major reasons.

Poor coordination and integration: This accounts for poor communication(Love *et al.* 2005), inaccessibility of designers for immediate changes, updates and confirmation, and last but not least lack of a "common language" (Roddis *et al.* 2006) which inhibits more advanced design approaches.

Poor quality management: This accounts for lack of formal quality management (Love *et al.* 2005) and good supervision and inspection process. As presented by Hall *et al.* (2001) and Kazaz *et al.* (2005), the application of a formal quality management is the optimization tool between failure costs incurred at the end of a project and the sum of prevention and appraisal costs during a project life cycle. By adopting such an optimization process, it is possible to achieve a minimized total rework cost. But the lack of a formal quality management results in accumulation of errors and omissions till the end of a project. This eventually makes the total rework cost very high as rectification costs much higher at project ends.

Poor standard of workmanship: This corresponds to implementation mistakes at the construction phase. According to Hwang *et al.* (2009) and Burati *et al.* (1992), implementation mistakes include all errors and omissions done by contractors and vendors at construction phase. And as such, these are attributed to poor technical performance, material procurement and contractor management (Frimpong *et al.* 2003).

In addition to the above five causes, two publications which addressed the contribution of variation in procurement methods and project types to the magnitude of rework costs were reviewed. The first is a study by Love (2002) and it considered 161 Australian construction projects. The second is by Hwang *et al.* (2009) and it considered data of 359 construction projects from Construction Industry Institute. Both studies showed that rework costs are not significantly affected by variations in either procurement methods or project types.

Mechanisms

The mechanisms presented in this sub-section represent the causal links between the cross-party conflicts and the final adverse effects. But among the above mentioned five conflicts, the requirement conflicts issue is ranked first in contributing for rework (Hwang *et al.* 2009). The other four issues are left for future researches.

Based on Hall *et al.* (2001), Hwang *et al.* (2009) and Love *et al.* (1999), the three mechanisms presented in figure 3 clearly depict how requirement conflicts eventually leads to cost overrun and schedule overrun. They are briefly explained below.

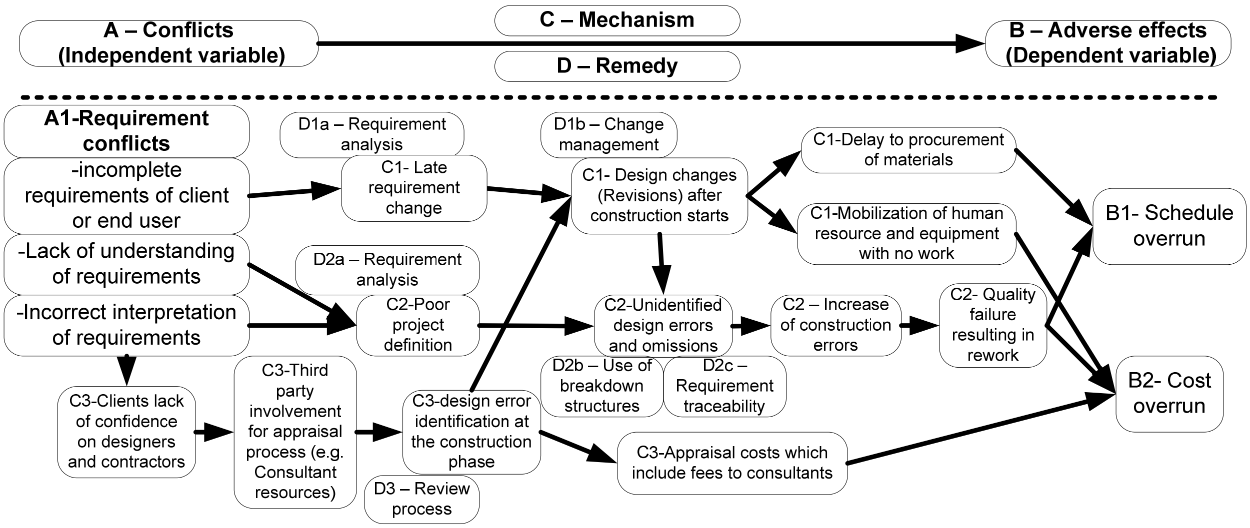

Figure 3: Mechanisms and system engineering remedies

Mechanism C1: The focal point here is the issue of design changes after the commencement of construction. Usually the requirements of clients or end users are incomplete at the beginning of projects. According to Hall *et al.* (2001), the requirement extraction process at the start of a project usually fails to develop a complete set of requirements of the client or end user. This is attributed to the communication problems especially in feedback processes between the client and designers.

Eventually there will be the need for addition or change of requirements. If such change happens after requirements have been approved and design had commenced, it results in late coming design changes or revisions. And in the condition that construction has already started, there will be adverse effects to the project in the form of:

- Delay to material procurement process which in turn creates schedule overrun
- Mobilization of human resources and equipment with no work but pay (Unnecessary cost)
- Additional design documents as a source of unidentified design errors (Input for mechanism C2) which leads to quality failure

Hwang *et al.* (2009) puts client requirement changes as the number one source of rework. In addition to requirement changes which result in late design changes, involvement of third parties for appraisal process (mechanism C3) also induces further revision. For instance, supervision process during construction phase usually identifies design errors which result in the request for design revision. This puts the project on hold till the revised designs arrive.

Mechanism C2: The focal point here is the issue of design errors and omissions that pass to the construction phase unidentified. Such errors and omissions in designs are ranked as second major cause of rework on Hwang *et al.* (2009). They are majorly caused by poor project definition and further aggravated by late design revisions.

Poor project definition is generally attributed to failure of designers in properly understanding and interpreting client requirements. In other words, the incorrect conversion of raw requirements to technical requirements causes the goal and constituencies of a project definition to be insufficient for design referencing.

Consequently, the approval step of the design process is not able to filter out all errors and omissions due to the poor technical requirement definition. This leads to the transfer of such errors and omissions to the construction stage without been detected.

In addition to this, late design changes or revisions that occur after construction commences also aggravate the situation by introducing new but yet to be identified design errors and omissions at the construction phase (input from mechanism C1).

Generally, if design errors and omissions pass to the construction phase before being identified, the number of construction errors will increase. This in turn means poor quality and unavoidable rework. Hence there will be a need for the expenditure of more money and time for rectification process.

Mechanism C3: As presented by Hall *et al.* (2001) and Love *et al.* (1999), the introduction of a third party for the sake of appraisal process is not only non-value adding but also a reason for addition cost.

Quality is initially a given, but as clients lack the confidence on designers and contractors performance, it is a common practice to involve a third party like a consultant as a quality controller. Such a quality control by a third party has two implications.

The first is the fact that it is non value adding. This means, quality control is done for the sake of preserving quality but not adding. Hence when quality preservation is done by a third party other than the designer or contractor, it means the client has to pay more for the additional service rendered.

The other implication is the identification of design errors by the quality controllers while the project is at the construction phase. This induces a request for design revision and as a result stagnation of the project (input for mechanism C1).

Therefore, such an approach of quality control is a reason for more expenses and further revision at a later phase of product creation.

System engineering remedies

In this sub-section, possible system engineering based remedies in relation to the above three mechanisms are presented. The notion is that, if these remedies are properly applied as presented in figure 3, it is possible to prevent the occurrence of the above three mechanisms and eventually reduce the adverse effects on housing development projects.

For the choice of the source of remedies, modern approaches like systems engineering, collaborative engineering, concurrent engineering, value engineering and constructability were considered. The criteria for selection were the approaches capability in reducing cross-party conflicts and the feasibility in the Dutch housing development sector.

Among the above listed, the goal of concurrent engineering, value engineering and constructability is in a different direction. For instance, concurrent engineering is applied for the reduction of overall project delivery time which is preferred for fast-tracked projects (Anumba *et al.* 1997). Value engineering on the other hand is targeted to developing a common understanding on the project definition and design alternatives (Thiry 1997). This makes it ideal for projects with large number of stakeholders and numerous alternatives. In case of constructability, integration of knowledge and experience is focused upon and is best for projects that need optimization (Arditi *et al.* 2002).

For housing projects with cross-party conflicts, an approach which concentrates on the improvement of communication, integration and interface definition is best suited. And for this reason, systems engineering and collaborative engineering are possible candidates. Both have the capacity to reduce adversarial relationships and improve project performance with respect to design satisfaction (Bahill *et al.* 1998) & (Kahn *et al.* 1997).

Nevertheless for this research, system engineering is chosen as it has superior advantages over collaborative engineering. Basically, systems engineering is a grand unified theory for making things work better (Bahill *et al.* 1998). Its goal is to provide a structured but flexible process focused on implementation by transforming requirements into specifications, architectures, and configuration baselines (Defense 2001) & (Sarshar *et al.* 2004). System engineering is the ideal choice for this research as a source of remedy for the following reasons. First of all, it concentrates on interrelationships and patterns of change. It also has the capability in addressing a wide scope including both soft and hard problems (Bahill *et al.* 1998). Moreover, system engineering has been already tested and proven successful in other construction sectors in the Netherlands. This has induced an acceptance in the housing development sector also.

Generally, the choice of systems engineering as a remedy source insures the following benefits.

- System engineering gives a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static ‘snapshots’ (Bahill *et al.* 1998).
- It accounts the use of interdisciplinary teams to state the problem, identify the system’s functions and requirements, define performance and cost figures of merit, investigate alternative designs, and test the system. The process is recursive, iterative, and much of it is done in parallel (Bahill *et al.* 1998) & (Honour 2004).
- Integration problems between different parties can be easily addressed (Sarshar *et al.* 2004).
- Problems of uncertain environments are solved by control coordination and traceability (Defense 2001).
- Lack of flexibility in processes is answered by system engineering (Defense 2001).
- Poor requirements are one of the major causes of project failures. System engineering consists of an efficient requirement development step which enables the development of good requirements (Tran 2005).
- The primary impact of the systems engineering concept is reducing risks early (Honour 2004).
- All teams are integrated in the process by using different roles for boundary management like glue-role, information management and coordination (Honour 2004) & (Sheard 1996).

On the other hand, in this research, the case project under consideration has initially started with the traditional approach and then after a while shifted to the system engineering approach. But according to Bahill *et al.* (2001), such a situation is not favored in comparison to a project which started with system engineering from the beginning. The reasons for this are:

- Starting SE in the middle of a project could result in a double to tenfold higher cost as compared to the cost of a SE started at the beginning of a project. Such cost escalation comes about due to the back-tracking process of the late started SE process. This back-tracking process will result in high costs of design changes at late stages of the project life cycle as well as costs of duplication of effort during the reproduction of already existing documents. The permanent loss of important information that could have been retrieved only at the beginning of the project also contributes to the increase of costs.
- Starting SE in the middle of a project could also result in the slip of the project schedule. This comes about in situations where the newly introduced SE approach contradicts with the already existing project management schedule.
- Lastly, a SE process which started at the middle of a project lacks the advantage of producing better technical products through better requirements, functions and wider possibilities of alternative designs. Instead the emphasis is only on system engineering management aspects.

Hence, as a general condition, the empirical testing of the remedies should also account for the capability reduction due to the late starting of system engineering.

Before passing directly to the remedies, a framework is required to clearly define the application area of the remedies. For this purpose, the three dimensional HKM Framework is used (Kasser 2007a).

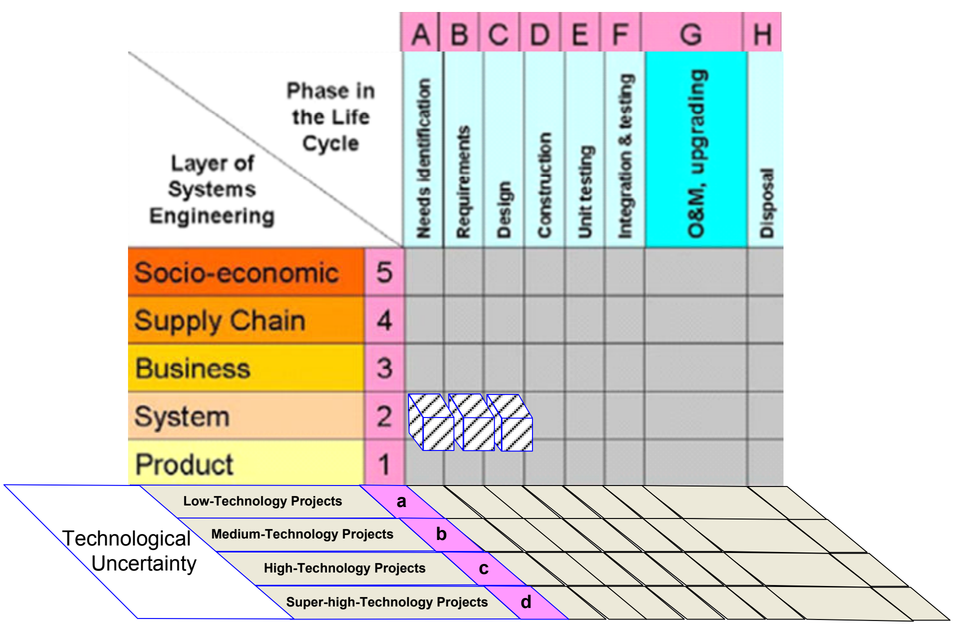

Figure 4: The HKM framework for system engineering

The HKM framework has three dimensions. The horizontal dimension as depicted in figure 2 represents the phases of system engineering life cycle. As our case project is a housing project, it usually covers the levels A to D. But as explained in previous sections; levels A, B and C are the contributors for rework.

The vertical dimension is based on the work of Hitchins (2000) and represents the complexity level based on a "nesting" model. The "nesting" model gives five layers in which one layer is a summation of a multiple of the lower layer. The five layers are briefly explained below.

Layer 1: Product layer: This perspective accounts for a single product without consideration for process.

Layer 2: Project or system layer: This layer is a combination of products and processes. This perspective accounts for a single project or system.

Layer 3: Business layer: This layer is a combination of projects. This perspective focuses on complex processes which involve many projects.

Layer 4: Supply chain layer: This layer is about an industry which is made up of multiple businesses. This perspective accounts for complete supply chains in an industry like the housing industry.

Layer 5: Socio-economic layer: This layer covers not only industries, but also how they are regulated by the society and the government.

This research is about cross-party conflicts in housing development projects. Generally, such conflicts can be mismatches between final products produced by different parties or differences in the processes of developing the products. Hence the researcher is not only interested on products but also processes. Furthermore, the empirical input is going to be extracted from a single case project. Hence the most ideal level of complexity for this research is the system or project perspective (Layer 2).

The product perspective (Layer 1) fails because it doesn't consider processes involved in the product development. On the other hand, the higher perspectives like the business, supply chain or socio-economic perspectives can't be considered because of the following reasons. The first reason is the limitation in the source of empirical data. There is only a single project that can be used for the case study. Hence it is not valid to make a generalization on such high level perspectives. Secondly, because of the short time available, it is necessary to limit the scope of the research to the most suitable perspective.

Lastly the third dimension represents the level of technological uncertainty (risk). It has four types (a, b, c & d) which vary from low-technology projects to super-high-technology ones. As housing construction is a very common practice, the case project in this paper is type a.

Based on the above description, this research considers housing development as a type a (low-technology) and adapts the system perspective to look into the first three phases of the construction life cycle.

Coming to the remedies, some of the technical and management processes of system engineering are considered as presented below. The application of these remedies requires the assignment of a system engineer (integrator) to the project. The system integrator is responsible to the follow-up of the technical processes and the supervision of the management processes along the life cycle of the project.

Requirement engineering

Requirements engineering is about (Davis *et al.* 2005):

- Gathering/uncovering requirements from stakeholders
- Analyzing these requirements for consistency, completeness etc...
- Determining which of these requirements should be addressed given the constraints of the budget.
- Documenting the selected requirements
- Verifying that the specified requirements conform to all quality standards
- Managing changes to requirements.

The goal of requirements engineering is to raise the likelihood that the right system will be built, and that the system when built satisfies its intended customers and addresses their needs to an acceptable degree (Davis *et al.* 2005). The success of this goal can be evaluated based on the following three dimensions (Klaus 1993):

1. Representation from informal into formal
2. Specification from opaque into complete and
3. Agreement from individual view into common view

Initial input is mostly informal, opaque and has personal views. Nevertheless, the desired output of the requirement practice should be formal, complete and with a common view. During the first phase of the system engineering process, the agreement dimension is mostly emphasized. That means, the first step is to direct the subjective interests of the stakeholders to a common view.

Then the aspects of representation and specification can be addressed in the next stages of system engineering. The way of approach also differs at this stage. The target here is to make a clear and formal representation of client's interests and produce complete requirements that satisfy the criteria of SMART.

Requirement engineering consists of two parts; requirements analysis and requirements traceability. The former is about distilling and analyzing the requirements from the client and other stakeholders, whereas the later is about tracing (forward and backwards) the effect of changes in requirements on the design and vice versa.

Requirement analysis (D1a & D2a on figure 3)

Requirement analysis is about distilling and analyzing the requirements from the client and other stakeholders. It is applied early in the life-cycle but the benefits occur later in the life cycle (Nuseibeh *et al.* 2000). Requirement errors are expensive to fix when found during construction phase. But if they are found and fixed early, considerable savings can be made. Requirements engineering is therefore seen as the cornerstone for efficient development of quality systems (Artem *et al.* 2005).

Procedures for requirement analysis should be: Eliciting requirements, modeling and analyzing requirements, communicating requirements, agreeing requirements and evolving requirements (Nuseibeh *et al.* 2000).

An important set of tools for this requirement analysis are the stakeholder identification and analysis techniques. These techniques which can be performed by the planning/designing team possibly joined by selected stakeholders help to identify and organize the different views of stakeholders. In addition to this they also help to find a solution that is carried and supported by the key-stakeholders (Bryson 2004).

Hence, this remedy can be used to prevent mechanism C1 and C2 of figure 3 at early stages. This is true because it will help in developing complete requirements at the initial stage of projects. Consequently, the project will be properly defined and the number of errors, omissions and changes would reduce significantly.

Requirement traceability (D2c on figure 3)

Requirement traceability is the principle of change tracking in the system engineering cycle between requirement analysis, functional analysis and design synthesis (Sutinen *et al.* 2001). So it follows the ability to describe and follow the life of a requirement in both a forwards and backwards direction. It is the mapping of requirement inheritance.

In general, systems engineering is equipped with tools that can achieve a good degree of traceability for requirements. For instance, we can use cross referencing schemes, key phrase dependencies, templates, RT matrices, matrix sequences, hypertext, integration documents, assumption-based truth maintenance networks and constraint networks (Gotel *et al.* 1994).

The application of requirement tracing helps in controlling misinterpretations, incompleteness and other failures of the final product. It also assists in change tracking in the development process.

Therefore, this remedy can be used as a backup plan for mechanism C2 of figure 3, if the requirement analysis fails to create a good project definition. It can be used in filtering errors and omissions that passed unidentified at early stages.

Change management *(D1b on figure 3)*

In order to avoid mismatch of developed products at a later stage, all parties should apply change management alongside their product development. Change management addresses two basic kinds of changes (Kasser 2007b). The first is budgetary change which directly determines the level of performance of a product. Budgetary changes are common in the real world for the reason that all projects are mostly dependent on the external environment (finance). All involved parties in a project should be aware of such budgetary changes and react to them systematically. The reaction can have the following two approaches.

- Reconfiguration of the product development process in order to meet the new budget or
- Playing with low priority requirements.

The other kind of change is related to requirements. Clients usually have the tendency to change their needs while the project is under progress. Hence, if final products do not incorporate variations, rework will become unavoidable at a later stage. For this reason, involved parties should be cautious in updating their requirement database.

Hence, this remedy is a backup plan for mechanism C1 of figure 3, if the requirement analysis fails to create a complete set of requirements. If prevention of mechanism C1 is not possible, involved parties could make themselves flexible to forth coming changes by properly applying change management.

Breakdown structures *(D2b on figure 3)*

In system engineering, a strong linkage is achieved between the initial requirements and the final planning using a series of breakdown structures (Bachy *et al.* 1997). As presented in the following figure, the breakdown structures include product (PBS), assembly (ABS), work (WBS) and organizational (OBS) breakdown structures.

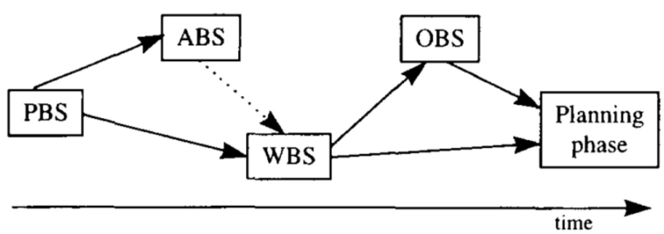

Figure 5: Main procedures to establish the project management plans

By applying these structural representations, it is possible to provide the boundaries between sub-systems and develop work packages which would be assigned to specific organizational units (Globerson 1994). Hence, project managers can lead a well structured project which can host proper change management and requirement traceability.

The relevance of this remedy comes in the form of providing a strong framework for the identification process of errors and omissions on mechanism C2 of figure 3. The existence of a framework that relates the different parts of a project enables a more efficient requirement tracing and reduction of unidentified errors and omissions.

Review process *(D3 on figure 3)*

The review process is a formal process done with and for the customer (Dean *et al.* 1997). It is the responsibility of the system engineer assigned for the project and should be executed at various points of the project life cycle.

The main objectives of this process are to:

- Check for adequacy of the existing verification plan

- Check for completeness in requirements, specifications and other outputs
- Check for unneeded inclusions with respect to the clients interest
- To get customer approval in order to proceed to the next phase of the project
- To make trade-offs between cost, schedule and performance as per the choice of the client

For this research, I present the review processes that can be done in the first three phases of the construction process as depicted on figure 4. At the end of the need identification phase, the system engineer shall perform a mission concept review with the client in order to approve the correct alignment of the project. Then when the requirements phase is over, a system requirements review shall be done for the final approval from the client. During the design phase, two reviews shall be done for all kinds of designs done. The first review will consider the acceptability of all preliminary designs within a given tolerance level, where as the second review is the critical design review where all finalized designs are checked for approval. All these reviews shall be done in the presence of the client, the system engineer and the respective professionals responsible for the product to be reviewed.

The proper application of the above review processes will help to remove mechanism C3 of figure 3. That means the repetitive reviews done will develop client confidence on designers and contractors. Eventually, the client will be able to reduce the project cost by avoiding appraisal costs.

Propositions

As the approach of the research is the testing of theory against empirical evidence, the following propositions are drawn. The propositions link causes to adverse effects based on the above mentioned mechanisms. Each proposition is made up of multiple sub-propositions which are considered as non-equivalent dependent variables. This means, the validity of any sub-proposition depends on the validity of the preceding sub-proposition. Hence for a mechanism to be generalized upon, all sub-propositions of the same mechanism should hold.

In addition to this, each proposition is supplemented with theoretically suitable systems engineering remedies for capability testing.

Proposition 1 (based on mechanism C1)

'Incomplete client or end user requirements which result in design changes after construction commencement lead to additional cost and schedule overrun. '

Proposition 1 is about design changes due to requirement incompleteness. The constituting sub-propositions are:

1a. Incomplete client or end user requirements lead to requirement changes after construction commencement.
1b. Such requirement changes result in design changes.
1c. Design changes after construction starts lead to:
   - Delay to material procurement process which in turn creates schedule overrun

- Mobilization of human resources and equipment with no work but pay (Unnecessary cost)
- Additional design documents as a source of unidentified design errors (Input for mechanism C2) which leads to quality failure

Remedies

- A proper requirement analysis can achieve client requirement completeness.
- Change management helps to reduce the effect of design changes by inducing flexibility.

Proposition 2 (based on mechanism C2)

'Poor understanding and interpretation of requirements lead to increase of unidentified errors and omissions which result in rework at the construction stage.'

Proposition 2 is about unidentified design errors and omissions that pass to the construction stage. The constituting sub-propositions are:

2a. Lack of understanding and incorrect interpretation of requirements results in poor project definition.
2b. The poorness of a project definition leads to the increase of the number of errors and omissions that pass to the construction stage unidentified.
2c. The passing of unidentified errors and omissions to the construction stage increases construction errors.
2d. The quality failure due to construction errors results in rework which costs time and money.

Remedies

- A proper requirement analysis can achieve a good project definition.
- The combined application of breakdown structures and requirement traceability helps to filter out errors and omissions before passing to the construction phase.

Proposition 3 (based on mechanism C3)

'Loss of client confidence on requirement handling capacity of designers and contractors entails in the employment of an external quality controller and as a result additional cost will be incurred by the client.'

Proposition 3 is about the need for and implications of an external appraisal process. The constituting sub-propositions are:

3a. Incorrectness of requirement interpretation by designers and contractors reduces client confidence toward them.
3b. This lack of client confidence leads to the involvement of a third party as external quality controller.

3c. The appraisal process by external parties results in:

- Consultant fees which raise the cost of the client
- Identification of design errors at the construction stage which leads to design revision (Input for mechanism C1)

Remedy

- The review process can help eliminate the need for an external appraisal processes by involving the client intensively.

Findings

The case study considered interviews done with five professionals involved on the Rombout Verhulst Almelo housing project. The housing project started with the traditional approach on January, 2006. But recently, it shifted to a system engineering approach and is being undertaken as a pilot project.

The project is now being handled by a project team which consists of three different parties. The first party represented in the project team is Beter Wonen. Beter Wonen is a housing development company which acts as the client, advisor and project manager of the case project. Beter Wonen also has a department that administers and maintains the residences after completion of construction. The second party represented in the project team is a potential and possible general contractor, Dura Vermeer. The last party involved is Loohuis installatiegroep, an installation design and construction company. All the three parties will be involved in conception, design and construction phases of the pilot project.

The respondents were chosen in such a way that all the three parties involved in the project team are represented. Among the four respondents, two are from Beter Wonen, two from Dura Vermeer and one from Loohuis. All the respondents had an extensive experience in housing development projects, with an average of 20 years. On the other hand, their experience in system engineering is only theoretical and is as old as the case project. One exception is the respondent from the Loohuis who had experience on customer oriented system engineering approach for the past 18 years.

For this research, the three propositions mentioned in the previous section were tested against the responses of the respondents. As the number of respondents is too small to make statistical evaluation, a proposition holds if only all the respondents agree to the proposed outcome. On the other hand, if there is even one response, the proposition will be questioned and be open for refinement. The refinement of the proposition could be in the form of introduction of additional pre-conditions or change of final outcomes of a given mechanism.

The same form of data analysis was applied for all the system engineering remedies suggested. But in addition to the checking of the specific remedies, the respondents were interviewed about the success of system engineering in general. This is done to avoid the threat of the validity of the responses with respect to the case study as system engineering was not started from the beginning.

According to the data, all the respondents agree about the better success of system engineering over the traditional approach. The major reasoning suggested by most is the transparency achieved by the system engineering approach. But one respondent reminded that there is the need to work on it to make it successful.

With respect to a late started system engineering process, the respondent from Loohuis believes that the effectiveness will not reduce if interviews done with the client prior to the introduction of system engineering are properly documented. The respondents from Beter Wonen also support this notion as long as the tracing back of all system engineering activities is done correctly.

In case of the project at hand, all the respondents agree that the project is still at the very beginning phase and it is being restarted with the system engineering approach from scratch. So the possibility of loss of effectiveness of system engineering is minimal.

On the other hand, the respondents from Beter Wonen confirmed the presence of an already produced architectural design from the initial traditional approach. At this moment, this design had been totally ignored for the sake of proper implementation of system engineering. But the fact is that there is already extra cost incurred and furthermore there is a possibility for bias on future architectural design.

Nevertheless, for this research, it can be concluded that the validity of the responses about the remedies is not compromised as the project is still at its earliest phases.

The following sub-sections present summaries of the responses obtained from the interviews, data interpretation and conclusions on the validity of the propositions.

Proposition 1 (based on mechanism C1)

'Incomplete client or end user requirements which result in design changes after construction commencement lead to additional cost and schedule overrun.'

All respondents agree that traditional housing projects often encounter incomplete client or end user requirements and sometimes this leads to requirement changes after construction commencement. They also support that such late requirement changes sometimes result in delay of material procurement. However, it was suggested that the procurement process should be on the critical path of the project for the delay to occur. It was also suggested that delays are avoided by paying more for faster delivery. The respondents from Beter Wonen also added that the implications of such a delay are directly related to the income of the client as the dwellers would postpone their rental payment to Beter Wonen if they don't receive the residences on time.

The other effect of incomplete requirements addressed was the lack of work for mobilized human resources and equipments. Two of the respondents suggested that such stagnation of human resources without any work is sometimes encountered due to late requirement changes. But the other respondents responded that such problems are avoided by reallocation of workers and equipment to other tasks.

The final effect checked under proposition 1 is the issue of lately introduced revision documents as additional sources of unidentified errors. Most of the respondents agree that it is less probable for such errors to emerge from revision documents as design changes are done by combined discussion of all teams involved.

From the above response, it can be deduced that theory of mechanism C1 fits with practice in case of procurement problems but still needs refinement as procurement delays are avoided by paying more money for faster delivery. This means the adverse effect is in the form of cost overrun, not schedule overrun. On the other hand, parts of mechanism C1 which concern stagnation of human resource and addition of new error sources are not supported by practice. Hence proposition 1 holds only with respect to procurement problems but should be linked to cost overrun instead of schedule overrun.

Remedy

On system engineering remedies suggested about incomplete requirements, four of the respondents are confident about the success of requirement analysis process in achieving a complete set of requirements. They believe that applying this process in system engineering is successful because transparency and explicitness in requirements are achieved easily. Moreover, more stakeholders are involved in the initial phases of the project as well as all informal requirements are properly changed to formal requirements.

Nevertheless, one respondent doubted the possibility of complete requirement at early stages of a project even though he is optimistic about requirement analysis. He argued that not all stakeholders are proactive in specifying requirements.

The other system engineering remedy, change management, which can be used to give flexibility to involved parties in a project, was also supported by all the respondents. Nevertheless its practicality was questioned by the respondent from Dura Vermeer as the remedy seemed hypothetical.

Based on the above response, it can be deduced that both requirement analysis and change management are perceived positively by the professionals. But even though supported by most respondents, the requirement analysis process was questioned for its ability to achieve complete requirements. The other doubt observed is the practicality issue and this can be attributed to lack of exemplary housing projects that applied system engineering.

Hence it can be concluded that requirement analysis helps in achieving better requirement completeness rather than total completeness. Moreover, change management gives the flexibility needed to cope with change. And any doubt of practicality is a concern for the future as the case project considered is a pilot case.

Proposition 2 (based on mechanism C2)

'Poor understanding and interpretation of requirements lead to increase of unidentified errors and omissions which result in rework at the construction stage.'

All respondents agree that traditional housing projects are often confronted with poor project definitions when looked from the system engineering perspective. The traditional approach which is usually followed doesn't impose any guidelines of how to define a project. Based on the respondents from Beter Wonen, most housing projects do not have functional requirements and the system requirements made are usually incomplete. Even in some cases, design precedes requirement development.

The respondents from Beter Wonen and Loohuis support that the poorness of project definitions leads to the presence of unidentified design errors and omissions which eventually pass to the construction phase. They also agree that sometimes the consequences of such unidentified errors and omissions could be increase of construction errors and eventually more rework.

On the other hand, the respondents from Dura Vermeer contradict the passing of errors to the construction phase based on the fact that contractors check each design step by step before commencing construction. Rather, the impact of such unidentified design errors and omissions comes about in the form of design tuning process. As most initial designs are off-budget and exotic, extra energy, time and cost have to be spent to refine the designs so that they would be practical. And usually the ones burdened with this task are contractors and sub-contractors even though the failure is from architects. An additional impact is the eventual delay of the construction procurement stage which is especially very much significant for renting companies like Beter Wonen.

From the above responses, it cannot be deduced that the whole proposition of mechanism C2 fits with practice. The existence of poor project definition in traditional housing projects holds up with practice. Nevertheless, the passing of unidentified errors and omissions to the construction stage as a consequence of poor project definition doesn't hold. Rather a new form of adverse effect in relation to poor project definition was suggested by the respondents. This adverse effect is the design refinement loop undertaken before the construction phase was entered.

Hence the second proposition should be changed to '*Poor understanding and interpretation of requirements lead to an iterative refinement process which takes up extra energy, time and cost and eventually delay the construction procurement stage.*' But it is important to keep in mind that, it is not possible to generalize upon the above revised proposition based on the data of this research. It requires further testing to be concluded upon.

<u>*Remedy*</u>

On system engineering remedies suggested about misinterpretation and misunderstanding of requirements, all respondents are confident about the success of requirement analysis process in achieving a good project definition. One respondent commented that applying a proper requirement analysis helps to reduce the loops of design tuning and eventually reduce the cost of contractors and subcontractors.

The other system engineering combo-remedy, a combination of breakdown structures and requirement traceability process, which can give a structured framework for filtering out errors and omissions, was also supported by all the respondents. Especially the graphical nature of breakdown structures is taken to be advantageous as most individuals are comfortable in working with graphic representations. Nevertheless, its practicality was questioned by the respondent from Dura Vermeer as the remedy seemed hypothetical.

In addition to the above remedies, the respondent from Loohuis suggested that involvement of potential contractors and sub-contractors at the conception and design phases could help in reducing the design refining loops. This could be very much helpful for Beter Wonen as it would help to avoid the extra cost that is usually spent for project redesign and retendering. Such redesign and retendering occurs when the budget allocated by Beter Wonen is less than the initial tender wining price.

Based on the above response, all respondents have a positive perspective towards the success of requirement analysis. The combination of breakdown structures and requirement traceability as a framework for error identification is also supported by all.

Hence it can be concluded that, a proper requirement analysis can achieve a good project definition. Moreover, the combined application of breakdown structures and requirement traceability helps to filter out errors and omissions before passing to the construction phase.

Proposition 3 (based on mechanism C3)

'Loss of client confidence on requirement handling capacity of designers and contractors entails in the employment of an external quality controller and as a result additional cost will be incurred by the client.'

There is a common understanding among respondents that mistrust is present on most traditional projects by default. In case of Beter Wonen, both the residential operations and project development departments do not trust contractors. But when it comes to the architect, they have a different view point. Usually the residential operations department is represented by non-technical individuals who are not able to understand the outputs of architects. Hence the residential operations department lacks confidence even on architects.

On the other hand, the project development department of Beter Wonen, which is usually composed of technical individuals, understands what the architect delivers. Furthermore, in case of traditional procurement process, usually there is no requirement database that can be used for the checking of design deliverables. For this reason, professionals of the project development department of Beter Wonen do not have the ground to doubt the architects and usually take the architects designs as initial project input instead of considering the residential operations department requirements.

All respondents also agree that lack of client confidence leads to employment of external quality controllers. But according to the respondents from Beter Wonen, the quality control is not meant for the architectural works but only for the checking of bill of quantities and the supervision of the construction process.

With respect to the necessity of quality controllers, the respondents from Beter Wonen and Loohuis believe that supervisors could be avoided as long as contractors can be fully trusted. Nevertheless, all the respondents agree that supervisors cannot be considered as non-value adding. The justification for this is the ability of supervisor in solving special problems by providing special knowledge and tailor-made solutions.

The other impact, request of design revision due to identification of errors during construction supervision, is supported by the respondents from Dura Vermeer and Loohuis. But the respondents from Beter Wonen believe that error identification during construction doesn't lead to design revision. Rather, it is a common practice to temporarily stop the task and immediately give site solutions. Generally the side effect here is the possibility of project delay.

Based on the above responses, it cannot be deduced that proposition 3 fits with practice. The fact that there is mistrust between client and other parties is empirically supported. The employment of a quality controller in relation to this mistrust is also a practical reality. However, the importance of the quality controller is not only limited to tackling mistrust but also in supplying expert knowledge and experience for the tackling of special problems. Hence the cost incurred for such quality control cannot be taken as unnecessary one. Furthermore the linkage between quality control and the request for design revision during the construction phase cannot be concluded upon as the responses are contradicting.

Hence, it can be concluded that proposition 3 doesn't hold with respect to unnecessary expense for quality control. And with respect to design revision, it should be modified as *'Loss of client confidence on designers and contractors entails in the employment of an external quality controller which could lead to design revision at the construction stage.'* But it is important to keep in mind that, it is not possible to generalize upon the above revised proposition based on the data of this research. It requires further testing to be concluded upon.

Remedy

With respect to the review process, which was suggested as a replacement of the external appraisal process, the respondents from Beter Wonen and Loohuis are confident that it would be successful in creating sufficient trust between client and other parties. But they also mention that the review process would require a good information system with higher initial project investment. And for this, awareness change is required among stakeholders. The one of the respondents from Dura Vermeer also agreed with the possible success of the review process in achieving trust, but believes that it might result in schedule overrun as it takes too much process.

Contrary to this, the other respondent from Dura Vermeer disagreed with the better success of the review process. He mentioned that the review process is a common practice in Dura Vermeer. However, supervisors are still necessary as plans on papers are not the same as plans on practice. The work on site is not as explicit as a machine. Supervisors help in handling unknown conditions like weather, theft and unpredictable human resources.

Based on the above responses, it is clear that the review process faces both acceptance and doubt. Its ability for involving the client intensively is a positive aspect in achieving trust and better quality. Nevertheless, its success is also questioned due to the requirement of a good data administration process and the inability of representing exact site conditions.

Hence the review process can't be used as a replacement for the external appraisal process even though it has good capability in achieving trust between client and involved parties.

Summary

Based on the findings and discussion presented above the following revised mechanisms and remedies diagram is developed. In the diagram, solid arrows represent empirically validated causal linkages between conflicts and adverse effects. The dashed arrows represent causal linkages which require further empirical testing to be generalized upon. The revised mechanisms are briefly explained below the figure.

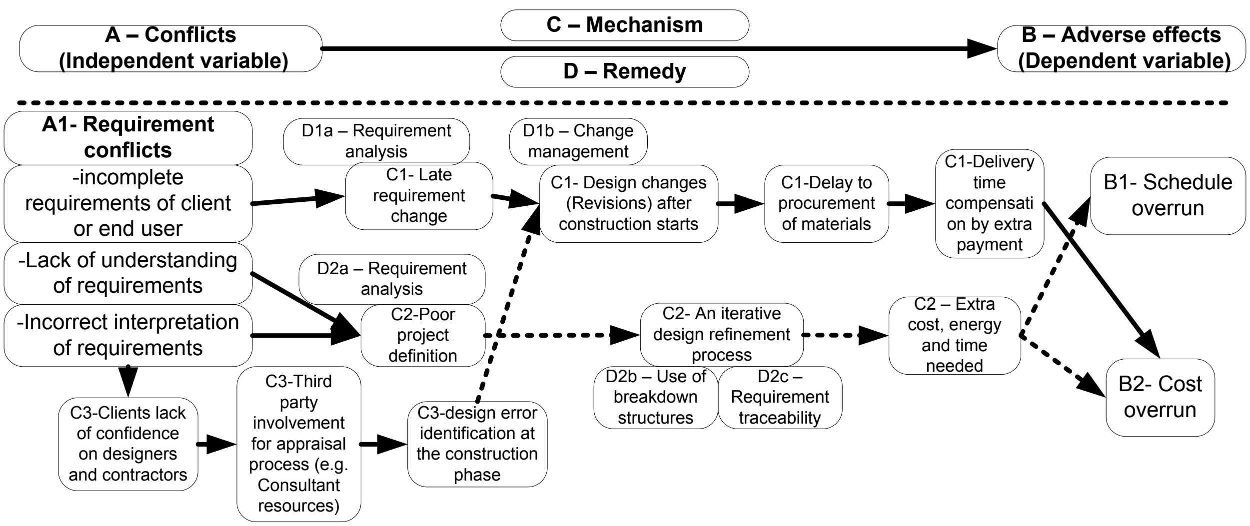

Figure 6: Revised mechanisms and system engineering remedies

<u>Revised Mechanism C1:</u> The focal point here is the issue of design changes after the commencement of construction. Usually the requirements of clients or end users are incomplete at the beginning of projects. According to Hall *et al.* (2001), the requirement extraction process at the start of a project usually fails to develop a complete set of requirements of the client or end user. This is attributed to the communication problems especially in feedback processes between the client and designers.

Eventually there will be the need for addition or change of requirements. If such change happens after requirements have been approved and design had commenced, it results in late coming design changes or revisions. And in the condition that construction has already started and a given procurement process is on the critical path of a project, renegotiation of price and delivery time is required between supplier and contractor. This is done in order to avoid the late delivery of materials by paying extra for the imposed time tension.

Hwang *et al.* (2009) puts client requirement changes as the number one source of rework. In addition to requirement changes which result in late design changes, involvement of third parties for appraisal process (mechanism C3) also induces further revision. For instance, supervision process during construction phase sometimes identifies design errors which result in the request for design revision. This puts the project on hold till the revised designs arrive. Nevertheless, this linkage between mechanism C3 and C1 needs further empirical testing.

With respect to system engineering remedies, requirement analysis helps in achieving better requirement completeness at early stages of a project. Moreover, change management can give the flexibility needed to cope with change.

<u>Revised Mechanism C2:</u> Poor project definition is generally attributed to failure of designers in properly understanding and interpreting client requirements. In other words, the incorrect conversion of raw requirements to technical requirements causes the goal and constituencies of a project definition to be insufficient for design referencing. The existence of poor project definitions in housing projects is empirically validated on this research.

Based on the suggestions made by the respondents, the effect of poor project definition is the need for an iterative design refinement loop during the pre-construction stages in order to achieve an error free design. Such a refinement process usually takes up extra energy, time and cost. And eventually, due to the extra time consumed, the procurement of the construction stage is delayed. However, such a mechanism between poor project definition and final adverse effects like cost and time overrun requires further empirical testing.

With respect to system engineering remedies, a proper requirement analysis can achieve a good project definition. Moreover, the combined application of breakdown structures and requirement traceability helps to simplify the refinement loop at the pre-construction phase.

<u>Revised Mechanism C3:</u> Quality is initially a given, but as clients lack the confidence on designers and contractors performance, it is a common practice to involve a third party like a consultant as a quality controller. Such a quality control by a third party could result in the identification of design errors while the project is at the construction phase. This induces a request for design revision and as a result stagnation of the project (input for mechanism C1). Therefore, such an approach of quality control is a reason for further revision at a later phase of product creation. Nevertheless, this linkage between mechanism C3 and C1 needs further empirical testing.

Generalization

The goal of this research was to check validity of theoretically developed mechanisms and test the capability of system engineering in the reduction of cross-party conflicts, specifically requirement conflicts. Three requirement related propositions were developed theoretically and had been tested empirically. The first proposition holds true for problems related to procurement of materials where as proposition two and three didn’t hold empirically. Furthermore the empirical analysis produced suggestions for other alternative mechanisms like the adverse effects encountered due to an iterative design refinement process.

Even though the findings of the research didn't fully support the initial theoretical propositions, the initial sub-propositions of all the three mechanisms developed were empirically supported (figure 6). That means it could be generalized that traditional housing development projects face:

- Incomplete requirements which result in design revisions after construction commencement and eventually affect the material procurement procedure in the form of extra cost.
- Poor project definition due to lack of understanding and incorrect interpretation of requirements and
- Mistrust between client and other involved parties which leads to the employment of quality controllers.

No further generalizations could be made between the requirement conflicts and the most commonly observed adverse effects like cost overrun and schedule overrun. This is due to data variation among respondents. However, respondents suggested additional possible mechanisms like the existence of a preconstruction design refinement process that could lead to both cost and schedule overrun.

With respect to remedies, four of the initially suggested five system engineering remedies were empirically supported. According to the experts, the requirement analysis process, change management process, breakdown structures approach and requirement traceability are potential remedies for the reduction of requirement related conflicts.

Hence, it can be generalized that there is a positive attitude about system engineering's success in reducing cross-party conflicts with respect to requirement problems. And in relation to the case project, the early introduction of system engineering could enable a more comprehensive requirement database and a qualifying project definition at early stage of the project.

Conclusion

Generally, in this paper, it was able to adapt and test generic sources and mechanisms of adverse effects specifically to the Dutch housing development sector. Furthermore, it was able to shade a light on how cross-party conflicts are linked to adverse effects on housing development projects. It was also able to show the validity of system engineering remedies in reducing the conflicts at early stages.

In addition to knowledge development, the findings of this research demonstrate how far the housing development sector is from theoretical support. The sector is more inclined to experience development and less attention is given to the scientific growth. This restricts adoptions of changes and innovations that come with time. More specifically to this research, what is prescribed in scientific materials about requirement conflicts and their linkage with adverse effects is not representative of the reality. Hence, the success of remedies tailor made for the theoretically prescribed problems is questioned when practicality is considered.

Even though the gap between theory and reality is large, this research also gives a hint on how to narrow it. If parties involved in the housing development sector are willing to participate in such research projects, the scientific approach can provide representative models of the reality and the best remedies with high rate of success.

The last contribution of the research is with respect to systems engineering. The findings of the research, gives a positive nudge for the adaption of systems engineering in the Dutch housing development sector. But still, exemplary projects are needed to develop full confidence on systems engineering.

With respect to the reliability, the research is threatened for two reasons. First the material available to extract mechanisms for the theoretical model was not sufficient. Secondly, the number of respondents considered is small and hence the representativeness could be questioned. Therefore, it is necessary to understand that what is done in this paper is the tip of the iceberg and further work is required to definitively ascertain the conclusions.

Recommendation

As discussed in the conclusion part, this research was scoped down to cross-party conflicts that are related to requirements only. To get the complete picture of the situation, the consideration of all forms of conflicts is essential. Hence the other four causes of rework could be good topics for further research.

The other issues that require further research are the revised mechanisms presented under the discussion summary. Revised mechanism C2 and C3 need further empirical support in order to be generalized upon.

With respect to the case project, the success of system engineering is optimistically viewed among the involved professionals. But bias from the already done architectural designs could threaten the performance of system engineering. Hence care should be taken in order not to be affected by the old design when the system engineering led design is produced.

References

Anumba, C J and Evbuomwan, N F O (1997) Concurrent engineering in design-build projects. *Construction Management and Economics*, **15**(3), 271 - 81.

Arditi, D, Elhassan, A and Toklu, Y C (2002) Constructability Analysis in the Design Firm. *Journal of Construction Engineering and Management*, **128**(2), 117-26.

Artem, K and Markku, S (2005) Requirements quality control: a unifying framework. *Requir. Eng.*, **11**(1), 42-57.

Bachy, G and Hameri, A P (1997) What to be implemented at the early stage of a large-scale project. *International Journal of Project Management*, **15**, 211-8.

Bahill, A T and Gissing, B (1998) Re-evaluating systems engineering concepts using systems thinking. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, **28**(4), 516-27.

Bahill, T and Briggs, C (2001) The Systems Engineering Started in the Middle Process: A Consensus of Systems Engineers and Project Managers. *Systems Engineering*, **4**(2).

Bryson, J (2004) What to do when stakeholders matter. *Public Management Review*, **6**(1), 21-53.

Burati, J J L, Farrington, J J and Ledbetter, W B (1992) Causes of Quality Deviations in Design and Construction. *Journal of Construction Engineering and Management*, **118**(1), 34-49.

Checkland, P and Holwell, S (1998) *Information, Systems and Information systems: making sense of the field*. Chichester: John Wiley & Sons.

Cnuddle, M (1991) Lack of quality in construction - Economic losses. *In*, *European Symposium on Management, Quality and Economics in Housing and Other Building Sectors*, 508-15.

Davis, M and Didar, Z (2005) Good requirements practices are neither necessary nor sufficient. *Requir. Eng.*, **11**(1), 1-3.

Dean, F F, Bentz, B and Bahill, A T (1997) *A Road Map for implementing System engineering*, Sandia National Laboratories.

Defense (2001) Systems Engineering Fundamentals. In, Fort Belvoir, Virginia: Defense Acquisition University Press.

Frimpong, Y, Oluwoye, J and Crawford, L (2003) Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. *International Journal of Project Management*, **21**(5), 321-6.

Globerson, S (1994) Impact of various work-breakdown structures on project conceptualization. *International Journal of Project Management*, **12**(3), 165-71.

Gotel, O C Z and Finkelstein, C W (1994) An analysis of the requirements traceability problem. *In*, *Requirements Engineering, 1994., Proceedings of the First International Conference on*, 94-101.

Haamarlund, Y, Jacobsson, S and Josephson, P (1990) Quality failure costs in building construction. *In*, *Proceedings of the CIB W55/W65 Joint Symposium*, Sydney. International Council for Building Research Studies and Documentation, 77-89.

Hall, M and Tomkins, C (2001) A cost of quality analysis of a building project: towards a complete methodology for design and build. *Construction Management and Economics*, **19**(7), 727 - 40.

Hitchins, D K (2000) World class Systems Engineering – the five layer model. In.

Honour, E C (2004) Understanding the value of system engineering. In: Honourcode, Inc.

Hwang, B-G, Thomas, S R, Haas, C T and Caldas, C H (2009) Measuring the Impact of Rework on Construction Cost Performance. *Journal of Construction Engineering and Management*, **135**(3), 187-98.

Josephson, P-E, Larsson, B and Li, H (2002) Illustrative Benchmarking Rework and Rework Costs in Swedish Construction Industry. *Journal of Management in Engineering*, **18**(2), 76-83.

Josephson, P E and Hammarlund, Y (1996) The cost of defects in construction. *In*, *CIB-W65 International Symposium for the Organization and Management of Construction: Shaping Theory and Practice*, University of Strathclyde, Scotland, U.K.

Kahn, K B and McDonough, E F (1997) An Empirical Study of the Relationships among Co-location, Integration, Performance, and Satisfaction. *Journal of Product Innovation Management*, **14**(3), 161-78.

Kasser, J E (2007a) A proposed framework for a systems engineering discipline. *In*, *CSER*, Hoboken, NJ. Stevens Institute of Technology, 57-71.

Kasser, J E (2007b) *A framework for understanding systems engineering*. Cranfield, Bedfordshire, England: The Right requirement Ltd.

Kazaz, A and Birgonul, M T (2005) Determination of Quality Level in Mass Housing Projects in Turkey. *Journal of Construction Engineering and Management*, **131**(2), 195-202.

Klaus, P (1993) The Three Dimensions of Requirements Engineering. In: *Proceedings of Advanced Information Systems Engineering*: Springer-Verlag.

Love, P E D (2002) Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects. *Journal of Construction Engineering and Management*, **128**(1), 18-29.

Love, P E D and Li, H (2000a) Quantifying the causes and costs of rework in construction. *Construction Management and Economics*, **18**(4), 479 - 90.

Love, P E D and Sohal, A S (2003) Capturing rework costs in projects. *Managerial Auditing Journal*, **18**(4), 329-39.

Love, P E D and Edwards, D J (2004) Forensic project management: The underlying causes of rework in construction projects. *Civil Engineering and Environmental Systems*, **21**(3), 207 - 28.

Love, P E D and Edwards, D J (2005) Calculating total rework costs in Australian construction projects. *Civil Engineering and Environmental Systems*, **22**(1), 11 - 27.

Love, P E D, Mandal, P and Li, H (1999) Determining the causal structure of rework influences in construction. *Construction Management and Economics*, **17**(4), 505 - 17.

Love, P E D, Mandal, P, Smith, J and Li, H (2000b) Modelling the dynamics of design error induced rework in construction. *Construction Management and Economics*, **18**(5), 567-74.

Love, P E D, Holt, G D, Shen, L Y, Li, H and Irani, Z (2002) Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management*, **20**(6), 425-36.

Mills, A, Love, P E D and Williams, P (2009) Defect Costs in Residential Construction. *Journal of Construction Engineering and Management*, **135**(1), 12-6.

Nuseibeh, B and Easterbrook, S (2000) Requirements engineering: a roadmap. *In*, *ICSE '00: Proceedings of the Conference on The Future of Software Engineering*. ACM Press, 35-46.

Roddis, W M K, Matamoros, A and Graham, P (2006) Interoperability in building construction using exchange standards. *In:* Smith, I F C (Ed.). Springer-Verlag Berlin, 576-96.

Sarshar, M, Haigh, R and Amaratunga, D (2004) Improving project processes: best practice case study. *Construction Innovation*, **4**, 69-82.

Sheard, S A (1996) Twelve systems engineering roles. *Software productivity consortium*.

Sutinen, K, Almefelt, L and Malmqvist, J (2001) Implementation of requirements traceability in systems engineering tools. In, Goteborg, Sweden: Chalmers University of Technology

Thiry, M (1997) *Value Management Practice*. Sylva (NC): Project Management Institute.

Thomas, N S, Roseb, T M, Makb, M and Chenb, S E (2002) Problematic issues associated with project partnering — the contractor perspective. *International Journal of Project Management*, **20**, 437–49.

Tran, X-L (2005) Towards improving the recognition and correction of poor requirements. In, Mawson Lakes, South Australia, 5095: Systems Engineering and Evaluation Centre, University of South Wales.

Vaaland, T I (2004) Improving project collaboration: start with the conflicts. *International Journal of Project Management*, **22**, 447–54.

Yin, R K (2003) *Case Study Research: Design and Methods*. 3 ed. Vol. 5, London: Sage Publications.

Appendix 1: Interview database

Case project: Rombout Verhulst Almelo						
1.Background information about respondent						
General						
	Respondents name	Ing. Robert B. Even	Ing. P.C. Berkers	Ing. G. Mekkelholt	Ing. B.G.M. Kuipers	Mr. Gert Van Werven
	Company name	Dura Vermeer	Beter Wonen (a non-profit company which develops and rents residential facilities)	Beter Wonen (a non-profit company which develops and rents residential facilities)	Loohuis installatiegroep B.V (Loohuise is a group of six Dutch and one German installation companies that subcontract installation works like lighting, heating, cooling, ventilation, plumbing…)	Dura Vermeer
	Job title	Head of calculations	Head of Projects	Project leader	Director of general affairs	Senior project coordinator (coordinating all pre-contract project aspects between architect, contractor and subcontractors)
The respondent's professional background and experience						
	Years of experience with housing development projects	20 Years	greater than 30 years	12 years	18 Years	22 Years
	Years of experience with system engineering	Just has taken two SE course sessions as an introduction	1 year theoretical experience	1 year theoretical experience	18 years of customer oriented SE on housing projects (Not much coverage of more stakeholders.) Have started applying complete SE approach since half a year.	No experience. Only has participated on some presentations about system engineering.

Condition of involvement with the case project						
	Representing	A potential and possible general contractor	Project development department of the project client (Beter Wonen). They work as advisor and project manager. The residential operations department of Beter Wonen does the project initiation and acts as the main client. Furthermore, when the construction is over, the residential operations department takes over the finalized buildings for renting and maintaining process.	Project development department of the project client (Beter Wonen). They work as advisor and project manager. The residential operations department of Beter Wonen does the project initiation and acts as the main client. Furthermore, when the construction is over, the residential operations department takes over the finalized buildings for renting and maintaining process.	Installation design company and installation contractor	General contractor
	At which project stage	In conception, design and construction stages	In design and construction stages. The conception stage is usually performed by the residential operations department.	In design and construction stages. The conception stage is usually performed by the residential operations department.	In conception, design and construction stages	Not involved at this moment. In case of other projects, he could be involved at all the various stages like conception, design or construction.
2.Test of proposition 1						
"Incomplete client or end user requirements which result in design changes after construction commencement lead to additional cost and schedule overrun."						
From your experience, are traditional housing projects confronted with incomplete client or end user requirements?		Yes, often	Yes, all the time.	Yes, all the time.	Yes, often	Yes, all the time
If yes,	Does such incompleteness result in requirement changes after construction phase is entered?	Yes, sometimes	Yes, often	Yes, often	Yes, sometimes	Yes, often

	If yes,	Do the design changes induced by such late requirement changes lead to delay in procurement of materials during construction?	Yes, sometimes. If the procurement is not on the critical path of the project, renegotiations can be done with the supplier to delay the delivery. But if there is no time to spare, higher price should be paid to make the supplier deliver in a shorter period of time. Hence for the sake of not affecting the critical path, the time lost for design change is replaced by more cost.	Yes, often	Yes, often	Yes, sometimes	Doesn't have experience in this. But generally he thinks that it is not common and happens rarely. For instance, addition of a requirement like adding a parking under an already started apartment is very rare but could happen. When such change happens, it affects cost and time in relation to procurement.
		Do the design changes induced by such late requirement changes lead to problems of human resources during the construction stage (or in other words: does it occur that people have to stop working in the production stage because of design changes)?	No, never. All the resources affected would be reallocated to other work posts.	Yes, sometimes	No, never. Workers are reallocated.	Yes, sometimes	No, never as the resources would be reallocated to another project.
		Do the design changes induced by such late requirement changes become additional source for unidentified design errors and eventually increase construction errors?	Not enough experience. But design changes are done by combined discussion of all teams. Hence additional unidentified design errors are not expected.	Yes, sometimes.	No, never.	No, never when the design change is done by the installation contractor (loohuis) itself. The reason for this is because; the construction experience loohuis has would be used during redesigning. But if the redesigning party doesn't have the construction experience, late requirement changes	Yes, sometimes

				could become additional source of unidentified design errors.	
If no,					
Where does the impact of such changes lay?		The starting and stopping of projects is costly. In relation to Beter Wonen, it results on delay of the final delivery time for tenants. This means dwellers would postpone the payment of rent. This late rent collection affects Beter Wonen very much.	The starting and stopping of projects is costly. In relation to Beter Wonen, it results on delay of the final delivery time for tenants. This means dwellers would postpone the payment of rent. This late rent collection affects Beter Wonen very much.		
<u>Testing of Remedies</u>					
According to your perception, can the proper application of requirement analysis on the case project achieve the extraction of a complete set of requirements at early stages of the project?	Yes, all the time. In traditional approaches, it is common for improper interpretation without any referencing. But SE gives transparency and explicitness in requirements. Hence misunderstanding and misinterpretation problems can be reduced.	Yes, all the time. The reasons are: more stakeholders are accounted; transparency is achieved as more parties other than architects and advisors are involved; architect is no more in first place; the back ground of requirements is more transparent.	Yes, all the time. The reasons are: more stakeholders are accounted; transparency is achieved as more parties other than architects and advisors are involved; architect is no more in first place; the back ground of requirements is more transparent.	Yes, all the time. If all informal requirements are changed to formal requirements, there would finally be a large database. Hence it would help in better project detailing and eventually less errors. Usually, in traditional approach, questions like 'which installation is required?' is asked. But in SE approach, all requirements of the client should be brought in paper. This means, questions like 'what temperature does the client want during the day?'	Looks wonderful but practicality is questioned. The question here is 'can all requirements be specified at early stages?' Dura always tries to achieve complete requirement as early as possible. But as stakeholders are not professional parties, they are not proactive about requirements. Usually, they need worked out drawings to specify their requirements. For example, stakeholders like human resource inspection and fire department are not

					able to specify what to be designed. Instead they participate by identifying the problems of an already finished design.
If 'no', why?					
Can the application of change management by parties involved in the case project induce flexibility and as a result reduce the effect of design changes?	Not enough experience. It is a positive idea but hypothetical. Hence practicality is disputed.	Yes, all the time.	Yes, all the time.	Yes, all the time.	Yes
If 'no', why?					
What other system engineering processes do you think can assist in achieving completeness in requirements and reduction of late coming changes? (If you have experience with system engineering.)	Not enough experience.	Not enough experience.	Not enough experience.		

3.Test of proposition 2					
"Poor understanding and interpretation of requirements leads to increase of unidentified errors and omissions which result in rework at the construction stage."					
From your experience, are traditional housing projects confronted with poor project definition?	Yes, often	Yes, all the time. In most traditional projects, functional requirements are never made and system requirements are not complete. Sometimes, first design is made then requirements developed. There is no transparency in architects work. Nevertheless, as there is no reference or guide line in the traditional approach, the project definition cannot be called poor from traditional perspective. On the other hand, from SE perspective, the project definition is always poor.	Yes, all the time. In most traditional projects, functional requirements are never made and system requirements are not complete. Sometimes, first design is made then requirements developed. There is no transparency in architects work. Nevertheless, as there is no reference or guide line in the traditional approach, the project definition cannot be called poor from traditional perspective. On the other hand, from SE perspective, the project definition is always poor.	Yes, often. For example, as most clients are not professionals, they employ advisors. And if advisors are not aware of proper interpretation between client need and technical terms, errors will occur at construction phase. For instance, 'top cooling' is a big confusion between clients and professionals. 'Top cooling' is a cooling system in which the cooling capacity is engineered for only maximum 3 degrees Celsius. If outside temperature is 30 degrees, inside of a house would have a temperature which is 3 degrees lower than the outside, so still 27 degrees. But any client who is not given proper explanation thinks that it means top quality cooling system. So if Loohuis is making the design itself, such problems are avoided. And if designs are made by a	Yes, sometimes

						different party, then Loohuis rechecks requirements based on its installation experience.	
If yes,	Is the level of unidentified design errors and omissions that pass to the construction phase dependent on the poorness of project definitions?		No, never. The misinterpretations pass to the design stage but not to construction stage. Usually, the architect does an exotic design, then the client and the contractor deal to reduce the costly parts and redesign the project in a functional way. Finally the contractor checks each design step by step in order not to miss any errors or omissions. Based on this the project price is assigned.	Yes. There are errors passing to the construction phase but the extent is not certain.	Yes. There are errors passing to the construction phase but the extent is not certain.	Yes, often	No, never
	If yes,	Does the passing of unidentified design errors and omissions result in increase of construction errors and eventually rework?		Yes, sometimes. But reduction of errors is usually tried by common discussion between the residential operations and project development departments of Beter Wonen.	Yes, sometimes. But reduction of errors is usually tried by common discussion between the residential operations and project development departments of Beter Wonen.	Yes, often	

If no,						
	Where does the impact of poor project definitions lay?	The project development process is usually: Design is subcontracted to architect by Dura Vermeer; The final design is checked by market parties of Dura Vermeer; Then the market parties request information from the client for the parts they have a doubt about; Based on the client feedback, the design is sent back to the architect for refining; This refinement process continues till the design is satisfactory. The refinement process requires extra time, cost and energy which are usually covered by the contractor and subcontractors. Contractor and subcontractors pay for the mistakes of architects. The other effect is the eventual delay of the construction procurement stage.				On the stages before construction, project definitions are refined. And doing this takes time and cost and eventually results in delay of construction stage.
	What is then the source for unidentified design errors and omissions which result in rework?					
<u>Testing of Remedies</u>						
According to your perception, can the proper application of requirement analysis on the case project achieve a good project definition?		Yes, the requirement analysis helps to reduce the loops of design tuning and eventually	Yes, all the time.	Yes, all the time.	Yes, all the time.	Yes

	reduce the cost of contractors and subcontractors.				
If 'no', why?					
Can the combined application of breakdown structures and requirement traceability help to filter out errors and omissions before they pass to the construction phase?	Yes. Breakdown structures are helpful as they are graphical. The graphical aspect gives simplicity and is desired most individuals. Hence it increases controllability. Nevertheless, it is hypothetical. Hence practicality is disputed.	Yes, all the time.	Yes, all the time.	Yes, often.	Yes
If 'no', why?					
What other system engineering processes do you think can assist in achieving good understanding and interpretation of requirements? (If you have experience with system engineering.)	Not enough experience.	Not enough experience.	Not enough experience.	In relation to this case project and Beter Wonen, there is a problem of mismatch between budget and minimum tender price from bidders. Usually, the minimum tender price would be greater than the budget of Beter Wonen. This forces the client to revise the design and retender. This redesign and retendering costs money which could have been avoided if bidders were involved at the conception and design phase.	The usual approach of Dura for this project definition refinement process is: Evaluate the initial project definition with experience, ask the client good questions, work together with architects and check each other. The number of refinement loops depends on the client's awareness.

4.Test of proposition 3						
"Loss of client confidence on designers and contractors entails in the employment of an external quality controller and as a result additional cost will be incurred by the client."						
From your experience, do clients of traditional housing projects lack trust on designers and contractors?		Yes, sometimes. There is this default mistrust. But the transparency achieved by SE helps to reduce mistrust.	The project development department doesn't trust the contractor but trusts the architect as they don't have any predefined reference like documented requirements. Hence they take what is provided by the architect as initial input. Nevertheless, the residential operations department doesn't trust both the architect and the contractor.	The project development department doesn't trust the contractor but trusts the architect as they don't have any predefined reference like documented requirements. Hence they take what is provided by the architect as initial input. Nevertheless, the residential operations department doesn't trust both the architect and the contractor.	Yes, often.	Yes, sometimes
If yes,	Does this lack of confidence result in the employment of external quality controllers?	Yes. There is a supervisor. But contractors should be able to show that they satisfy quality.	Yes, all the time. But the quality control is not for the architect as there are no reference requirements to evaluate him with. The quality control is for the bill of quantities and construction works. The bill of quantities is checked by external parties where as the construction works are supervised by professionals from Beter Wonen.	Yes, all the time. But the quality control is not for the architect as there are no reference requirements to evaluate him with. The quality control is for the bill of quantities and construction works. The bill of quantities is checked by external parties where as the construction works are supervised by professionals from Beter Wonen.	Yes, often.	Yes, sometimes

	If yes,	In theory, quality is taken as a given. Does this mean that the costs of a third party as a quality controller is unnecessary one?	No, never. Supervisors add value as they can help in solving special problems, especially when unexpected and tailor-made solutions are required.	If contractor is fully trusted, yes it is unnecessary all the time. But supervisors can be value adding in cases like: identification of rare errors or provision of special knowledge and experience.	If contractor is fully trusted, yes it is unnecessary all the time. But supervisors can be value adding in cases like: identification of rare errors or provision of special knowledge and experience.	Yes, all the time.	No, never. People make mistakes. So the more the professionals the better the margin of error. Therefore, combining forces with supervisor parties gives more strength. The supervisor is hence still adding value.
		Does the identification of design errors by the quality controllers while the project is at the construction phase induce design revision and as a result stagnation of the project?	Yes, sometimes. Especially, when the errors identified can't be undone, supervisors ask for design revision. For example, when an already constructed concrete foundation is wrong, the structure it supports should be redesigned. But if errors are not extreme and can be corrected, site solutions are usually given.	No, never. Supervisors don't inquire for redesign. If there is something wrong, they just stop projects which results in project delay or give direct corrections on site.	No, never. Supervisors don't inquire for redesign. If there is something wrong, they just stop projects which results in project delay or give direct corrections on site.	Yes, often.	Yes, sometimes
If no,							
	If it is not mistrust and loss of confidence, then what is the reason for the involvement of third party as a controller?						

Testing of Remedies					
Can the review process replace the external appraisal process as it involves the client intensively and eventually lead to trust and confidence?	Sometimes, it could be better than applying an external appraisal process. But it would be highly administrative and with a lot of documents. Moreover, it would be difficult to show quality as contractor can't provide all information. As it takes too much process, it could result in time overrun. So the critical path for the project schedule is applying the external appraisal process.	Yes, all the time. But it requires an information system which means a higher initial investment. And for this, awareness change is required among stakeholders.	Yes, all the time. But it requires an information system which means a higher initial investment. And for this, awareness change is required among stakeholders.	Yes, all the time.	No, never. The review process is commonly done, but supervisors are still necessary as planes on papers are not the same as plans on practice. The work on site is not as explicit as a machine. Supervisors help in handling unknown conditions like weather, theft, unpredictable human resources... For example, unpredictable things like when subcontractors do not show up at the appointed time.
If 'no', why?					
What other system engineering processes do you think can assist in achieving client trust? (If you have experience with system engineering.)	Not enough experience.	Not enough experience.	Not enough experience.	If design is done by a separate body, multiple sub-contractors would be expected to compete for the work. For the sake of winning the tender, each candidate tries to find a point on the design which can be compromised so that more profit can be made with less bid price. This leads to loss of quality and as a result imposes quality control and a lot of paper work. The best	

				solution for this is to combine design and construction under one company.	
5.Test of system engineering success					
"The late starting of system engineering approach on the project lifecycle reduces the capability of the remedies proposed."					
From your experience (and/or perception), is system engineering more successful in comparison to the traditional housing development process generally?	Yes, all the time as SE results in transparency.	Yes, all the time.	Yes, all the time.	Yes, all the time.	It is a wishful thinking. SE has good things in it, but we need to work on it to make it successful. SE puts a lot of effort during design stage which is a worthwhile. But all the problems of construction stage can't be accounted at the design stage. It is not worth it to make an 80% design effort to make a 20% effect on construction.
As system engineering is introduced into the project lately, do you think it would be effective enough as compared to a project which started with system engineering from the beginning?	Yes, the SE effectiveness on the case project won't reduce as the case project is still at the very beginning phase. There are no documentations or decisions.	No. For the case project, there is already a design done by the architect. But now it had been totally neglected so it is an additional cost for the project. Furthermore, there is the possibility of bias of future designs due to the already done architectural design. Nevertheless, as the project is started as a totally new housing development project, the effectiveness loss may not happen. In	No. For the case project, there is already a design done by the architect. But now it had been totally neglected so it is an additional cost for the project. Furthermore, there is the possibility of bias of future designs due to the already done architectural design. Nevertheless, as the project is started as a totally new housing development project, the effectiveness loss may not happen. In	Yes.	

				case of late started SE, if the tracing back of all SE activities is done properly, effectiveness may not be lost.	case of late started SE, if the tracing back of all SE activities is done properly, effectiveness may not be lost.		
If no,							
	Why do you think that a late starting of system engineering doesn't affect its capability even though there are system engineering processes that need to be applied at a very early stage of a project? (Wouldn't important information and opportunities that would have been collected at early phases of a project be lost?)					As long as initial interviews done with the client are documented, the effectiveness of SE won't be reduced.	

Appendix 2: Condensed version of the thesis report

The condensed version of the thesis report presented in the following pages is prepared according to the guidelines of the journal of construction management and economics.

University of Twente

Understanding and reduction of cross-party conflicts in housing development projects from systems engineering perspective

Abstract

In housing projects where many parties are involved, it is common to observe reduction of project success in the form of cost overrun and schedule overrun. In most literatures, such adverse effects are partly attributed to requirement incompleteness, misinterpretation and misunderstanding. However, there isn't enough information on the mechanisms between requirement conflicts and adverse effects. There is also lack of specific remedies for the reduction of such conflicts.

In this research project, general theories of such mechanisms were tested on the Dutch housing development sector. Furthermore, the applicability of systems engineering remedies in the reduction of requirement conflicts was checked. The research accounts for a broad theoretical review of literature materials around the topic and a single case study as a source of empirical input. Pattern matching was used for the analysis process.

The result of this research shows that the propositions that relate requirement conflicts with adverse effects partially hold. Nevertheless, they require refinement and further empirical support for better generalization. The findings also support the capability of systems engineering remedies in the reduction of requirement conflicts.

Keywords: Housing development, conflict, failure, defects, error, delay, system engineering

Introduction

The existing housing construction process in The Netherlands has conflicting aspects with respect to cross-party relations among involved parties. As a result, it is a common trend to see project cost and schedule overruns. And in serious and repeated situations, involved parties would end up losing their competitiveness and reputation.

The starting point for the problem under consideration is the traditional approach, the Design-Bid-Build system. Such an approach is typified by skepticism, suspicion and contempt. As a result there is a lot of adversarial attitude, loss of productivity and increase in costs. Furthermore, efforts of partnering are usually unsuccessful because of the individualistic culture of involved parties. This often works against open relationships (Thomas *et al.* 2002).

In most materials studied, such conflicting aspects are presented under the issues of rework, variations and failure cost. This is so because such effects are visible and can be quantified easily. According to Josephson, Larsson and Li (2002), rework is any unnecessary effort applied for rectifying construction errors and by errors it is meant by failures in conformance to requirements.

The quantification of rework comes about with its manifestation in the form of cost overrun and schedule overrun. Schedule overrun is easily measureable as it is the measure of the extra time any project took with respect to its planned schedule. On the other hand, cost overrun measurement needs a more systematic approach. Josephson *et al.* (2002), Hall *et al.* (2001) and Kazaz *et al.* (2005) present the cost of rework as the combination of the costs of failure, appraisal, prevention and intangible costs.

In the articles considered here, not all the above costs were determined by the authors. Most studies done concentrated on the measurement of direct rework costs only and avoided the indirect ones. This is because of the difficulty of the identification and quantification process of such indirect costs. For instance, Love *et al.* (2000) suggests that direct costs of rework are about to 10 – 15% of the contract value of projects and it would be higher if latent and indirect costs like schedule delays, litigation costs and poor quality effects were to be included. In table 1, a summary of the articles studied is presented with respect to the extent of rework costs.

'Insert Table 1 here'

From Table 1, it can be depicted that most projects face high rework costs and schedule overrun irrespective to the very small profit margins that are apparent in the construction industry. Moreover, the theoretically suggested phases which are the major contributors to overall conflicts in construction processes are the conception and design phases.

Hence the area of concern in this paper is the cost and schedule overrun encountered in most traditional housing projects. In addition to this, as the case project used for the research is a systems engineering based project, the applicability of systems engineering as a remedy source was also considered. The objectives of this study are to:

- Find out the sources of conflicts between different parties that work on traditional housing projects.
- Test the applicability of theoretically proposed systems engineering based remedies for the reduction of cross-party conflicts in housing projects.

Based on the later presented literature study, there are five kinds of cross-party conflicts. Among the five, requirement conflicts are rated as leading causes of rework. Hence the scope of the research had been limited to requirement problems of the conception and design phases of the construction process. The rest of the conflicts presented in the theoretical study part are left for future research.

The aim of the research is the better understanding of the current situation of housing development process by testing it against generic sources and mechanisms of adverse effects that are prescribed for the general construction industry. Furthermore, it is targeted to reinforce the low level of knowledge about mechanisms that lead to adverse effects in traditional housing projects. It also helps to test the applicability of systems engineering approach which is new for the Dutch housing development sector.

In this paper, first a theoretical study section about sources, mechanisms and remedies of cross-party conflicts is presented. Then the propositions which were developed from the theoretical model follow. In the methodology section, the research process is briefly presented. Following that, in the findings section, the outputs of the case study is covered. Finally the conclusion is presented.

Theoretical study

Based on the area of concern and research objectives described above, a broad theoretical study was done in the following three areas. First a literature review was done on main causes of rework. Secondly, the mechanisms that link the identified causes to the final adverse effects were addressed. After that, theoretically supported system engineering based remedies were presented. Finally, propositions were drawn from the mechanisms for empirical testing.

Causes of rework

Basically rework, variation and failure generate mostly from conception (need specification and requirement development) and design phases (Love *et al.* 2002). As can be seen on table 1 above, the contribution of pre-construction phases to rework is significant. These phases are the phases were a temporary multi-organization is formed from members of different organizations. On the other hand, each member has its own function, interest and most often has a specific engagement point in the project lifecycle.

Based on the materials studied, especially Love *et al.* (2002), Hall *et al.* (2001), Burati *et al.* (1992), Hwang *et al.* (2009) and Love *et al.* (2004), the following five issues are found to be the main causes of rework, variations and failure.

Requirement conflicts: This refers to lack of understanding and incorrect interpretation of client and end-user requirements. This goes hand in hand with communication problems especially in feedback processes (Hall and Tomkins 2001). It is furthermore aggravated by the incompleteness of initially provided client requirements which eventually leads to requirement changes at a later stage. Hwang *et al.* (2009) puts client requirement changes as the number one source of rework.

Documentation problem: It could be in the form of inaccurate designs, conflict between different designs or incompleteness in general. Such errors and omissions in designs are ranked as second major cause of rework on Hwang *et al.* (2009).

Poor coordination and integration: This accounts for poor communication(Love and Edwards 2005); inaccessibility of designers for immediate changes, updates and confirmation; and last but not least lack of a "common language" (Roddis, Matamoros and Graham 2006) which inhibits more advanced design approaches.

Poor quality management: This accounts for lack of a formal quality management and a good supervision and inspection process (Love and Edwards 2005).

Poor standard of workmanship: This corresponds to implementation mistakes at the construction phase. According to Hwang *et al.* (2009) and Burati *et al.* (1992), implementation mistakes include all errors and omissions done by contractors and vendors at construction phase.

Mechanisms

The mechanisms presented in this sub-section represent the causal links between the cross-party conflicts and the final adverse effects. But among the above mentioned five causes, the requirement conflicts issue is ranked first in contributing for rework (Hwang *et al.* 2009). The other four issues are left for future researches.

Based on Hall *et al.* (2001), Hwang *et al.* (2009) and Love *et al.* (1999), the three mechanisms presented in figure 1 clearly depict how requirement conflicts eventually leads to cost overrun and schedule overrun. They are briefly explained below.

'Insert Figure 1 here'

Mechanism C1: The focal point here is the issue of design changes after the commencement of construction. Hwang *et al.* (2009) puts client requirement changes as the number one source of rework. Usually the requirements of clients or end users are incomplete at the beginning of projects. According to Hall and Tomkins (2001), the requirement extraction process at the start of a project usually fails to develop a complete set of requirements of the client or end user.

Eventually there will be the need for addition or change of requirements. If such change happens after requirements have been approved and design had commenced, it results in late coming design changes or revisions. And in the condition that construction has already started, there will be adverse effects to the project in the form of:

- Delay to material procurement process which in turn creates schedule overrun
- Mobilization of human resources and equipment with no work but pay (Unnecessary cost)
- Additional design documents as a source of unidentified design errors (Input for mechanism C2) which leads to quality failure

Mechanism C2: The focal point here is the issue of design errors and omissions that pass to the construction phase unidentified. Such errors and omissions in designs are ranked as second major cause of rework on Hwang *et al.* (2009). They are majorly caused by poor project definition and further aggravated by late design revisions.

Poor project definition is generally attributed to failure of designers in properly understanding and interpreting client requirements. In other words, the incorrect conversion of raw requirements to technical requirements causes the goal and constituencies of a project definition to be insufficient for design referencing.

Consequently, the approval step of the design process is not able to filter out all errors and omissions due to the poor technical requirement definition. This leads to the transfer of such errors and omissions to the construction stage without been detected.

Generally, if design errors and omissions pass to the construction phase before being identified, the number of construction errors will increase. This in turn means poor quality and unavoidable rework. Hence there will be a need for the expenditure of more money and time for rectification process.

Mechanism C3: As presented by Hall *et al.* (2001) and Love *et al.* (1999), the introduction of a third party for the sake of appraisal process is not only non-value adding but also a reason for additional cost.

Quality is initially a given, but as clients lack the confidence on designers and contractors performance, it is a common practice to involve a third party like a consultant as a quality controller. Such a quality control by a third party has two implications.

The first is the fact that it is non value adding. This means, quality control is done for the sake of preserving quality but not adding. Hence when quality preservation is done by a third party other than the designer or contractor, it means the client has to pay more for the additional service rendered.

The other implication is the identification of design errors by the quality controllers while the project is at the construction phase. This induces a request for design revision and as a result stagnation of the project (input for mechanism C1).

Therefore, such an approach of quality control is a reason for more expenses and further revision at a later phase of product creation.

System engineering remedies

In this sub-section, possible system engineering based remedies in relation to the above three mechanisms are presented. The notion is that, if these remedies are properly applied as presented in figure 1, it is possible to prevent the occurrence of the above three mechanisms and eventually reduce the adverse effects on housing development projects.

For the choice of the source of remedies, modern approaches like systems engineering, collaborative engineering, concurrent engineering, value engineering and constructability were considered. The criteria for selection were the approaches capability in reducing cross-party conflicts and the feasibility in the Dutch housing development sector.

Among the above listed, the goal of concurrent engineering, value engineering and constructability is in a different direction. For instance, concurrent engineering is applied for the reduction of overall project delivery time which is preferred for fast-tracked projects (Anumba and Evbuomwan 1997). Value engineering on the other hand is targeted to developing a common understanding on the project definition and design alternatives (Thiry 1997). This makes it ideal for projects with large number of stakeholders and numerous alternatives. In case of constructability, integration of knowledge and experience is focused upon and is best for projects that need optimization (Arditi, Elhassan and Toklu 2002).

For housing projects with cross-party conflicts, an approach which concentrates on the improvement of communication, integration and interface definition is best suited. And for this reason, systems engineering and collaborative engineering are possible candidates. Both have the capacity to reduce adversarial relationships and improve project performance with respect to design satisfaction (Bahill and Gissing 1998) & (Kahn and Mcdonough 1997).

Nevertheless for this research, system engineering is chosen as it has superior advantages over collaborative engineering. Basically, systems engineering is a grand unified theory for making things work better (Bahill and Gissing 1998). Its goal is to provide a structured but flexible process focused on implementation by transforming requirements into specifications, architectures, and configuration baselines (Sarshar, Haigh and Amaratunga 2004). System engineering is the ideal choice for this research as a source of remedy for the following reasons. First of all, it concentrates on interrelationships and patterns of change. It also has the capability in addressing a wide scope including both soft and hard problems (Bahill and Gissing 1998). Moreover, system engineering has been already tested and proven successful in other construction sectors in the Netherlands. This has induced an acceptance in the housing development sector also.

Coming to the remedies, some of the technical and management processes of system engineering are considered as presented below. The application of these remedies requires the assignment of a system engineer (integrator) to the project. The system integrator is responsible to the follow-up of the technical processes and the supervision of the management processes along the life cycle of the project.

Requirement engineering

The goal of requirements engineering is to raise the likelihood that the right system will be built, and that the system when built satisfies its intended customers and addresses their needs to an acceptable degree (Davis and Didar 2005). The success of this goal can be evaluated based on the following three dimensions (Klaus 1993):

4. Representation from informal into formal
5. Specification from opaque into complete and
6. Agreement from individual view into common view

Initial input is mostly informal, opaque and has personal views. Nevertheless, the desired output of the requirement practice should be formal, complete and with a common view. During the first phase of the system engineering process, the agreement dimension is mostly emphasized. That means, the first step is to direct the subjective interests of the stakeholders to a common view.

Then the aspects of representation and specification can be addressed in the next stages of system engineering. The way of approach also differs at this stage. The target here is to make a clear and formal representation of client's interests and produce complete requirements that satisfy the criteria of SMART.

Requirement engineering consists of two parts; requirements analysis and requirements traceability. The former is about distilling and analyzing the requirements from the client and other stakeholders, whereas the later is about tracing (forward and backwards) the effect of changes in requirements on the design and vice versa.

Requirement analysis (D1a & D2a on figure 1): Requirement analysis is about distilling and analyzing the requirements from the client and other stakeholders. It is applied early in the life-cycle but the benefits occur later in the life cycle (Nuseibeh and Easterbrook 2000). Requirements analysis is therefore seen as the cornerstone for efficient development of quality systems (Artem and Markku 2005).

Procedures for requirement analysis should be: Eliciting requirements, modeling and analyzing requirements, communicating requirements, agreeing requirements and evolving requirements (Nuseibeh and Easterbrook 2000).

An important set of tools for this requirement analysis are the stakeholder identification and SWOT analysis techniques. These techniques which can be performed by the planning/designing team possibly joined by selected stakeholders help to identify and organize the different views of stakeholders. In addition to this they also help to find a solution that is carried and supported by the key-stakeholders (Bryson 2004).

Hence, this remedy can be used to prevent mechanism C1 and C2 of figure 1 at early stages. This is true because it will help in developing complete requirements at the initial stage of projects. Consequently, the project will be properly defined and the number of errors, omissions and changes would reduce significantly.

Requirement traceability (D2c on figure 1): Requirement traceability is the principle of change tracking in the system engineering cycle between requirement analysis, functional analysis and design synthesis (Sutinen, Almefelt and Malmqvist 2001). So it follows the ability to describe and follow the life of a requirement in both a forwards and backwards direction. It is the mapping of requirement inheritance.

In general, systems engineering is equipped with tools that can achieve a good degree of traceability for requirements. For instance, we can use cross referencing schemes, key phrase dependencies, templates, RT matrices, matrix sequences, hypertext, integration documents, assumption-based truth maintenance networks and constraint networks (Gotel and Finkelstein 1994).

The application of requirement tracing helps in controlling misinterpretations, incompleteness and other failures of the final product. It also assists in change tracking in the development process.

Therefore, this remedy can be used as a backup plan for mechanism C2 of figure 1, if the requirement analysis fails to create a good project definition. It can be used to simplify the detection of errors and omissions at later stages of the construction process.

Change management (D1b on figure 1)

In order to avoid mismatch of developed products at a later stage, all parties should apply change management alongside their product development. Change management addresses two basic kinds of changes (Kasser 2007). The first is budgetary change which directly determines the level of performance of a product. Budgetary changes are common in the real world for the reason that all projects are mostly dependent on the external environment (finance). All involved parties in a project should be aware of such budgetary changes and react to them systematically.

The other kind of change is related to requirements. Clients usually have the tendency to change their needs while the project is under progress. Hence, if final products do not incorporate variations, rework will become unavoidable at a later stage. For this reason, involved parties should be cautious in updating their requirement database.

Hence, this remedy is a backup plan for mechanism C1 of figure 1, in case the requirement analysis fails to create a complete set of requirements. If prevention of mechanism C1 is not possible, involved parties could make themselves flexible to forth coming changes by properly applying change management.

Breakdown structures (D2b on figure 1)

In system engineering, a strong linkage is achieved between the initial requirements and the final planning using a series of breakdown structures (Bachy and Hameri 1997). The commonly used ones are functional, product, assembly, work and organizational breakdown structures. By applying these structural representations, it is possible to provide the boundaries between sub-systems and develop work packages which would be assigned to specific organizational units (Globerson 1994). Hence, project managers can lead a well structured project which can host proper change management and requirement traceability.

The relevance of this remedy comes in the form of providing a strong framework for the identification process of errors and omissions on mechanism C2 of figure 1. The existence of a framework that relates the different parts of a project enables a more efficient requirement tracing and reduction of unidentified errors and omissions.

Review process (D3 on figure 1)

The review process is a formal process done with and for the customer (Dean, Bentz and Bahill 1997). It is the responsibility of the system engineer assigned for the project and should be executed at various points of the project life cycle.

The main objectives of this process are to check for adequacy of the existing verification plan; check for completeness in requirements, specifications and other outputs; check for unneeded inclusions with respect to the clients interest; get customer approval in order to proceed to the next phase of the project and make trade-offs between cost, schedule and performance as per the choice of the client.

The proper application of the above review processes will help to remove mechanism C3 of figure 1. That means the repetitive reviews done will develop client confidence on designers and contractors. Eventually, the client will be able to reduce the project cost by avoiding external appraisal costs.

Propositions

As the approach of the research is the testing of theory against empirical evidence, the following propositions are drawn. The propositions link causes to adverse effects based on the above mentioned mechanisms. Each proposition is made up of multiple sub-propositions which are considered as non-equivalent dependent variables. This means, the validity of any sub-proposition depends on the validity of the preceding sub-proposition. Hence for a mechanism to be generalized upon, all sub-propositions of the same mechanism should hold.

In addition to this, each proposition is supplemented with theoretically suitable systems engineering remedies for capability testing.

Proposition 1 (based on mechanism C1)

'Incomplete client or end user requirements which result in design changes after construction commencement lead to additional cost and schedule overrun. '

Proposition 1 is about design changes due to requirement incompleteness. The constituting sub-propositions are:

1a. Incomplete client or end user requirements lead to requirement changes after construction commencement.

1b. Such requirement changes result in design changes.

1c. Design changes after construction starts lead to:

- Delay to material procurement process which in turn creates schedule overrun

- Mobilization of human resources and equipment with no work but pay (Unnecessary cost)
- Additional design documents as a source of unidentified design errors (Input for mechanism C2) which leads to quality failure

<u>*Remedies*</u>

- A proper requirement analysis can achieve client requirement completeness.
- Change management helps to reduce the effect of design changes by inducing flexibility.

Proposition 2 (based on mechanism C2)

'Poor understanding and interpretation of requirements lead to increase of unidentified errors and omissions which result in rework at the construction stage.'

Proposition 2 is about unidentified design errors and omissions that pass to the construction stage. The constituting sub-propositions are:

2a. Lack of understanding and incorrect interpretation of requirements results in poor project definition.

2b. The poorness of a project definition leads to the increase of the number of errors and omissions that pass to the construction stage unidentified.

2c. The passing of unidentified errors and omissions to the construction stage increases construction errors.

2d. The quality failure due to construction errors results in rework which costs time and money.

<u>*Remedies*</u>

- A proper requirement analysis can achieve a good project definition.
- The combined application of breakdown structures and requirement traceability helps to filter out errors and omissions before passing to the construction phase.

Proposition 3 (based on mechanism C3)

'Loss of client confidence on requirement handling capacity of designers and contractors entails in the employment of an external quality controller and as a result additional cost will be incurred by the client.'

Proposition 3 is about the need for and implications of an external appraisal process. The constituting sub-propositions are:

3a. Incorrectness of requirement interpretation by designers and contractors reduces client confidence toward them.

3b. This lack of client confidence leads to the involvement of a third party as external quality controller.

3c. The appraisal process by external parties results in:

- Consultant fees which raise the cost of the client
- Identification of design errors at the construction stage which leads to design revision (Input for mechanism C1)

Remedy

- The review process can help eliminate the need for an external appraisal processes by involving the client intensively.

Research methodology

A research design (methodology) is by definition a logical plan that helps to reach from the research questions to the final conclusions. It is a means by which the evidence collected is aligned with the research questions. For the development of the strategy in this research, the book of Yin (2003) is used as a guide.

The choice of the research approach is majorly based on the type of research questions and the possibilities for empirical data. As can be observed from the research objectives presented in the introduction, the research starts with answering 'why adverse effects occur among projects which involve multiple parties'. Then it passes to the question 'How to reduce the cross-party conflicts'. With respect to empirical data, there is a single project to be externally observed without any chance of project manipulation. Moreover, the focus of the study was on contemporary events as the project was started in January, 2009, and was going on during the research period.

Hence base on Yin (2003), for a research with a 'why' and 'how' questions, with no control on behavior of events to be studied and with a focus on contemporary events, the recommended research approach is the case study approach.

The case project qualifies for a single case project due to its unique nature. All previous housing development projects followed traditional procurement approaches. But this project is the first of its kind for adapting systems engineering approach. Hence by taking it up as a unique case, it is possible to satisfy the objective of capturing the circumstances and conditions of a new and unexplored situation in the housing development sector of the Netherlands.

Data treatment

For this research, the data sources were limited to academic articles and direct interviews due to language restrictions. The first step of the research was to make a literature review and drawing a list of theoretical propositions. The propositions link requirement conflicts with adverse effects based on the mechanisms presented on figure 1. Each proposition was accompanied by theoretically suggested systems engineering based remedies.

The next step was the testing of the propositions empirically. The analytical strategy applied here is the reliance on theoretical propositions which were previously made. This helped to properly guide the interviews and isolate the important type of data. Hence, the collected data at this stage was filtered and categorized based on the propositions produced during the first step of the research. In order to achieve a proper evaluation process, the technique of pattern matching of nonequivalent dependent variables was applied (Yin 2003).

In this study, there were only five respondents which made it irrelevant for statistical evaluation. Hence, a proposition will hold if only all the respondents agree to the proposed outcome. On the other hand, if there is even one contradiction, the proposition will be questioned and be open for refinement. The refinement of the proposition could be in the form of introduction of additional pre-conditions or change of final outcomes of a given mechanism.

Research qualification

The research can be qualified by applying the following tests as a judging mechanism of the quality.

Construct Validity: This test is to check the establishment of correct operational measures. This corresponds to the existence of a choice of a specific item of study and whether the collected data is related to the specific chosen item. To achieve this, multiple sources of evidence are considered. For instance, a wide range of publications were studied in order to achieve good theoretical propositions. The other tactic applied to achieve construct validity is by creating a chain of evidence between the research questions, the case study protocol, the case study database and the final report. Last but not least, draft review of the interview responses were done by the respondents or translators.

Internal Validity: This is dedicated to the evaluation of inferences of interviews for correctness and the convergence of the collected evidence. Internal validity in this research is achieved by proper pattern-matching of the responses collected and the theoretical propositions made.

External Validity: This test is about establishing the domain to which the study’s findings can be generalized to. And in this single case study, the domain is the Dutch housing development sector as the respondents are all professionals from this domain.

Reliability: This test is to demonstrate the repeatability of the operations of the study with the same results. The operations could be like the data collection or data analysis procedure. To achieve this, a proper case study protocol and database system was developed in order to properly document all procedures applied during the study.

Findings

The case study considered interviews done with professionals involved on a housing project. The housing project is a systems engineering project and was started on January, 2006. The project is now being handled by a project team which consists of three different parties. The first party represented in the project team is Beter Wonen. Beter Wonen is a housing development company which acts as the client, advisor and project manager of the case project. Beter Wonen also has a department that administers and maintains the residences after completion of construction. The second party represented in the project team is a potential and possible general contractor, Dura Vermeer. The last party involved is Loohuis installatiegroep, an installation design and construction company. All the three parties will be involved in the conception, design and construction phases of the pilot project.

The respondents were chosen in such a way that all the three parties involved in the project team are represented. Among the four respondents, two are from Beter Wonen, two from Dura Vermeer and one from Loohuis. All the respondents had an extensive experience in housing development projects, with an average of 20 years. On the other hand, their experience in system engineering is only theoretical and is as old as the case project. One exception is the respondent from the Loohuis who had experience on customer oriented system engineering approach for the past 18 years.

Based on the data collected from interviews and the analysis done, the following revised mechanisms and remedies diagram is developed (figure 2). In the diagram, solid arrows represent empirically validated causal linkages between conflicts and adverse effects. The dashed arrows represent causal linkages which require further empirical testing to be generalized upon. The revised mechanisms are briefly explained below the figure.

'Insert Figure 2 here'

Revised Mechanism C1: The focal point here is the issue of design changes after the commencement of construction. Hwang *et al.* (2009) puts client requirement changes as the number one source of rework. Usually the requirements of clients or end users are incomplete at the beginning of projects. According to Hall and Tomkins (2001), the requirement extraction process at the start of a project usually fails to develop a complete set of requirements of the client or end user.

Eventually there will be the need for addition or change of requirements. If such change happens after requirements have been approved and design had commenced, it results in late coming design changes or revisions. And in the condition that construction has already started and a given procurement process is on the critical path of a project, renegotiation of price and delivery time is required between supplier and contractor. This is done in order to avoid the late delivery of materials by paying extra for the imposed time tension.

In addition to requirement changes which result in late design changes, involvement of third parties for appraisal process (mechanism C3) also induces further revision. For instance, supervision process during construction phase sometimes identifies design errors which result in the request for design revision. This puts the project on hold till the revised designs arrive. Nevertheless, this linkage between mechanism C3 and C1 needs further empirical testing.

With respect to system engineering remedies, requirement analysis helps in achieving better requirement completeness at early stages of a project. Moreover, change management can give the flexibility needed to cope with change.

Revised Mechanism C2: Poor project definition is generally attributed to failure of designers in properly understanding and interpreting client requirements. In other words, the incorrect conversion of raw requirements to technical requirements causes the goal and constituencies of a project definition to be insufficient for design referencing. The existence of poor project definitions in housing projects is empirically validated on this research.

Based on the suggestions made by the respondents, the effect of poor project definition is the need for an iterative design refinement loop during the pre-construction stages in order to achieve an error free design. Such a refinement process usually takes up extra energy, time and cost. And eventually, due to the extra time consumed, the procurement of the construction stage is delayed. However, such a mechanism between poor project definition and final adverse effects like cost and time overrun requires further empirical testing.

With respect to system engineering remedies, a proper requirement analysis can achieve a good project definition. Moreover, the combined application of breakdown structures and requirement traceability helps to simplify the refinement loop at the pre-construction phase.

Revised Mechanism C3: Quality is initially a given, but as clients lack the confidence on designers and contractors performance, it is a common practice to involve a third party like a consultant as a quality controller. Such a quality control by a third party could result in the identification of design errors while the project is at the construction phase. This induces a request for design revision and as a result stagnation of the project (input for mechanism C1). Therefore, such an approach of quality control is a reason for further revision at a later phase of product creation. Nevertheless, this linkage between mechanism C3 and C1 needs further empirical testing.

Conclusion

The goal of this research was to check validity of theoretically developed mechanisms and test the capability of system engineering in the reduction of cross-party conflicts, specifically requirement conflicts. Three requirement related propositions were developed theoretically and had been tested empirically. The first proposition holds true for problems related to procurement of materials where as proposition two and three didn't hold empirically. Furthermore the empirical analysis produced suggestions for other alternative mechanisms like the adverse effects encountered due to an iterative design refinement process.

Even though the findings of the research didn't fully support the initial theoretical propositions, the initial sub-propositions of all the three mechanisms developed were empirically supported (figure 2). That means it could be generalized that traditional housing development projects face:

- Incomplete requirements which result in design revisions after construction commencement and eventually affect the material procurement procedure in the form of extra cost.
- Poor project definition due to lack of understanding and incorrect interpretation of requirements and
- Mistrust between client and other involved parties which leads to the employment of quality controllers.

Moreover, four of the initially suggested five system engineering remedies were empirically supported. According to the experts, the requirement analysis process, change management process, breakdown structures approach and requirement traceability are potential remedies for the reduction of requirement related conflicts.

Hence, it can be generalized that is a positive attitude about system engineering's success in reducing cross-party conflicts with respect to requirement problems. And in relation to the case project, the introduction of system engineering could enable a more comprehensive requirement database and a qualifying project definition at early stage of the project.

Generally, in this paper, it was able to adapt and test generic sources and mechanisms of adverse effects specifically to the Dutch housing development sector. Furthermore, it was able to shade a light on how cross-party conflicts are linked to adverse effects on housing development projects. It was also able to show the validity of system engineering remedies in reducing the conflicts at early stages.

In addition to knowledge development, the findings of this research demonstrate how far the housing development sector is from theoretical support. The sector is more inclined to experience development and less attention is given to the scientific growth. This restricts adoptions of changes and innovations that come with time. More specifically to this research, what is prescribed in scientific materials about requirement conflicts and their linkage with adverse effects is not representative of the reality. Hence, the success of remedies tailor made for the theoretically prescribed problems is questioned when practicality is considered.

Even though the gap between theory and reality is large, this research also gives a hint on how to narrow it. If parties involved in the housing development sector are willing to participate in such research projects, the scientific approach can provide representative models of the reality and the best remedies with high rate of success.

The last contribution of the research is with respect to systems engineering. The findings of the research, gives a positive nudge for the adaption of systems engineering in the Dutch housing development sector. But still, exemplary projects are needed to develop full confidence on systems engineering.

With respect to the reliability, the research is threatened for two reasons. First the material available to extract mechanisms for the theoretical model was not sufficient. Secondly, the number of respondents considered is small and hence the representativeness could be questioned. Therefore, it is necessary to understand that what is done in this paper is the tip of the iceberg and further work is required to definitively ascertain the conclusions.

Further research should also be done on mechanisms of other cross-party conflicts, if a complete representation of the reality is needed. The other issues that require further research are the revised mechanisms presented under the findings part. Revised mechanism C2 and C3 need further empirical support in order to be generalized upon.

References

Anumba, C J and Evbuomwan, N F O (1997) Concurrent engineering in design-build projects. *Construction Management and Economics*, **15**(3), 271 - 81.

Arditi, D, Elhassan, A and Toklu, Y C (2002) Constructability Analysis in the Design Firm. *Journal of Construction Engineering and Management*, **128**(2), 117-26.

Artem, K and Markku, S (2005) Requirements quality control: a unifying framework. *Requir. Eng.*, **11**(1), 42-57.

Bachy, G and Hameri, A P (1997) What to be implemented at the early stage of a large-scale project. *International Journal of Project Management*, **15**, 211-8.

Bahill, A T and Gissing, B (1998) Re-evaluating systems engineering concepts using systems thinking. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, **28**(4), 516-27.

Bryson, J (2004) What to do when stakeholders matter. *Public Management Review*, **6**(1), 21-53.

Burati, J J L, Farrington, J J and Ledbetter, W B (1992) Causes of Quality Deviations in Design and Construction. *Journal of Construction Engineering and Management*, **118**(1), 34-49.

Cnuddle, M (1991) Lack of quality in construction - Economic losses. *In*, *European Symposium on Management, Quality and Economics in Housing and Other Building Sectors*, 508-15.

Davis, M and Didar, Z (2005) Good requirements practices are neither necessary nor sufficient. *Requir. Eng.*, **11**(1), 1-3.

Dean, F F, Bentz, B and Bahill, A T (1997) *A Road Map for implementing System engineering*, Sandia National Laboratories.

Globerson, S (1994) Impact of various work-breakdown structures on project conceptualization. *International Journal of Project Management*, **12**(3), 165-71.

Gotel, O C Z and Finkelstein, C W (1994) An analysis of the requirements traceability problem. *In*, *Requirements Engineering, 1994., Proceedings of the First International Conference on*, 94-101.

Haamarlund, Y, Jacobsson, S and Josephson, P (1990) Quality failure costs in building construction. *In*, *Proceedings of the CIB W55/W65 Joint Symposium*, Sydney. International Council for Building Research Studies and Documentation, 77-89.

Hall, M and Tomkins, C (2001) A cost of quality analysis of a building project: towards a complete methodology for design and build. *Construction Management and Economics*, **19**(7), 727 - 40.

Hwang, B-G, Thomas, S R, Haas, C T and Caldas, C H (2009) Measuring the Impact of Rework on Construction Cost Performance. *Journal of Construction Engineering and Management*, **135**(3), 187-98.

Josephson, P-E, Larsson, B and Li, H (2002) Illustrative Benchmarking Rework and Rework Costs in Swedish Construction Industry. *Journal of Management in Engineering*, **18**(2), 76-83.

Josephson, P E and Hammarlund, Y (1996) The cost of defects in construction. *In*, *CIB-W65 International Symposium for the Organization and Management of Construction: Shaping Theory and Practice*, University of Strathclyde, Scotland, U.K.

Kahn, K B and McDonough, E F (1997) An Empirical Study of the Relationships among Co-location, Integration, Performance, and Satisfaction. *Journal of Product Innovation Management*, **14**(3), 161-78.

Kasser, J E (2007) *A framework for understanding systems engineering*. Cranfield, Bedfordshire, England: The Right requirement Ltd.

Kazaz, A and Birgonul, M T (2005) Determination of Quality Level in Mass Housing Projects in Turkey. *Journal of Construction Engineering and Management*, **131**(2), 195-202.

Klaus, P (1993) The Three Dimensions of Requirements Engineering. In: *Proceedings of Advanced Information Systems Engineering*: Springer-Verlag.

Love, P E D (2002) Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects. *Journal of Construction Engineering and Management*, **128**(1), 18-29.

Love, P E D and Li, H (2000) Quantifying the causes and costs of rework in construction. *Construction Management and Economics*, **18**(4), 479 - 90.

Love, P E D and Sohal, A S (2003) Capturing rework costs in projects. *Managerial Auditing Journal*, **18**(4), 329-39.

Love, P E D and Edwards, D J (2004) Forensic project management: The underlying causes of rework in construction projects. *Civil Engineering and Environmental Systems*, **21**(3), 207 - 28.

Love, P E D and Edwards, D J (2005) Calculating total rework costs in Australian construction projects. *Civil Engineering and Environmental Systems*, **22**(1), 11 - 27.

Love, P E D, Mandal, P and Li, H (1999) Determining the causal structure of rework influences in construction. *Construction Management and Economics*, **17**(4), 505 - 17.

Love, P E D, Mandal, P, Smith, J and Li, H (2000) Modelling the dynamics of design error induced rework in construction. *Construction Management and Economics*, **18**(5), 567-74.

Love, P E D, Holt, G D, Shen, L Y, Li, H and Irani, Z (2002) Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management*, **20**(6), 425-36.

Mills, A, Love, P E D and Williams, P (2009) Defect Costs in Residential Construction. *Journal of Construction Engineering and Management*, **135**(1), 12-6.

Nuseibeh, B and Easterbrook, S (2000) Requirements engineering: a roadmap. *In*, *ICSE '00: Proceedings of the Conference on The Future of Software Engineering*. ACM Press, 35-46.

Roddis, W M K, Matamoros, A and Graham, P (2006) Interoperability in building construction using exchange standards. *In:* Smith, I F C (Ed.). Springer-Verlag Berlin, 576-96.

Sarshar, M, Haigh, R and Amaratunga, D (2004) Improving project processes: best practice case study. *Construction Innovation*, **4**, 69-82.

Sutinen, K, Almefelt, L and Malmqvist, J (2001) Implementation of requirements traceability in systems engineering tools. In, Goteborg, Sweden: Chalmers University of Technology

Thiry, M (1997) *Value Management Practice*. Sylva (NC): Project Management Institute.

Thomas, N S, Roseb, T M, Makb, M and Chenb, S E (2002) Problematic issues associated with project partnering — the contractor perspective. *International Journal of Project Management*, **20**, 437–49.

Yin, R K (2003) *Case Study Research: Design and Methods*. 3 ed. Vol. 5, London: Sage Publications.

Tables

Table 2: Summary of previous studies (adapted from Josephson, et al. (2002) and modified)

Previous study	**Subject of study**	**Rework costs and schedule overruns**	**Pre-construction phase contribution to rework**
(Cnuddle 1991)	-	10 - 20% of total project cost	46%
(Burati, Farrington and Ledbetter 1992)	9 fast-track industrial construction projects	12.4% of total project cost	79%
(Haamarlund, Jacobsson and Josephson 1990)	-	4% of total project cost	51%
(Josephson and Hammarlund 1996)	-	2.3 – 9.4% of contract value of project	32%
(Love *et al.* 2000)	-	10 – 15% of contract value of projects	-
(Love and Edwards 2005)	Australian construction projects	6.4% of contract values (direct costs) 5.9% of contract values (indirect costs)	-
	Singapore	5 – 10% of contract values of projects	-
	United Kingdom	-	50%
(Josephson, Larsson and Li 2002)	Seven case projects	4.4% of contract values of projects and 7.1% schedule delay	57%
	In housing projects	-	50%
(Love and Sohal 2003) & (Love and Li 2000)	A case study of a residential project in Australia	3.15% cost overrun and 11.6% time overrun	73.1% for cost overrun and 57% for time overrun
(Mills, Love and Williams 2009)	10,548 residential properties in Australia between 1983 & 1997	4% cost overrun	-
(Love 2002)	161 Australian construction projects	12.6% cost overrun and 20.7% schedule overrun	-
(Hwang *et al.* 2009)	Information on 359 projects from Construction Industry Institute	5% cost overrun	-

Illustrations

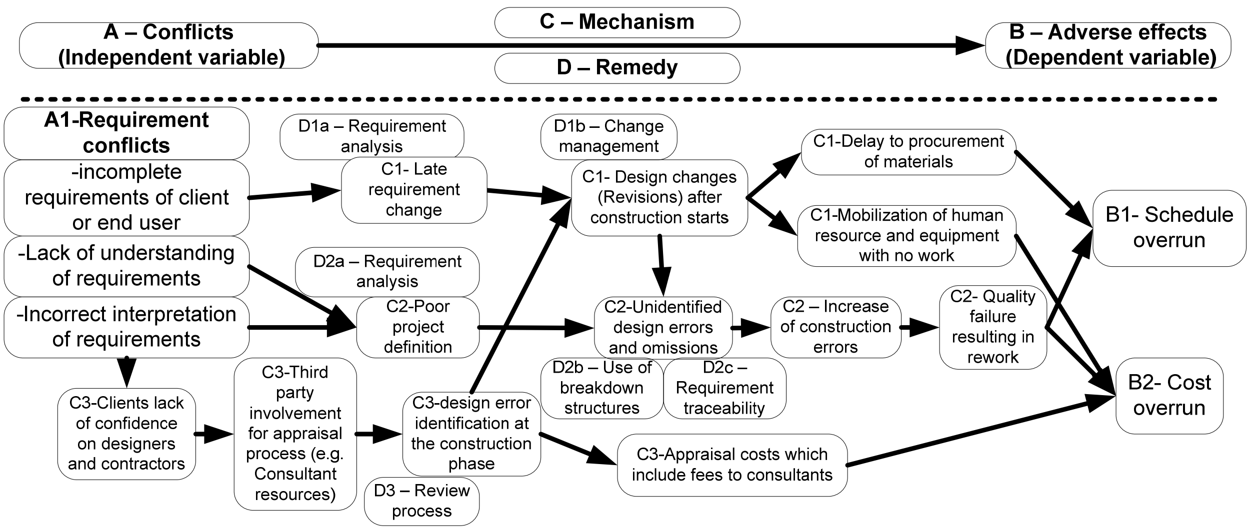

Figure 1: Mechanisms and systems engineering remedies

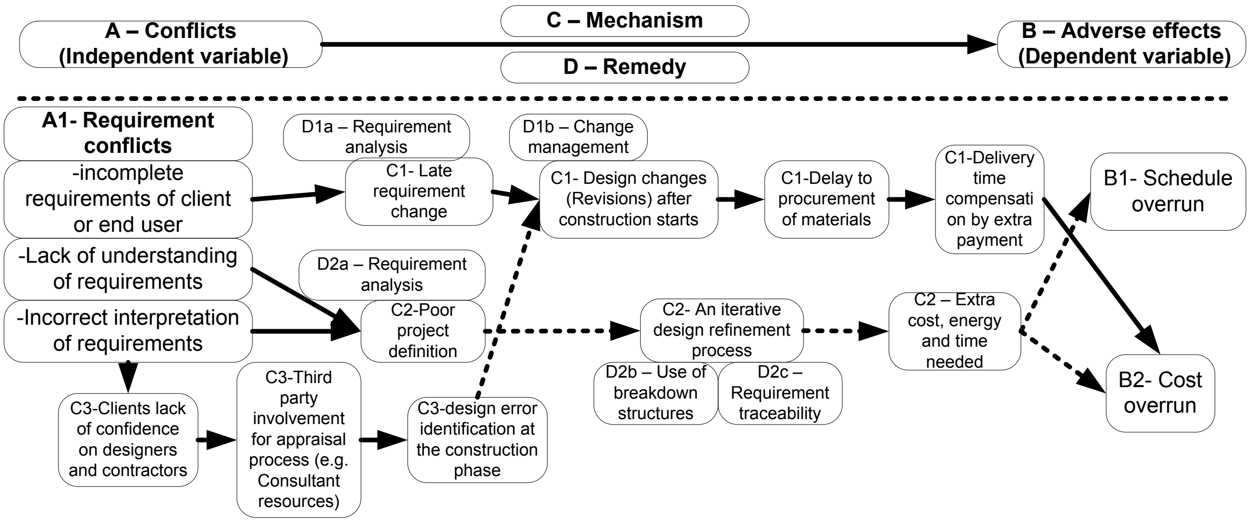

Figure 2: Revised mechanisms and systems engineering remedies