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MULTILAYERED CHANGE: ENGINEERING CHANGE IN BUILDING REFURBISHMENT

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1. Introduction

The design and production of complex engineered products shares a number of parallels with construction projects: they both provide technical solutions for specific projects and both systems must manage the prevailing constraints of strict timescales, restricted budgets, challenging regulatory frameworks and variable supply chain relationships. As they each constitute major financial investments in their design and manufacture, both building projects and new product developments are tightly planned and any divergence may entail significant levels of change. Whilst complex engineered products, such as aircraft are frequently refurbished, effort is predominantly directed towards creating new products based on existing version of the product. In building refurbishment however, change focuses on the existing structure. The aim of this paper is to investigate whether changes to building projects create similar patterns of change propagation to those observed in engineering change. If this is the case, both may benefit from the same tools and in addition, insights from construction may afford some benefit for engineering. The paper draws on a case study of the refurbishment of a hospital neo-natal ward carried out as part of a wider study, seeking to improve the resilience of hospitals to climate change.

For many years there has been a perception that significant developments in engineering process, for example developments in lean production, concurrent engineering, collaborative systems and agile management are slow to infiltrate the wider construction sector. Kagioglou et al. [Kagioglou et al. 2000] suggested that the perceived lack of process driven improvement in the UK construction industry was a result of the “one-off” nature of construction projects and the proliferation and fragmentation of many construction sub-contractors [Kagioglou et al. 2000]. However in his 2003 paper, Winch reasoned that the “mass production” system may have limited relevance for the low volume construction sector. He argued that process models typical of the shipbuilding and aeronautic industries may be more applicable to construction projects, particularly the complex systems approach [Winch 2003]. Recently Gambatese and Hallowell [Gambatese and Hallowell 2011] concluded that a lack of innovation is a major problem in the US construction sector. They identified strong barriers to innovation, typified by a reluctance to change and a lack of available resource to develop knowledge [Gambatese and Hallowell 2011]. However, this reluctance to innovate might also be interpreted as caution. Green [Green 2011], advises against simply transplanting successful strategies from very different contexts. He suggests that progress is contingent on an understanding of the historical constraints and the pervading sectoral influences that apply. He argues that continuity of demand may be a more important priority for a construction sector more sensitive to cyclical economic pressures than to cost efficiency, a key focus for engineering process research [Green 2011]. However, the specification of standardised or purpose-built modular buildings, assembled under factory conditions is becoming increasingly common and hospital examples include wards, cleanrooms and operating theatres, all constructed with significantly reduced fabrication times. These modules, with a design life of sixty years or more, are increasingly being considered as an alternative to traditional construction. Consequently, an understanding of developments in product engineering, especially those related to change and the introduction of technical innovation, may be very useful in helping to conceptualise the change process in building refurbishment and vice versa. In particular, the way in which contractual relationships affect the change process is very evident in construction and is considered here as part of a model, developed to clarify the process (see Figure 1). Equally, insights obtained during the development of the model may be relevant to engineering product development. The main purpose of this paper is to examine change in a refurbishment application and to determine if mechanisms, similar to those identified in engineering change, apply. The management of the change process is also considered, with the eventual aim of identifying options for reducing the risk of serious propagation. *Section 2* looks at how change manifests in engineering systems. *Section 3* explains the medothodology adopted and describes the case-study. *Section 4* examines sector specific constraints in construction and *Section 5* considers the case study changes, along with specific constraints and discusses how the various examples of change progressed. *Section 6* looks at change in the case study example and *Section 7* describes a framework model developed to unravel change processes in refurbishment projects. *Section 8* discusses the key change mechanisms and *Section 9* draws together the influencing or mitigating factors identified and includes suggested areas for further research.

2. Change in product engineering

Change in the engineering context may be used to systematically progress a product to suit a range of new objectives, for example; to introduce technological innovation; address new legislative requirements; respond to changes in demand; correct errors; or to reduce costs [Terwiesch and Loch 1999]. Typically engineering products have a high degree of interconnection between components and systems, so that changes to one element are likely to affect other components either directly or through other connected systems. The consequential surge of change which may develop from a single initiated change is termed "change propagation" and this has been described by Eckert et al. [Eckert et al. 2004] as "the process by which a change to one part or element of an existing system configuration or design, results in one or more additional changes to the system, when those changes would not have otherwise been required". They identified specific modes of change propagation: change *carriers* transfer change to connected components but are not significantly affected by change; change *absorbers* accommodate changes, and whilst total absorbers are rare, partial absorbers or *buffers* contain the majority of changes, allowing a small proportion to be passed on. *Resistors* are critical aspects of a system and are only changed if there is no other option. Changes to strongly connected components resulted in numerous changes to connected systems and can be considered as change *multipliers.* These can lead to problematic avalanche of changes, where the volume of required changes increases and may be uncontrollable. Less challenging change episodes present as *ripples* where only a small number of follow on changes is required. Larger, but predictable changes may result in change *blossoms*, which may require substantial effort to resolve, although the process may remain controlled, with the numerous changes being ultimately directed towards change absorbers.

3. Methodology and description of the case study

The case study for this research was carried out as part of a nationally funded project, aimed at improving the resilience of the NHS Retained Estate against future climate change.

3.1 The research methodology

This study adopted a critical realist approach based on the work of Baskar (in [Collier 1994]) which accepts that interpretations of the world can be inconsistent, and consequently there is a requirement for wide-ranging investigation using a variety of methods, in an attempt to relate knowledge as closely as possible to reality. Thus the diversity of insights gained from the combination of methods helps to build a "rich picture" of the events and relationships under study [Downward and Mearman 2007]. Particular access to an NHS refurbishment review process made the case-study approach especially suitable [Yin 2009].

3.2 The project case study: The refurbishment of a UK neo-natal unit

The case study concerns the successful £10m "state of the art" refurbishment of a neo-natal unit based on two non-adjacent floors within a 1960s multi-storey hospital building. The hospital is part of a large UK Trust, located within a busy city centre, serving a population in excess of 300,000 people and with a maternity service delivering 10,000 babies each year. A key constraint was to minimise disturbance to the other occupied floors of the building. The Trust originally planned to use a traditional procurement route but changed course early in the proceedings to the NHS procurement strategy, Procure 21 (P21), a more expensive but lower risk option, in order to expedite the project. Under this system, any unspent "risk mitigation" funding, is shared between clients and contractors and a spirit of collaboration is fostered. The project was initially planned to include both floors of the unit, however the funding proved to be insufficient and the development was re-scoped to concentrate on the refurbishment of the lower floor. The work to the upper floor was postponed until further funding could be secured. The authors obtained access as observers, to the post-project review meeting, where all involved parties were represented. Key project members were invited to give their observations and reflections on the planning, briefing, procurement, design, management and construction stages of the project, together with their views regarding the outcome. Notes were taken throughout by two researchers and compared for agreement and consistency. Following the post project review, key actors took part in semi-structured interviews (as shown in Table 1) and recordings were transcribed for analysis. Due to the number of interviews and the volume of transcriptions, a deep grounded theory analysis was not attempted; however transcriptions of the interviews were interrogated against themes which emerged from the post-project review. Other research avenues for this case study include the evaluation of reports and documentary evidence.

Table 1. Interviews with case study participants

Nr	Client appointed participants	Role	Time (mins.)
1	Client Project Director	Overall project lead. Liaison with trust board	48
3	Internal Project Manager	Develop and coordinate trust projects	103
4	Clinical Lead	User group design development lead	31
5	Nurse Manager (Matron)	User group design development	55
2	Consultant Project Manager	External consultants advising on procurement	59
6	Cost Advisor	Advise trust on cost issues related to project	41
7	Project Site Supervisor (PSS)	Site supervision (trust's representative)	41
PSCP (Principal Supply Chain Partner) appointed participants			
8	Construction Manager	Strategic support (all projects)	32
9	Project Manager	Project planning communication/ liaison	15
10	Design Manager	Management of design information	55
11	Senior Quantity Surveyor	Cost control and advice	42
12	Quantity Surveyor	Cost control and advice	53

4. Change in the refurbishment context

Similar change mechanisms to those in engineering operate in construction projects although the diverse constraints and options for managing the process of change result in alternative patterns of development. Consequently, change appears to present in ways quite different to those seen in engineering projects.

4.1 Key features of refurbishment projects

Drawing on themes identified in the literature and discussions with case study participants, the following key characteristics of refurbishment projects were identified and considered in relation to the case with complex engineered products, (see Table 2 below). These considerations appear to profoundly affect how changes are carried out and whether and where changes propagate.

Table 2. Distinctive features of construction refurbishment and complex engineered projects

Characteristic	Construction Refurbishments	Engineered Products
Key indicators of success	Project duration/cost remain key indicators of success and penalties for delay have led to careful risk management. Compromises on build quality, value for money or advances in process, may compensate for time lost.	Product sales are the key indicator of success. Warranty claims and reorder rates indicate success in operation. Recalls are costly and affect brand image.
Inherent high risk	The original structure is largely unknown and surprises are common; pricing is problematic and tends intensify the "fuzzy front end" uncertainty.	Risk is related to the maturity of the technology in new product development and the degree of compatibility with the existing product.
Design changes	Frequent changes: Users' understanding of their needs matures with the emerging building.	Early changes related to "user-led" requirements. Later changes respond to problems. Constraints can be varied, e.g. by freezing components or systems.
Post-project changes	Expensive post-project amendments can provide an alternative option to delaying the hand-over date.	Occasional post production upgrades for specific customers; option package amendments or distinct redesign projects.
Possibility to negotiate directly with clients.	"Workaround" solutions that clients can "live with" may be preferable to expensive alternatives.	User input during requirement gathering.
Refurbishment issues	Refurbished buildings are rarely optimised. The tendency is to balance the level of improved performance against the likelihood of escalating the cost.	High volume automotive refurbishment is integrated into the "auto-servicing" sector. With "low volume/high value" products, refurbishment provides an opportunity for introducing innovation.
Certification	Building standards are not retrospective and do not (at present) extend to unaffected areas of the building.	Certification relates to the whole product and onerous testing is required to ensure that the entire product performs safely.
Contractual arrangements are complex.	These vary from project to project with many sub-contractors. Each new venture will have a significant learning curve as contractual and "working" relationships are confirmed or negotiated and the scale and extent of the work is understood.	Contractual relationships for supply chains can be complex. However control of production is largely located within a single company or group and relationships can endure.
Learning from one project may not be retained.	Knowledge gained or investments in producing effective "temporary" project teams may not be available for future use.	Successful teams can be redeployed on further projects and knowledge can accumulate.

4.2 Change in refurbishment projects

Large refurbishment projects have complex planning, design and construction phases and changes to any aspect of the process, once the designs and specifications have been agreed and signed off, are very problematic. Unanticipated changes can be particularly troublesome and decisions tend to be made swiftly with limited consultation. Frequently such changes result in the need for further change to construction schedules and require substantial coordination. Typically, a change to the dimensions or function of a space might involve changes to any or all of the following; heating and ventilation calculations; electrical connections; lighting and service cabling; additional structural support; hot water, waste and medical gas connections; fire safety systems; access arrangements; quantity and pricing information; and interior design. Such change may also affect connected spaces and involve further redesign. Clearly the stage at which a change is made is crucial and once a Guaranteed Maximum Price (GMP) has been agreed between the contractor and the client, further change will have cost implications. As the project progresses other factors may force changes, such as unexpected structural issues or the failure of a contractor. In a tightly constrained programme, these changes can be very challenging. One key aspect of managing hospital projects involves limiting the propagation of any proposed changes beyond the geographic boundary to prevent possible cost escalation and disruption to the whole building. This type of trade-off is common in refurbishment, where the more a change or improvement to a system is localized, the consequential cost is minimized, but the potential benefit to other areas of the building is correspondingly reduced.

4.3 The effect of constraints on changes throughout the project

Building projects are subject to a number of constraints which limit the options for change mitigation;

- *Regulatory constraints:* A complex regulatory framework applies to construction projects in health-care, with onerous Department of Health recommendations, local planning conditions, Building Standards etc., which complicate design work and are not always appropriate for refurbishment projects. Advisory standards that could not be met in all respects were reflected back to the Trust directors and agreed as an ongoing risk.
- *Financial and contractual constraints:* Contractual issues are significant features of construction projects and historically have been a continual source of problems. Nationally agreed contracts such as the Joint Tribunals Contract (JCT) are used and underpin each party's perceptions of the construction process. However, the change to P21 and the introduction of the New Engineering Contract (NEC) resulted in delay at a fairly crucial stage. Financially, delay is problematic, as interest rates and inflation are calculated for identified project stages and associated with specific accounting periods.
- *P21 and the Guaranteed Maximum Price (GMP):* When using the NHS procurement system P21, a GMP is agreed between the client and the Principal Supply Chain Partner (PSCP). Problems identified before this agreement can be included in the contract sum. Surprise discovery of problems after this point involves significant extra work and will impact on the construction schedule, unless there is some mechanism for absorbing the extra cost or delay.
- *Building and process issues:* Minor refurbishments to occupied buildings usually take place in a piecemeal fashion, working on small sections with continual interruptions and complex restrictions. Essential services cannot simply be disconnected, as other areas of the building may still be in use and as a result, refurbishment work is scheduled around existing hospital priorities. Work by the contractors involving noise or significant intrusion, was carefully scheduled and time-limited and this was a key feature of the project risk assessment.
- *Physical constraints:* Changes to particularly constrained systems such as soil waste systems, may be low-cost, but may require expensive floor plan changes or may seriously affect user satisfaction ("process" layer changes propagating to the "building" and "user" layer of Figure 1). Some systems may be so highly constrained that changes cannot be made, not because they are highly connected, but because they must be carried out at specific stages. For example, when component can not be used because it does not meet a newly revised standard; or a replacement component has a lead time of many months. Such changes cannot propagate as there is no downstream option and consequently the change is reflected back to the point of origin [Eckert et al. 2004].

5. Changes affecting the case study project

Rather than exhaustively discussing the project changes we highlight selected classes of change with a view of relating them to an analytical framework (Figure 1), described in Section 7. The refurbishment project can be envisaged as a simple scaffold composed of a number of "layers" relating to distinct sequences of connected processes. Changes can take place on different layers, propagate between them or be mitigated across them. In this framework, the "governance" layer corresponds to the underlying legal relationships, structural hierarchy and financial management of the project; the "process" layer includes the scheduled events, processes, or operations; the "building" layer embraces the structure, access and envelope characteristics; and the "use" layer includes all aspects of user or client requirements, including functionality and design aspirations.

5.1 Procurement and contract changes: change in one layer propagating to an adjacent layer

The change of procurement route to P21 occurred at a late stage in the project planning process, when it was clear that there was insufficient time for the protracted traditional procurement route. The P21 Framework provided a short and vetted selection of possible contractors, which afforded a level of security in the crucial choice of PSCP, who sub-contracts and manages the project. This change propagated widely at first (a change blossom) but was limited by the relatively early stage of the project development. The change propagated financially and administratively along the "governance" layer due to the increased costs of the P21 Framework (6% of budget) and across to the "process" layer as there was an unanticipated need for an environmental assessment (a further 6% of budget).

5.2 Emergent changes

The original survey was limited in scope due to the constraints of a working hospital and the need to minimize intrusion to other parts of the hospital and maintain patient privacy in adjacent wards. As with many older buildings, modifications over the years were poorly documented, so there were many structural surprises; with active water pipes and electric cables embedded in walls. Voids were often fully utilized or contained unexpected live services. A number of problems emerged during the construction phase and most involved changes to building services and affected various layers of the project. The real concern was the extent to which they might propagate beyond the project boundary to the rest of the building.

Contractor related issues: change propagation along a single layer

The electrical subcontractor became insolvent during the last few weeks of the project. The learning curve for a replacement contractor would have been immense. Consequently the Mechanical and Electrical (M&E) contractor redeployed their own workforce to complete the contract, thereby also acting as "absorbers" and internalising what could have been a significant delay. However the arrival of twenty to thirty craftsmen, needing orientation, information and organisation, significantly contributed to the compression of the project in final six weeks of the contract period. This had further external propagation effects; in that the M&E's other contracts were considerably delayed.

Survey related issues: change propagation across multiple layers

Subsequent to achieving an agreed Guaranteed Maximum Price (GMP), the water supply system was found to be in such a poor condition that it resulted in replacement throughout the entire building and required Trust Board approval to meet the extra costs. In addition, the presence of asbestos was greatly underestimated, resulting in significant delay and requiring specialist contractors. Consequently the changes propagated from the process layer across to the governance layer. Change also propagated to the user layer as design changes were required to accommodate new service runs.

Survey related issues: change absorption and the GMP

By contrast, the vulnerable condition of the heating system had been identified during the original survey, and full costs were included in the GMP and an additional change order was not required.

5.3 Redirected change: propagation across all project "layers"

Design change: change reflection

The most sustained challenge to the project was associated with the issue of the Interior Design and layout. Interior design, although a relatively low cost item, is particularly important to clients as the very tangible end result of their aspirations. The contractor had commissioned an architectural practice, who after several consultations and workshops provided the clients with unsatisfactory designs and were then dismissed. However there was no provision for an alternative option in the contract documentation and the change was reflected back to the client. The clients eventually took the interior design function back "in house". This "contractual" layer change had a considerable effect on the scheduling of the projects due to the long lead times for furnishing and fabrics. While the final result was entirely adequate, the end users were not overly enthusiastic.

Change of scope: Change "refraction"

As the project progressed and the costs became clearer, it was apparent that either a change to the brief or alternative funding would be required if targets were to be met. The primary focus of the project was the main neo-natal wards on the lower level. The refurbishment of the areas devoted to supporting functions on the upper level was of less critical importance and was eventually separated out for alternative funding. However this diverted work package still remained under the overall project umbrella. In effect, when the project hit a cost barrier, the necessary change was "refracted" along a substantially different pathway. This "change refraction" was pervasive and propagated to all layers of the project (See Figure 1). Although it resulted in ripples of change across each project layer and required work to revise the project documentation, schedules and contracts, it did not get out of hand. Critically, it allowed more time to complete the work to the lower floor of the building. An estimated £300-500K of additional funding was needed to complete the work to the upper level and fortunately, this was realised from unspent project resources and augmented by charitable donations.

6. The management of change

Financial decisions regarding any significant cost deviations were reliant on approval from the Trust Board of Directors. Hence contractual changes with serious financial implications were dependant on the monthly schedule of Board Meetings. Other changes were considered by groups set up at the outset of the project. The User Group considered any changes that might impact on the clinical functioning of the unit, whereas cost control was the remit of the project Quantity Surveyors. The Project Manager attended as many of the group meetings as possible and reported potential problems or necessary changes to the Project Director. Conflict at key points of the project, relating to the interior design concerns, resulted in a failure to progress or "project drift". This subsequently compressed the clients' aspirations into the final few weeks of the contract. The project remained within budget, chiefly due to the reduction in scope and to the very detailed project risk register, which identified the major anticipated risks and set aside sums to cope with such eventualities. The most serious anticipated risk was associated with construction noise causing disturbance to patients, limiting the time available for drilling tasks. Pre-emptive action included agreeing quiet periods or short service disruptions and identifying "low-noise/low vibration" drills. In addition, the PSCP, as a major supplier of health-care services was able to secure discounts from its supply chain partners further along the chain which minimised the cost consequences of specific changes.

7. A framework model of the change process in refurbishment

In engineering design the focus of change research has been on the management of the engineering design process, however in construction a wider perspective is required to include the contractual frameworks that underpin projects. There is also greater flexibility in the use or function of a building than with most engineered products which tend to be carefully optimized for a particular use. For building users, there is a certain degree of flexibility over how a function is carried out within a particular space, for example, it is possible to vary how a laundry process is sequenced, affording options for where the laundry room is located. Figure 1 shows a model that distinguishes the different layers and reflects the behaviour of change.

Changes can propagate horizontally along any of the layers during the project. For example, a change to a scheduled event on the *process* layer which causes a delay may affect connected or subsequent operations in the layer. This delay may be contained within the *process* layer by using "slack" or buffer periods. However change may propagate between layers, as there are usually cost or design implications associated with change. As the project progresses, some changes may cascade across all layers, resulting in significant extra work to achieve realignment with project goals or targets. Conversely, changes can be mitigated on a specific layer which then absorbs or limits change to other layers, as part of this mitigation. To make sense of the interlaced relationships and procedural priorities it was useful to differentiate between changes that impacted the project globally, across all layers; changes that propagated just beyond their immediate boundary; and changes that did not cascade beyond their operative layer. The previous section identified examples of these changes, demonstrating the malleable nature of change in construction. Within the wide scope of the project only very minor changes were restricted to a single layer. Changes to the physical building almost always had an impact on the project execution and generally extended to the use of the building.

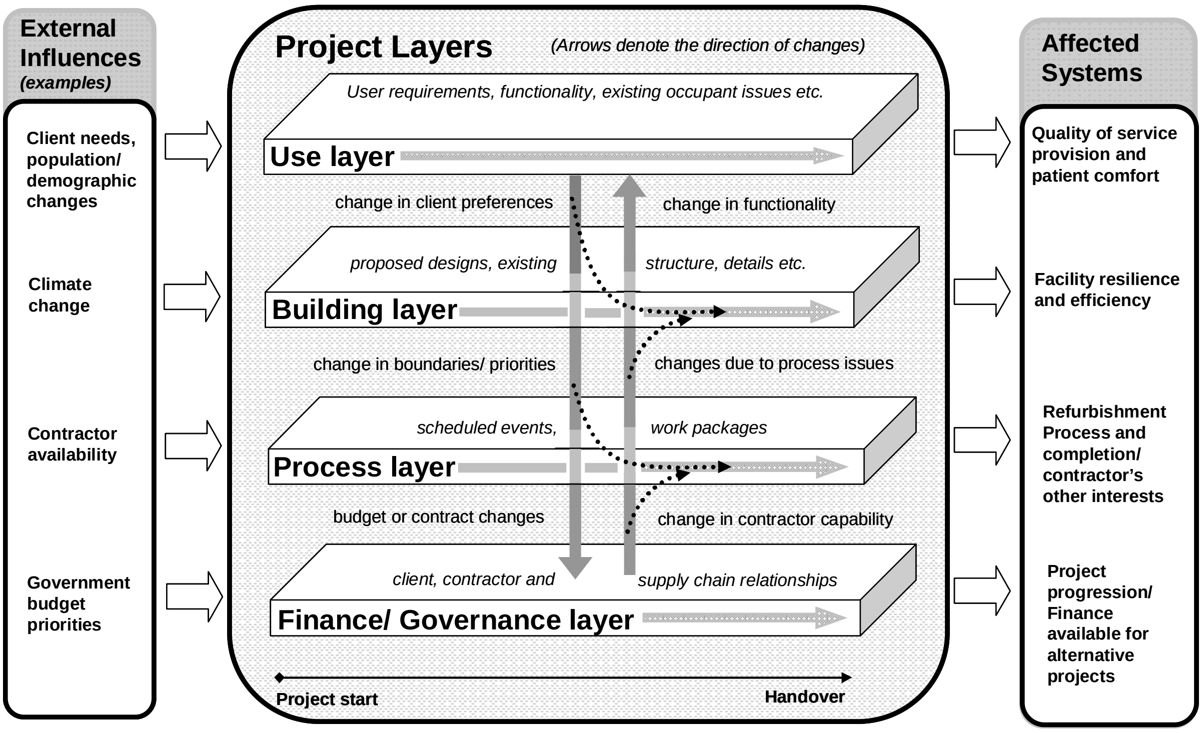

Figure 1. Project layers showing direction of changes

8. Discussion: consequences and mitigation of potential changes

The changes observed during the project were a combination of initiated changes, arising from user requirements and emergent changes where the team needed to respond to problems that occurred during the construction process. Some of the emergent changes resulted from previously unknown problems and remediation was essential. Other changes followed an initial change which propagated in a very similar way to change propagation in engineering. However as described above, in construction there are more options for mitigating against the risk of change propagation.

Malleable scope

Often there are multiple options for managing a particular change but the goal is usually to minimise change propagation or disruption. In the case study, scheduled float time absorbed much project delay. Costs were, on occasion, absorbed through negotiated price concessions with supply chain partners. Reducing the project scope and value engineering absorbed or buffered some pressure for change. Design changes were limited by including flexible open-plan spaces. As expected, change multipliers tended to escalate costs and the replacement of the water supply propagated to financial planning and project scheduling. Major project changes resulted in significant change "blossoms" as with the change of procurement route. Such issues required careful handling so that the change did not propagate beyond manageable levels and could be directed towards an absorber such as the GMP. The malleable nature of most construction changes make them easier to handle, but much harder to predict. This is because there are many different ways in which project teams can respond, including the option not to respond at all. For example the client decided to replace windows only on the refurbished floor, even though total replacement would be more cost-effective in the long-term.

Reflected change

The case-study project had many *change reflectors*, i.e. parts of the system which could under no circumstances be changed. Modifications to the building footprint, or to the supporting structure, were not contemplated due to the cost and structural implications. Hence, these reflectors redirected the change effort back to the system from which the change originated and in effect, increased the overall change volume. Where there was no alternative direction for a change, then either the change could not occur or there was a level of change propagation. The failure of the interior design work is extremely interesting as an example of reflected change because the environment surrounding the problem was particularly intransigent. Once the initial design was rejected there were virtually no alternative options for revisiting the issue. The construction schedule was severely constrained and there was no outlet for the change and it was simply reflected back to the client. A possible remedy might have involved some form of change absorption e.g., further scheduled consultation with the interior designers or a contractual requirement for an alternate scheme.

Comparison with complex engineering products

The construction case study displayed many similar characteristics to those observed in engineering change, as well as some significant differences. Due to the client-focused nature of the construction project it was possible to negotiate workarounds for problems and minor changes could be carried out once the project was handed over. Engineering solutions typically need to be robust and function for a range of users under different conditions. Once an engineering product is released, follow on changes or recalls, are expensive and negatively affect brand image. The cost of such changes is amplified by the volume of the components produced. There are also significant re-tooling costs, when modifying engineered products; whereas construction projects use similar procedures and equipment to those identified in the original schedule. Engineering changes have little scope for expanding the boundaries of the physical product and often the external shape of the product is fixed early, so that the geometry of the product is extremely restricted. Any change propagation needs to be absorbed within the physical structure of the product. There is however, an interesting area where boundaries can be flexible, concerning the hours of use for which engineering products are certified or guaranteed.

The emphasis on change research in engineering has been on the product and process layer. Little attention has been paid to date, to the contractual layer of engineering change. This is a significant issue and involves complex supply chain relationships. For example when suppliers produce components to their customer's specification, the customer typically carries the cost of changes. However if the supplier and customer work in a form of partnership, then the cost of changes can be shared or absorbed by the supplier. Where the supplier is paid to carry out a change, it depends on the stage of the design, whether actual cost arises. If the design is at an early stage, then the change will represent little additional cost. The issue of contractual relationships to accommodate to this aspect of product design has not been addressed in the engineering design literature.

9. Conclusions and further work

Typically, when a project encounters a serious barrier such as a significant budget overspend or a physical size limitation, changes in some form become inevitable and can propagate in multiple directions. This propagation may be the result for example, of essential value engineering decisions; or from the scaling-down of design aspirations; or perhaps a change of focus has been required. To avoid ongoing propagation it is possible that a section of the project work can be separated out for alternative funding or out-sourcing. This was the situation in the case study, when it was identified that the project funding would be insufficient and the change was "refracted" towards a very different trajectory. Hence change refraction was used as a mechanism for avoiding serious change propagation whilst maintaining the integrity of the project. Nevertheless, due the shared resources and the eventual need to integrate with the final project, there still remains the possibility of divergence from specifications or interference between the separated package of work and the main project schedule.

However the problem of reflected change is extremely difficult to manage. Where the change environment is so severely constrained, that there are no options for a change to occur, it is suggestive that tolerance margins may be too restrictive. It is clear from the case study that pre-planning to ensure that change absorbers were included at critical project stages, would have significantly improved project resilience. Identifying these critical stages during programming with a level of accuracy, will be an issue for further research. The prediction of risk intensity and the nature of constraints will also be considered. This will inform the development of change prediction tools for construction projects, which can cater for the malleable nature of construction change. The ability to mitigate risk may reduce the need for change and limit associated change propagation. Emergent issues may also benefit from analysis to highlight predisposing conditions or limiting factors.

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