A PROPOSED CONSTRUCTION DESIGN CHANGE MANAGEMENT TOOL TO AID IN MAKING INFORMED DESIGN DECISIONS

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Current practice shows that construction design change management (CDCM) relies heavily on the experience of practitioners to assess the impact of proposed design changes. This UK government and industry (Arup) funded research is concerned with mitigating the risk associated with a practitioner making a judgment disproportionate to the true impact of a design change. Several design management and planning tools have been reviewed (including the Analytical Design Planning Technique (ADePT) and the 'last planner' methodology), suggestions have been made on how they can be adapted to apply to design change management. A CDCM model has been proposed as a possible solution, enabling practitioners to make a better informed decision regarding the true impact of a proposed design change. The CDCM model incorporates a design structure matrix (DSM) and process map generation to create a checklist of rework; it also records the reason for deviation if the true impact is different to the assessed impact. The cost, resource, deviation, and reason for deviation are stored in a database and are available when a similar change is required on a similar project, allowing compensation to be applied to the predicted impact. The analysis used in the CDCM model is demonstrated using a generic simple building case study.

Keywords: design change management, decision-making, impact assessment, last planner, risk.

INTRODUCTION

All projects can be represented by the project management triangle where, scope, cost and time are the project constraints represented on each corner. In all projects scope, time and cost are connected. Likewise, when a design change occurs there is a change to the scope of the project and therefore it is necessary to change the project cost and/or duration. When referring to the impact of the design change it is this change to the project cost and/or duration, which needs to be considered. In order to calculate the additional project cost it is necessary to know the additional resource needed to complete the rework or redesign. This research considers the deviation between the predicted impact of a design change and the true impact once a design change has been implemented; this deviation is in terms of cost, resource and time.

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It is acknowledged that construction projects incur changes. As such best practice protocols exist, to log and manage change (Oracle White Paper, 2009). Both this best practice protocol and those used in the sponsor company, Arup North West, require an impact assessment of the change. However, little guidance is given on how to carry out this impact assessment. Sun *et al.* (2006) describe current practice as 'ad hoc' with each project team usually adopting different procedures for managing change.

Design changes during the detailed design phase, of a built environment project, usually have a negative impact on the design programme, in terms of additional resource, cost and project duration. Since design is iterative in nature, the consequences of a change can rattle through various engineering disciplines, making the impact difficult to predict. Current practice, within the project sponsor organization, shows that project teams calculate the effect of a design change on the programme, using their experience of similar changes during previous projects. There is a risk in relying solely on a practitioner's knowledge, in that they could make an inaccurate assessment or they may leave the business, resulting in a reduction in specialist decision-making expertise.

A number of design management models (DMM) and planning techniques have been reviewed such as the Analytical Design Planning Technique (ADePT) (Austin *et al*. 1999a, 1999b, 1999c) and the 'last planner' methodology (Ballard *et al*. 1998, Choo *et al*. 1999, Ballard 2000, Choo *et al*. 2003). These tools/techniques can be adapted to address design change management. A CDCM model is proposed to support practitioners in making informed decisions with respect to the true impact of proposed changes.

PROBLEMS IN CDCM

After gathering data from industry specialists in Arup, the sponsor company, it is evident that various protocols are used depending upon the project managers preference. Many practitioners believe construction design is being managed effectively using protocols documenting change requests. However, after deeper interrogation of such protocols it is evident that within each protocol, in order to aid the decision on whether to implement a change, an assessment of the impact, in terms of resource and cost, is required.

Figure 1 represents the process currently used within Arup Northwest to assess the impact of design changes. When a change request comes in, the team leader of each discipline is notified and asked to assess the impact for their team. At this stage, the team leader identifies the individual team members, which will be affected; these team members are then asked to assess the impact of the change on their specialist area. This team member provides an estimate of the impact, in terms of cost, time and resource, based upon their experience of changes, which have occurred on previous jobs.

There are two tiers of risk for any design change, each discipline team leader is asked to assess the impact of the change for their discipline. The first tier of risk occurs when the team leader decides which team members to consult. These team members are then asked how they will be impacted by the change. The second tier of risk occurs when the team member assesses the impact based upon their experience. Changes that are not managed appropriately can cause project delays and overspending (Sun *et al.* 2006).

The next section of this paper is summary of current design management tools, which can be adapted and developed to address the problem of solely using a practitioner's experience in assessing design changes.

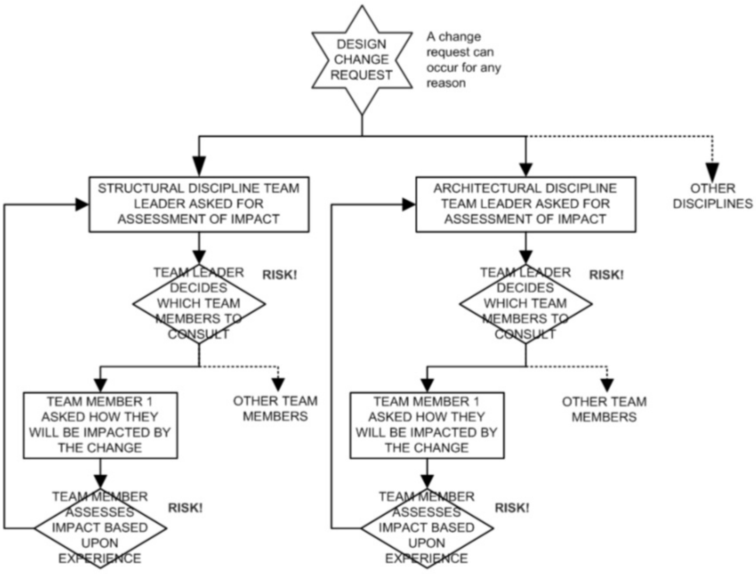

Figure 1: Assessing the impact of a change

A REVIEW OF SOME PREVIOUS LITERATURE

In 1965 Steward (1981) developed the design structure matrix (DSM), a matrix representation of a process. See Figure 4 for an example DSM. The matrix can be reordered and interrogated to find the optimum order of carrying out tasks, through eliminating the amount of rework. Design tasks are carried out in the order they are listed in the matrix and are listed both down the left hand side and along the top of a matrix. Each marker in the matrix determines the relationship between two tasks, the task on the left of the marker is dependent upon information from the task above the marker. Any marker under the diagonal is reliant only on tasks, which have already been completed. Whereas, a marker above the diagonal represents design iterations, where the information/data required is initially estimated. The need to estimate and carry out design iterations can be reduced through reordering the matrix, hence changing the order in which tasks are carried out. When reordering the matrix, the aim is to eliminate the markers above the diagonal, if this cannot be done, it is optimum to cluster the markers into groups as close to the diagonal as possible; this is called partitioning.

The DSM was incorporated into the Analytical Design Planning Technique (ADePT) during the late 1990s. Austin *et al* (1999a, 1999b, 1999c) identified that design is an iterative process requiring assumptions and rework until a suitable solution has been developed. Previous network analysis planning techniques (e.g. traditional programmes, made up of bar charts) do not account for the iterative nature of design and monitor progress based upon the completion of design deliverables. ADePT uses a DSM to identify the information required to carry out a task, the availability of this information is then monitored to facilitate more effective planning and management of building design.

ADePT management have recently used ADePT to assess the rework required as a consequence of design change, through manipulating the DSM, on a commercial project (Paul Waskett, ADePT Management Ltd, personal communication, October 2, 2009). After identifying a task that requires re-evaluation because of an imposed design change, it is necessary to copy that task to a future period in the schedule. This means copying the task down the matrix until it is below the task currently being completed. Once the task is in place, it is necessary to identify if any other tasks require rework by checking if the task has any dependencies in the upper diagonal. If other tasks require rework, they must also be repeated after the current position in the matrix. The process is only complete once all rework is identified and there are no more dependencies in the upper diagonal (or the dependencies have been partitioned).

At a similar time to Austin *et al* developing ADePT, Choo *et al* (1999) developed the WorkPlan database programme to aid in developing weekly work plans adopting the last planner methodology. The term 'last planner' refers to the individual or group of people who decide what tasks are to be carried out on a day-to-day basis. Traditionally the last planner will allocate work either based on "project schedule" or "whatever is generating the most heat" (Ballard 2000). Choo *et al* (1999) explains that, traditionally programme schedules are produced by a project manager who may not have a clear understanding of the work to be performed. For example, they may be unaware of what the constraints are on a task and whether the resources required to carry out the task are available at the required time. This traditional schedule identifies what task SHOULD be carried out at a given time, in order to satisfy the project objectives. The Last Planner System (LPS) proposes that the last planner also executes a schedule; their schedule should take into account both what the management believe SHOULD be done and combine this with what physically CAN be done. The last planners schedule represents what WILL be done. Ballard and Howell (1998) suggest that the last planner should carry out this schedule on a weekly basis using a weekly work plan.

HOW CAN THE PREVIOUS LITERATURE BE ADAPTED TO ADDRESS CDCM?

Current practice within the sponsor company shows the most common method used for design planning continues to be the traditional project programme, usually using MS Project or Primavera, software packages. Applying sections of ADePT in the reverse order will allow a traditional project programme to be converted into a DSM. Once a design change is proposed, this DSM can be manipulated as suggested by ADePT management to reorder the matrix and determine a checklist of design tasks, which require rework. This checklist can then be converted into an IDEF0v process map, which will allow the practitioners assessing the impact of a change to visualize the required rework

The last planner philosophy applies to project planning; a similar philosophy can be used to analyse the impact of a change. Throughout this paper, this is referred to as the 'last practitioner' philosophy. The term last practitioner refers to the person or people asked to assess how a given change will affect them. The last practitioner is aware of the physical constraints on carrying out the tasks; they can assess what physically CAN be done in addition to what the change dictates SHOULD be done. The last practitioner can make a more informed impact assessment than someone higher in the hierarchal tree (for example a project manager) since the last practitioner is aware of the physical constraints of a task. Current practice within the sponsor company, uses this last practitioner philosophy, where the 'team member assesses impact based upon experience'. The proposed CDCM model is concerned with supplying the last practitioner with as much information as possible to allow them to make an informed decision and hence mitigate the risk associated with the practitioner making a judgment disproportionate to the true impact of the design change.

The 'last planner' philosophy uses 'Percentage Plan Complete' (PPC) and reasons to track the percentage of assignments completed in each weekly work plan (Ballard 2000). This can be adapted for tracking the deviance in assumed impact in terms cost/time/resource compared to the actual impact of a change. The reasons for any deviance can be recorded and feedback given to the 'last practitioners'. This deviance can also be stored in a database, so that compensation can be given for future changes on similar projects

PROPOSED CDCM MODEL

Figure 2, represents the proposed CDCM in visual form; this section summarizes the model by describing each element of the model in turn.

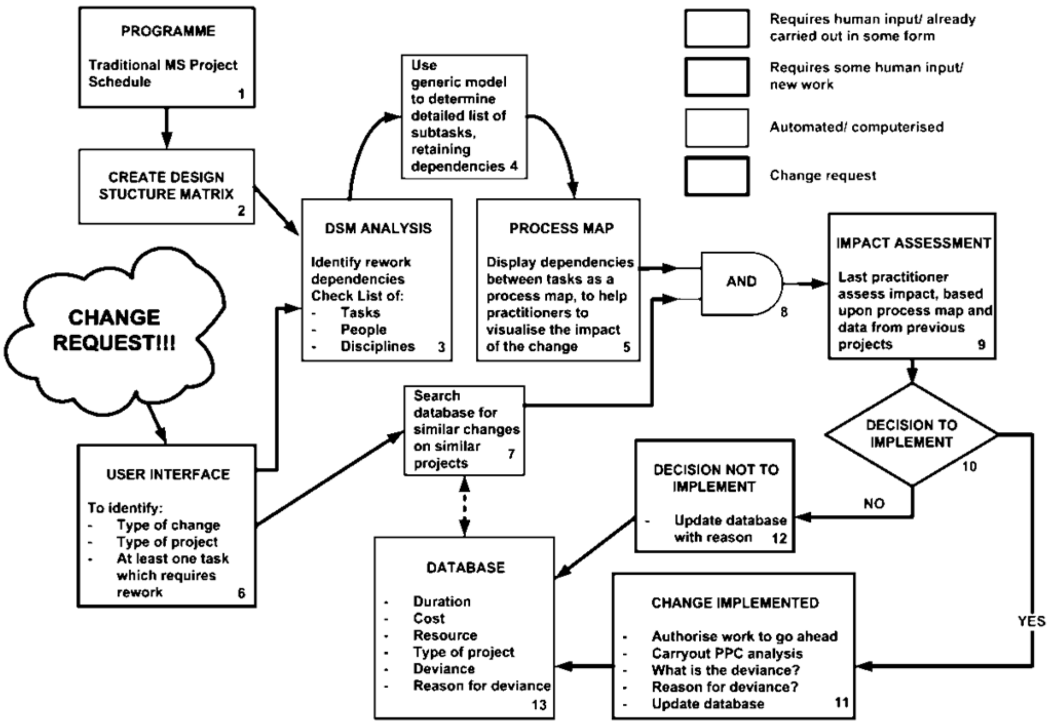

Figure 2: Proposed CDCM Model

The important factors in proposing a CDCM model is that it is of benefit to the practitioner who will use it. It is not possible to eliminate the risk of incorrect impact assessments being made. However, it is possible to supply those practitioners with as much data as possible, to enable them to make a better informed impact assessment; using both a checklist created from DSM analysis of the current programme and a database of previous changes on similar jobs.

The first stage of the CDCM model is to take the current project programme and convert it into a DSM. Once a change has been requested and some project characteristics have been inputted into the user interface, DSM analysis can be carried out to identify a list of tasks requiring rework. A generic model will be used to split the list of tasks into a more detailed list of subtasks. The list of subtasks will be converted into a process map, allowing the last practitioner to visualize the rework process, when making the impact assessment. The last practitioner is also supplied with historic data of similar changes on similar projects, from the database, to enable a better informed impact assessment to be made. When the discipline leader has collated the impact assessments from each affected last practitioner a decision on whether to implement the change is made (this decision may need authorization from the client). Once the decision is made, the last practitioners are informed whether to implement the change. If the change is not implemented, the reason is recorded in the database. If the change is implemented, PPC analysis is carried out; recording any deviance between the expected and actual cost and time to carry out the rework, the reason for any deviance is also recorded in the database.

A CASE STUDY EXAMPLE TO DEMONSTRATE THE ANALYSIS USED WITHIN THE CDCM SUPPORT TOOL

As part of the wider research project, a focus group of structural design specialists, from the sponsor company, has been formed to develop a process map of a generic simple building (for examples, a 3-storey office block). Within this section, the process map is presented and the generic simple building is used as a case study to show how the CDCM support tool analysis is applied. After three focus group meetings the process map shown in Figure 3 was agreed, by all specialists present, to be an accurate representation of the process used to design a generic building.

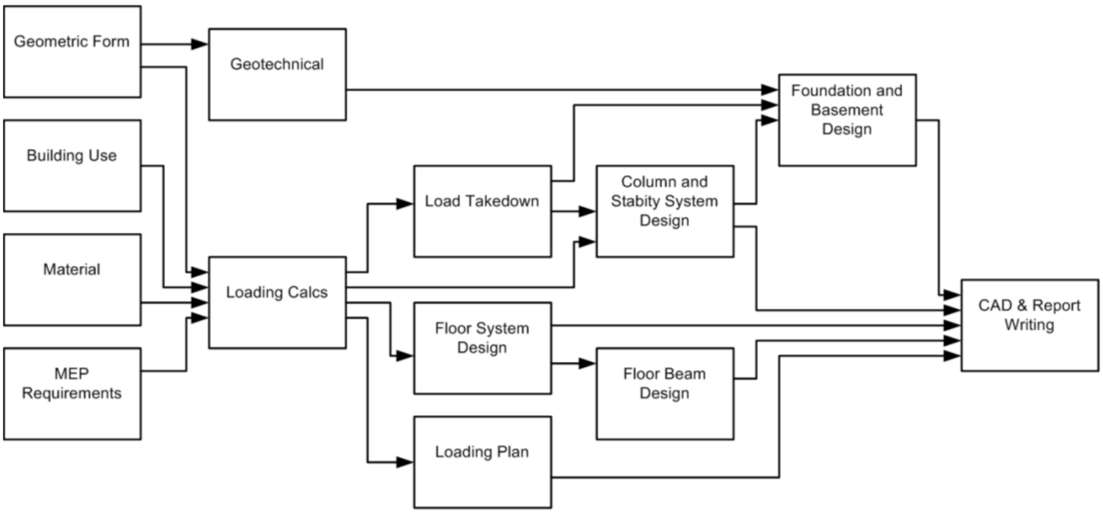

Figure 3: Generic simple building process map

MS Project Programme

Prior to starting any design project a design programme is created, this will show the design tasks, the duration for these tasks and which team members are responsible for carrying out each task. A hypothetical MS project programme, showing the tasks and their duration, for the generic simple building has been produced, a summary Gantt can be seen in Table 1.

Table 1: Process Gantt chart

Task Name	**Duration**	**Predecessors**	**SEPT**	**OCT**	**NOV**	**DEC**	**JAN**	
Geometric Form (Concept)	0 days							
Building Use (Concept)	0 days							
Material (Concept)	0 days							
MEP Reqirements (Concept)	0 days							
Geotechnical	23 days	1						
Loading Calcs	7 days	2,1,3,4						
Load Takedown	3 days	6						
Floor System Design	12 days	6						
Floor Beam Design	8 days	8						
Loading Plan	3 days	6						
Column and Stability System Design	21 days	7,9						
Foundation and Basement Design	10 days	5,7,11						
CAD and Report Writing	67 days	10,8,9,11,12						

Design Structure Matrix (DSM)
A DSM can be created directly from a MS Project Gantt Chart.

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 9	Task 10	Task 11	Task 12	Task 13
Task 1: Geometric Form	X												
Task 2: Building Use and Client Req.		X											
Task 3: Material			X										
Task 4: MEP Requirements				X									
Task 5: Geotecnics	●				X								
Task 6: Loading Calculations	●	●	●	●		X							
Task 7: Load Takedown						●	X						
Task 8: Floor System Design						●		X					
Task 9: Floor beam Design						●			X				
Task 10: Loading Plan						●				X			
Task 11: Column & Stability Design							●		●		X		
Task 12: Foundation & Basement Design					●		●				●	X	
Task 13: CAD & Docmentation								●	●	●	●	●	X

Figure 4: DSM for the generic simple building

(a)

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 2	Task 9	Task 10	Task 11	Task 12	Task 13
Task 1: Geometric Form	X													
Task 2: Building Use and Client Req		X							X					
Task 3: Material			X											
Task 4: MEP Requirements				X										
Task 5: Geotecnics	●				X									
Task 6: Loading Calculations	●	●	●	●		X			●					
Task 7: Load Takedown						●	X							
Task 8: Floor System Design						●		X						
Task 2: Building Use and Client Req		X							X					
Task 9: Floor beam Design						●				X				
Task 10: Loading Plan						●					X			
Task 11: Column & Stability Design							●			●		X		
Task 12: Foundation & Basement Design					●		●					●	X	
Task 13: CAD & Docmentation								●		●	●	●	●	X

(b)

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 2	Task 6	Task 9	Task 10	Task 11	Task 12	Task 13
Task 1: Geometric Form	X														
Task 2: Building Use and Client Req		X							X						
Task 3: Material			X												
Task 4: MEP Requirements				X											
Task 5: Geotecnics	●				X										
Task 6: Loading Calculations	●	●	●	●		X			●	X					
Task 7: Load Takedown						●	X			●					
Task 8: Floor System Design						●		X		●					
Task 2: Building Use and Client Req		X							X						
Task 6: Loading Calculations	●	●	●	●		X			●	X					
Task 9: Floor beam Design						●				●	X				
Task 10: Loading Plan						●				●		X			
Task 11: Column & Stability Design							●				●		X		
Task 12: Foundation & Basement Design					●		●						●	X	
Task 13: CAD & Docmentation								●			●	●	●	●	X

(c)

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 2	Task 6	Task 7	Task 9	Task 10	Task 11	Task 12	Task 13
Task 1: Geometric Form	X															
Task 2: Building Use and Client Req		X							X							
Task 3: Material			X													
Task 4: MEP Requirements				X												
Task 5: Geotecnics	●				X											
Task 6: Loading Calculations	●	●	●	●		X			●	X						
Task 7: Load Takedown						●	X			●	X					
Task 8: Floor System Design						●		X		●						
Task 2: Building Use and Client Req		X							X							
Task 6: Loading Calculations	●	●	●	●		X			●	X						
Task 7: Load Takedown						●	X			●	X					
Task 9: Floor beam Design						●				●		X				
Task 10: Loading Plan						●				●			X			
Task 11: Column & Stability Design							●				●	●		X		
Task 12: Foundation & Basement Design					●		●				●			●	X	
Task 13: CAD & Docmentation								●				●	●	●	●	X

(d)

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 2	Task 6	Task 7	Task 8	Task 9	Task 10	Task 11	Task 12	Task 13
Task 1: Geometric Form	X																
Task 2: Building Use and Client Req		X							X								
Task 3: Material			X														
Task 4: MEP Requirements				X													
Task 5: Geotecnics	●				X												
Task 6: Loading Calculations	●	●	●	●		X			●	X							
Task 7: Load Takedown						●	X			●	X						
Task 8: Floor System Design						●		X		●		X					
Task 2: Building Use and Client Req		X							X								
Task 6: Loading Calculations	●	●	●	●		X			●	X							
Task 7: Load Takedown						●	X			●	X						
Task 8: Floor System Design						●		X		●		X					
Task 9: Floor beam Design						●				●			X				
Task 10: Loading Plan						●				●				X			
Task 11: Column & Stability Design							●				●		●		X		
Task 12: Foundation & Basement Design					●		●				●				●	X	
Task 13: CAD & Docmentation								●				●	●	●	●	●	X

Figure 5: DSM Analysis

Example change
When a change request occurs, it is necessary to identify both the first task(s) requiring rework and the current position within the programme. One possible change is a request from the client to produce a 4-storey office building instead of a 3-storey office building, the DSM analysis associated with this change can now be carried out. This is a change to the building use and client's requirements. The severity of the change is dependent upon how much work has already been completed. For this example, we will assume the floor system design has just been completed.

DSM Analysis
The first stage of the DSM analysis is to move the first task requiring rework to the current position. In Figure 5(a) task 2 (building use and client requirements) has been moved down and across the matrix to the position after task 8 (floor system design).

After completing the first move, a marker has occurred in the upper diagonal. This marker shows that the loading calculations (task 6) that have previously been produced were based upon the buildings and the client requirements. Since the client requirements have changed the loading calculation are no longer accurate and must be redone. Therefore the loading calculations must be reworked and moved to the current position in the matrix (this is shown in Figure 5(b))

After the second move further markers appear in the upper diagonal. The first marker appears because the load takedown is dependent upon the load calculations, which will now change during rework. Therefore, the load takedown must be reworked and is moved down the DSM to the current position. As shown in Figure 5(c).

Figure 5(c), shows another marker in the upper diagonal. Again this marker is removed from the upper diagonal by reworking the task (in this case task 9, floor system design) moving it down the matrix to the current position. This can be seen in Figure 5(d).

Figure 5(d), shows the completed DSM after rescheduling the rework. It shows that task 2, task 6, task 7 and task 8 all require rework.

Rework check list and process map
From the completed DSM analysis a checklist of rework can easily be extracted, since the tasks requiring rework are all those which have been moved down and across in the matrix.

For the generic simple building example the checklist of rework is:

- Task 2: Building Use and Client Requirements
- Task 6: Loading Calculations
- Task 7: Load Takedown
- Task 8: Floor System Design

The corresponding rework process map is shown in Figure 6.

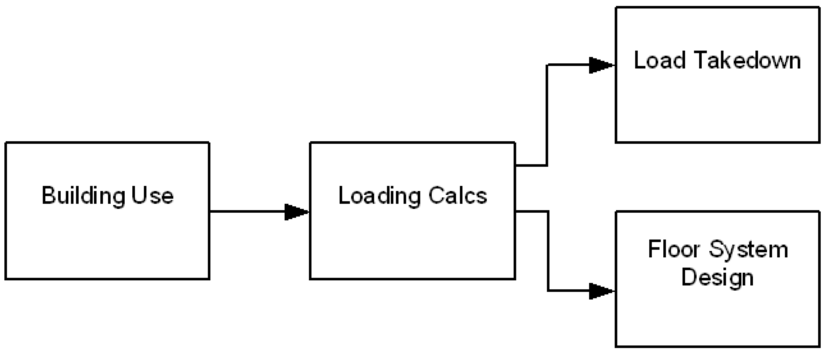

Figure 6: Example Rework Process Map

CONCLUSIONS

In construction design, no single protocol is used to manage design changes. Very little is known about the consequence of design changes. Currently design practitioners use their experience to assess the impact on their specialist field. A CDCM tool is required to help mitigate the risk associated with a practitioner making a judgment disproportionate to the true impact of a design change.

The research carried out so far has clearly identified a need for the CDCM tool. Various design management models have been reviewed and suggestions have been made regarding how they can be adapted in order to help evaluate design changes. A

CDCM model has been proposed, incorporating DSM analysis and process maps to create a checklist and visualization of redesign tasks, in addition to creating a historical record of the impact of a change for future reference. The reason for any deviance between the real impact and the expected impact of a change is recorded in a database and recalled when a similar change on a similar project has been proposed.

The authors believe that there are no other CDCM support tools of this nature currently being used in any design industry, therefore further work in this area will provide a significant contribution to research. A benchmarking study is currently being carried out to uncover any applicable tools and techniques used in the aerospace and manufacturing industries, which could be incorporated into the CDCM model. The use of the proposed CDCM support tool will have benefits for the construction design industry through enabling practitioners to better informed decisions on whether it is worth implementing the change, in turn, this will maximize efficiency in the design process and prevent overruns.

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