DEVELOPMENT OF A CONCURRENT ENGINEERING CONSTRUCTION PROCESS PROTOCOL

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Many of the problems encountered during the construction phase of a project are initiated during the front-end phase of the project planning process. This paper identifies poor client briefs, pre-project planning and uncoordinated design as contributory factors to overall poor project performance. It is known that manufacturing product development techniques have proven success in the pre-planning phase of product manufacture. This paper reviewed the product development process as used in the manufacturing sector to identify potential processes, such as product design specifications, which may be transferable into construction practice and aid the development of a generic construction process protocol. The paper presents a draft process model which aims to optimise the working processes within construction.

Keywords: Collaboration, concurrent engineering, internal impacts, optimisation, product design specification, total design.

INTRODUCTION

In 1994 Sir Michael Latham published his review and recommendations of the UK construction industry. The Latham Report stated that significant savings (up to 30% per project) could be attained by reducing adversarial confrontation and variation orders (Latham 1994). This would then enable an improvement in the performance of the design and construction process, also known as the project planning process. Currently in the Irish construction industry, which is similar in many ways to the UK industry, there does not exist a means by which to do this.

CRITICAL REVIEW OF THE PROJECT PLANNING PROCESS

Research, through case-study analysis and literature review, has noted that throughout the current project planning process it is possible to identify two types of system impact, when assessing a project plan, these are 'internal' and 'external' impacts (El-Shahhat 1995, 84-92, Jamieson 1994, 107-114). The external impacts are what are mainly considered by project planners and thus by ignoring the internal impacts this must reduce the likelihood of obtaining a 100% successful result.

- External impacts are mainly related to the construction and operational phases of a project, and are the major contributing factors to the achievement of the end result. They are associated with the design of a project and can be anticipated, removed or mitigated by alterations in the design or operational phases. Residual impacts are an accepted part of the trade-off with project

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benefits. If planning is done well then unexpected external impacts are unlikely to occur.

However, through the normal operation of the project planning and development procedures, internal impacts arise as unwanted by-products (El-Shahhat 1995, 84-92).

- Internal impacts are usually not recognised explicitly, because they are viewed as inevitable side-effects generated through the project planning procedures that are currently used. Any disadvantages are balanced by the commercial efficiency which results but the presence of internal impacts highlights the systemic inefficiency of these procedures.

Internal impacts, many of which are linked to human error (El-Shahhat 1995, 84-92), are difficult to manage as their sources are spread out through the project planning process and cannot be removed or at least modified without a major restructuring of the project planning process, which could affect the integrity of the project. Internal impacts are avoidable and only add to the overall project cost. To make a significant reduction to overall project costs, internal impacts must be eliminated from the planning process, or at least reduced in magnitude. Research identified three factors related to the project development process which are the primary generators of internal impacts, these are:

1. The staged structure of the project planning process;
2. The simplifications and assumptions involved in the procedures used;
3. The treatment of risk and uncertainty is affected by the attitudes adopted by project participants.

Through progressive distinct stages construction projects gradually evolve. The stages are linked in linear fashion (Figure 1). They consist of related groups of activities and at every stage specific questions must be asked. The subsequent answers generated automatically become inputs to the following stage. At the end of each stage the project's viability and prospects for success are accounted and assessed. At the end of the first two stages conclusion, major reconsideration’s may occur.

Each project stage involves a defined set of procedures and data but with a different group of specialists. Thus it makes each stage relatively self-contained with little transfer of information with external sources. All procedures use specific assumptions or simplifications which are based on the level of knowledge about the project topic and dependent on the reliability of the data available. At each stage the procedures and their operation are well known by those involved including the nature and magnitude of errors which may be introduced. This also applies to the data selected as suitable for distribution as the output of the stage.

Risks which will occur as a result of the future use of such data in other calculations are known and accepted, but are founded on the individual's conceptions of the levels of risk which are acceptable to the project and the projects reliability (El-Shahhat 1995, 84-92). This may not be a realistic assessment of the accumulated risk acceptance or reliability of the project. Thus, when the input of one stage is the output of the preceding stage there may be a lack of appreciation or understanding of the inputs limitations which may be ignored by the new specialists in the stage. Now what occurs in each subsequent stage is that the input data is assumed to be reliable and thus used in new procedures and calculations. The data, however, may be affected by inaccuracies or inadequacies which can produce a variety of errors but whose magnitude and effects are not correctly recognised. The worst scenario is the output may be incorrect or not what is required. Thus minor errors, which singularly are deemed insignificant, can become magnified as they are passed on through the stages either on their own or in combination with others culminating in production of larger more significant errors. However, the point to emphasise is that initial unintended and unforeseen generation of internal impacts makes subsequent recognition and thus removal extremely difficult.

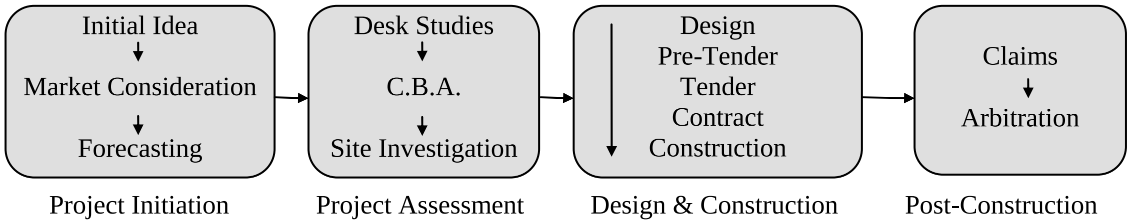

Figure 1. The Project Development Process

The progressive accumulation and magnification of errors is aided by the design (through evolution) of each stage as self-contained. This results in the participants in each stage having little appreciation or understanding of the procedures used in other stages. As a result participants tend to assume the data input from previous stages is correct and no allowances for inherited errors are made. Also, ignorance of what procedures occur in later stages makes it impossible for participants to adjust errors they may have noted in their own results and output to avoid problems later on. This creates a cascading process which needs to be controlled and moderated.

PROBLEMS OF INFORMATION DISTRIBUTION AND CONTROL

Additionally, a study carried out by Professor Sadi A. Assaf into the causes of delay in large building construction projects concluded that according to contractors one of the most important delay factors was “design changes by owners” (Assaf 1995, 45-50). Two important delay factors were identified by A/E's as “the relationships between different sub-contractors’ schedules in the execution of the project”, and “the slowness of the owners decision-making process”. Owners cited “excessive bureaucracy in project-owner organisations” as a major cause for delay. Research by the Building Research Establishment has shown that the biggest single cause of quality problems on site is unclear or missing project information. Another significant cause is uncoordinated design, and on occasions much of the time of site management can be devoted to searching for missing information or reconciling inconsistencies in the data supplied (BRE 1995).

Thus, there are many difficulties presented by the complex-information-flow-pattern generated by all the constituent parties during the project planning process. Optimisation of the manual project planning control systems could benefit from integrated I.T. policies which address communication and data storage difficulties.

However, in the Irish situation it became apparent early on during research that there was an inherent reluctance by construction practitioners to be involved in any extensive development of I.T. to address construction-process management problems. Research noted that in the Irish construction sector, not one of the large contractors had an I.T. management position within their organisational hierarchy. The adoption of computer based solutions and the introduction of computing hardware was still very much dependent upon an individual's own initiative within a company and not directed by a corporate policy. In a study by Healy and Orr it was noted that medium to large Irish construction companies have as yet developed no strategic policies for the adoption and implementation of I.T. solutions (Healy & Orr 1996, 44-46).

NOTED BENEFITS OF CONCURRENT ENGINEERING PRACTICES

Research was carried out in the form of interviews and a survey to appraise how Irish construction practitioners marketed their core services. It was discovered that of the top 100 construction firms, 43% have in-house design teams. All rely to some extent on independent architects and design practices. Although some firms specialise in particular types of work, design and build services cover the full range of building and civil engineering work including water treatment plants, hospitals and roads.

Several firms claimed that design and build provided one of the most effective ways of reducing building times and gave impressive examples of the reduction in time and cost of building shopping centres, industrial facilities and commercial premises. This was especially the case when they worked with regular clients whose standards and approach to business were well understood and where there was a close rapport with the professionals employed by the client. Clients confirmed the benefits of such close working relationships in achieving fast building times. A few companies were able to obtain over 50% of their work from long-term continuing clients, much on a negotiated basis. Continuing clients were able to insist on faster building and reduced costs.

It was reported that over a period of seven years, building times for some projects, for example out-of-town retail developments, were reduced by two-thirds and costs were reduced significantly. Such improvements to the project planning process were identified by clients as being attributable to the familiarity between the project-involved organisations. Contractors and designers identified much improved client-briefs due to familiarity with previous projects as being a major factor. Overall:

1. Conflict was reduced;
2. There were no major surprises;
3. Responsibilities for design and construction were not split; and
4. The original price was more likely to be adhered to.

Thus, the survey concluded that through an holistic examination of the current situation in the Irish construction industry, successful projects were more likely when:

1. There was communication between all concerned parties, especially at project level and a detailed brief had been obtained from the client and was accessible to all parties;
2. Concurrency was established and encompassed all stages of the project planning process thus reducing internal impacts within that process;
3. Institutional barriers were removed.

STRATEGY IDENTIFICATION

Construction Industry Group

To examine and develop these key issues further the Dept. of Civil & Environmental Engineering, UCC created a cross-departmental ‘Construction Industry Group’ (CIG). Utilising the above findings the CIG aimed to identify:

1. Strategies and
2. Agenda for action,

for the construction industry in Ireland, to provide a means to improve the construction project planning process. The CIG then launched the academic/industrial ‘Innovation & Strategy Forum’ (ISF) to ensure industrial involvement in the strategy-development-process.

Innovation and Strategy Forum

The aims of the Forum included:

1. To encourage the rapid transfer of management 'best practice' across industry and EU boundaries;
2. To span all the professional disciplines which operate within the diverse structure of the industry, including major client organisations;
3. To match the agenda of the Forum with the real concerns of the industry;

The ISF held it's inaugural session on Friday 20th September, 1996, at UCC. The first discussion workshop was entitled ‘Constructing the Future’ (Jamieson 1996, 44) and was attended by industry clients, practitioners from all relevant professions and institutional bodies such as the ‘Construction Industry Federation’ (CIF), and ‘The Institution of Engineers of Ireland’ (IEI). The leading question for the event was: “What are the strategic challenges facing the Irish construction industry?”

Forum Proceedings

The initial morning session of the ISF presented an open platform for cross-disciplinary debate, deliberately avoiding a framework for discussion topics in an attempt to stimulate open interaction and debate. The afternoon session provided a structured debate addressing the problem issues identified during the morning session.

It became clear early in the morning debate that there was confusion as to what formally constituted the project planning process. The current contemporary model (Figure 1) of the project planning process was seen to be inadequate in it's description of the project pre-planning function. Consensus was reached on the point that many of the problems encountered during the project planning process were associated with poor or incomplete design. The causes of incomplete design were examined further and the process of poor client briefing was highlighted as a major initial contributory factor. This conclusion confirmed the research's previous finding that a detailed client brief had significantly contributed to the success of major projects.

The ISF delegates also agreed that the expertise and knowledge of professionals involved in the design and construction process needed to be recognised by all parties equally and incorporated at each stage of the project process. This view also confirmed the research's previous finding that institutional preferences were causing a hindrance to the project planning process.

The self-contained staged nature of the project planning process was considered re-iterative and the successive fortification of each stage exemplified the complexity of the decision processes involved. Due to the specialised knowledge bases required to input into each stage, it was suggested that there was a need for independent management, such as the project management function favoured in the US (Clark & Wheelwright 1993). It was argued that during the design stage in particular, such an independent management role would enable an unbiased audit of the process and require a full documented analysis of each stage. The inherent flaws in the current project planning process need to be recognised. To be able to identify internal impacts (possibly cumulative) would aid project optimisation (Jamieson 1994, 107-114) and reduce delays during project assessment procedures. The introduction of an holistic auditing procedure which would examine the project planning process as an inter-connected whole sum was seen as imperative and procedures should be critically re-appraised.

It was suggested that such an audit procedure would provide planners with an improved understanding of the sources of impacts and make them more aware of their existence. The desired result would be more collaboration during the pre-project planning and design stages (an issue proposed by the ISF), and greater scrutiny of critical points in finished plans. Such a procedure could reduce the likelihood of incorrect or flawed plans from being passed on and thus reduce the likelihood of subsequent delays. Thus it was concluded that at each stage of the project planning process, team membership must be optimised and expert knowledge used to review each stage. During the design stage it was considered necessary that a contracting professional be retained on a consultative basis to assure buildability.

Forum Recommendations

In summation, the workshop concluded that all professional parties involved in the project planning process should afford one another equal status. This in turn would enamour a project culture of collaboration, the basic factor in concurrent engineering philosophy. An improved means of communicating with clients to the industry was deemed essential. The products of such improved communication would be better informed clients, with more realisation of the intricacies of construction, and also improved detailed client briefs which would reduce the effects of design alteration after construction commencement.

Access to the client brief by all professional parties involved in the project planning process was also seen as an essential pre-requisite condition, together with the introduction of a contractor consultant during the design stage. Breakdown of the staged structure of the project planning process was seen as a means of encouraging cross-fertilisation of ideas and collaborative relationships. Also it would reduce the risk of generating cumulative internal impacts, as individuals would be capable of accessing plans during development and also be in a position to critically examine decisions before they are made absolute. The introduction of an audit procedure to complement the entire project planning process was suggested and received well by the majority of the ISF delegates. Introduction of such a procedure, it was envisaged, would create a more stable, risked reduced project plan and heighten the 'group/team' confidence of all the parties to the project plan.

THE TOTAL DESIGN PARADIGM

At this stage in the research it was clear that improvements to the project planning process could be made in the specific areas of the development of the client brief and the subsequent pre-project plan formulation and design process. Attention was focused on the manufacturing industry, which has been held up as an example to the construction industry in many recent industry review reports including Latham (Latham 1994). Research, through interviews and literature review, established that manufacturing firms approach design in a fundamentally different way to construction professionals. In manufacturing, much greater emphasis is placed on establishing the market/user need (in construction this would be the client) and incorporating this fundamental requirement into the 'Total Design' process (Cooper 1994, 3-14). At all future stages of product development, constant referral is made back to the market/user product brief. The total design process encompasses product, process, people and organisation. This is sometimes called the 'Product Development Process' (Pugh 1990, 64-144) (PDP) and is similar, in outline, to the project planning process used in construction. The total design philosophy consists of a central core of activities, all of which are imperative for any design, irrespective of domain. The 'Design Core' consists of:

1. Market/user need;
2. Product design specification (PDS);
3. Conceptual design;
4. Detail design;
5. Manufacture and sales.

All design starts with a statement of need. From this statement - the product brief - a 'Product Design Specification' (PDS) is formulated - the specification of the product to be designed. Once this is established, it acts as the mantle that envelops all subsequent stages in the design core. The PDS thus acts as the control for the total design activity, because it places the boundaries on the subsequent designs. Conceptual design is carried out within the envelope of the PDS, and this applies to all succeeding stages until the end of the core activity, which is usually referred to as the 'Design Core'. The main flow of design information is an iterative process, constantly under review and updated if new concepts emerge. At all stages the design core activity is operated iteratively, yet can appear to be passed through sequentially. The main design flow is capable of reversing at any point in the design activity, and some iteration is inevitable, but operating the design core rigorously and systematically minimises iteration.

Iteration occurs because of changed circumstances (a common scenario in construction). This causes inter-action between the design core and the enveloping PDS, leading to the evolution of the PDS. A PDS must be comprehensive and unambiguous. If an experienced designer is asked to design something with less than a comprehensive PDS, he/she will almost, without thinking, fill in the gaps based on his/her experience and feelings; if these happen to be at variance with the true user needs, he/she will be designing to the wrong base. Research, through interviews with consultants and clients, found that this situation is more common than construction practitioners care to admit. This conclusion re-affirms the findings of Professor T. Glavinich's study of methods to improve the design phase during the project planning process (Glavinich 1995, 73-76). In construction, designers do not spend enough time defining the client brief with the client and do not produce a PDS as is common within the manufacturing sector. The PDS, as used in manufacturing, acts in part as an audit check to the design process. Research established that ISF delegates regarded the introduction of an audit procedure into the project planning process as a means of increasing confidence in the design process and subsequent stages of construction.

DEVELOPMENT OF GENERIC CONSTRUCTION PROCESS MODEL

The research had identified a number of inherent inadequacies in the formal structure of the project planning process, especially in the areas of client brief preparation, pre-project planning, and design. Such inadequacies (internal impacts) were cumulative generators of problems further along the project planning process, especially during the construction stage. Acknowledgement of the complexity of the passage of information between the diverse parties involved in the construction process indicated that the use of I.T. could act as an aid, not a solution, to an improved construction process. The next stage for the research was to develop a draft generic construction process model (still under development) which would incorporate both a PDS type method of concurrent manufacture and I.T. into the model structure.

Previous Attempts of Generic Models

Several attempts have been made to diagrammatically represent the complicated construction process. These have included the BAA model (Figure 2) (Whitelaw 1996, 18-23), the ‘Process Plant Activity Model’ (PISTEP 1994), the ICON project strategic level model (Aouad 1994), and the ‘Integrated Building Process Model’ (Sanvido 1990), and also the Jewel model (Jewel 1986). However, as yet no model has been capable of representing the diverse interests of all the parties involved in the process or been able to provide a complete overview. All the previously mentioned models, excluding the BAA model (activity focused), focused on data management and all were specific to the developer’s operations or industry segment.

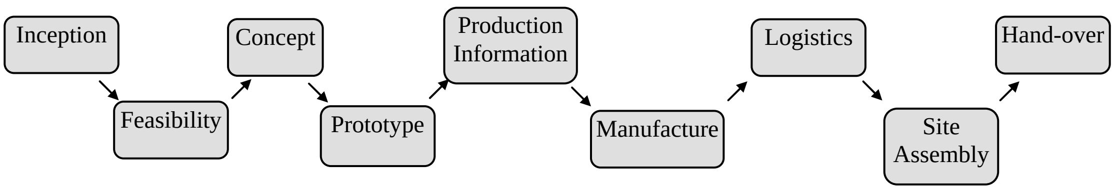

Figure 2. *BAA Model*

Methodology

It was decided that due to the complexity of the industry structure, and it’s multi-component composition, that a methodology was needed to organise the research effort. From literature review of published research into process model development, IDEF-0 Structured Analysis and Design Technique (SADT) methodology (Marca and McGowen 1988) was chosen to represent the construction process at the project level. Professor E.K. Chung of the Computer Integrated Construction (CIC) Research Project (Chung 1988), Pennsylvania State University, had examined several modelling methodologies and determined that the IDEF-0 methodology was the best suited to modelling construction processes. His research concluded that to model construction processes a model needed to be: 1) hierarchical, 2) modular, 3) standardised in structure and 4) capable of representing the complex processes of the construction industry. Further reasons for choosing this model methodology included: 1) it had been proven successful in the past for planning manufacturing and construction procurement processes, 2) it provides a structured and hierarchical framework suitable for modelling construction processes, 3) it had been used in previous academic literature related to construction (Sanvido & Medeiros 1990, 365-379, Gibson, Kaczmarowski & Lore 1995, 312-318).

Model Development

The model under development has two layers: **Layer 1** (Figure 4) The Draft Overview Model provides an overall graphical representation of the complex inter-relationships (displaying inputs, project development, paths of communication, participant involvement & knowledge acquisition) within the project planning process. It utilises a 'total design' approach (cyclical in nature) to project planning with input at each stage of the design core processes from the elements identified in the product design specification (PDS). Core input information, encompassing acquired 'experience', (an intangible but vital input component) is encapsulated within the framework of the PDS (Figure 3).

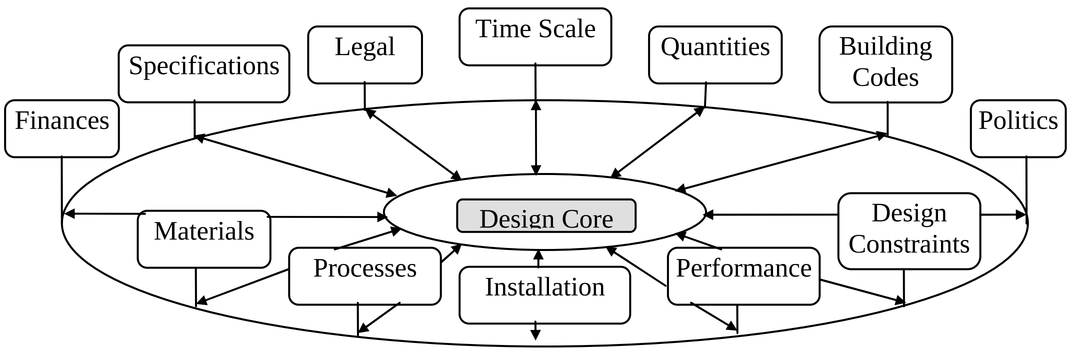

Figure 3. *Simplified Example of Elements of the PDS*

Communication between PDS levels is iterative. Research intends to determine whether it is feasible to enhance such communication through the application of I.T. The model represents the life-cycle of the project planning process up-to and including hand-over to the client. As yet, from the Irish situation, there is limited information regarding industry's participation with the project once the finished structure/product has been transferred to the total control of the client.

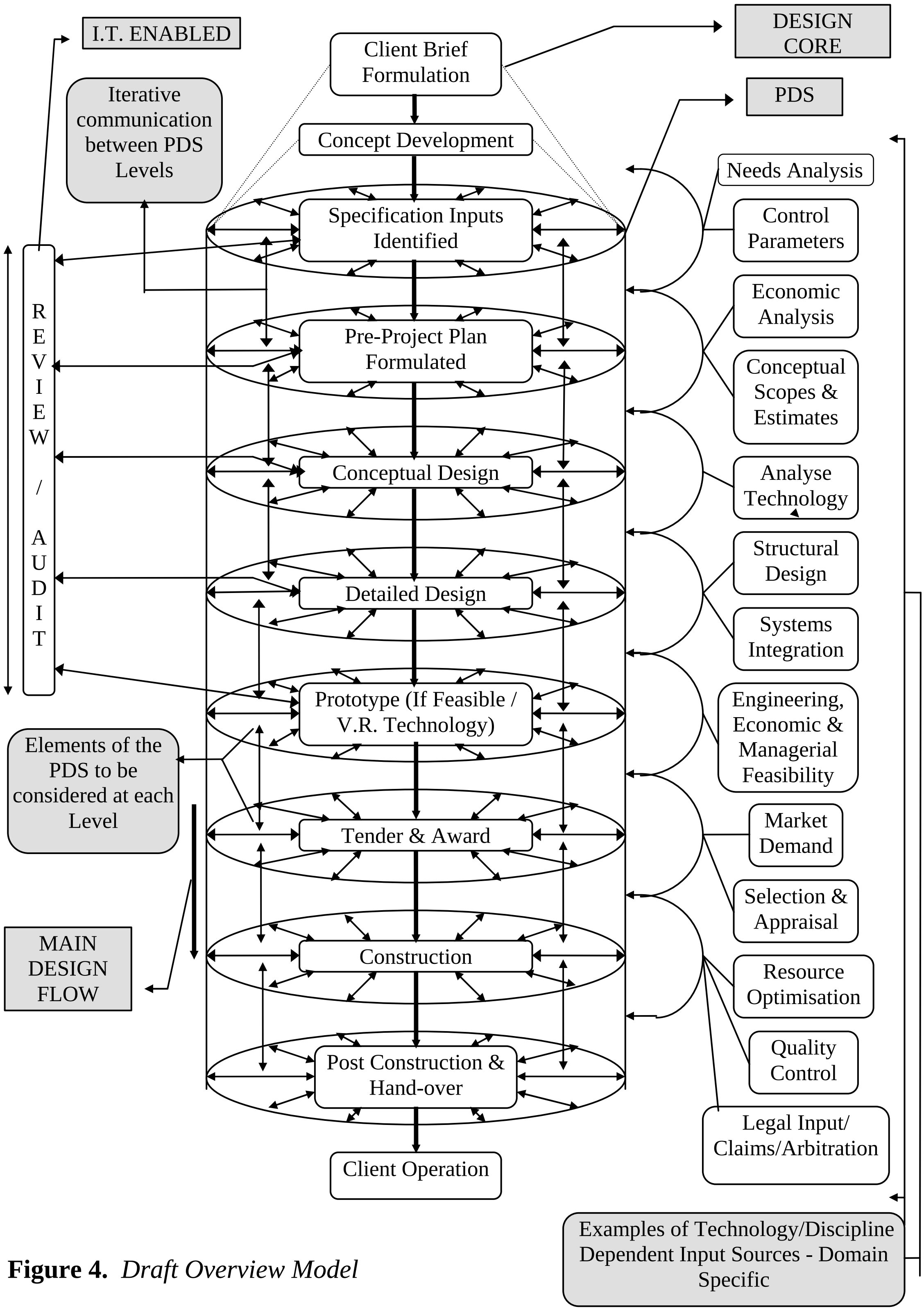

Figure 4. *Draft Overview Model*

Layer 2 (Figure 5) The Draft Process Model is being developed using the IDEF-0 methodology to graphically represent the planning process at the project level. The generic design core phases used in layer 1 of the model are expected to remain unchanged. Each phase consists of hierarchical sub-processes, which will be notated on a sub-level basis to each phase. The model will focus on the functional aspects of the planning process, addressing the information needs of participants involved within it. Industrial collaboration from ISF participants will be used to develop the model. It will be used to identify and overcome 'critical episodes' in the planning process and utilise, if feasible, I.T. to communicate the relevant information, at the required detail, to those parties which need to create/use/monitor/modify and apply it.

For the Draft Process Model, the basic construction of the graphics are detailed in Figure 5. Figure 6 shows the first-level IDEF-0 diagram that expands the context diagram (Figure 5) and describes the individual functions involved in that process which is addressed in the context diagram.

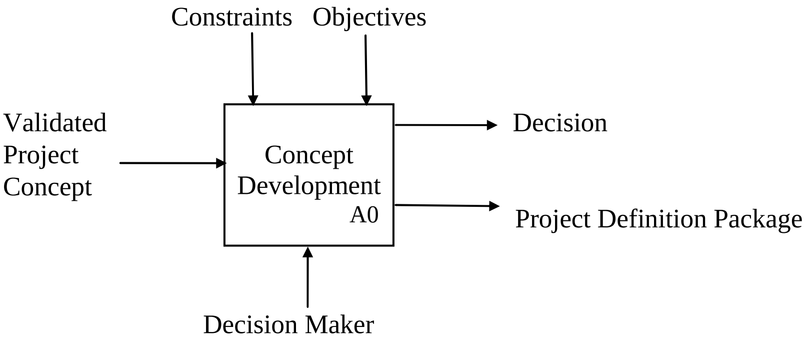

Figure 5. Context IDEF-0 Diagram - Concept Development

Thus Figure 6 shows a first level IDEF-0 diagram which represents the major sub-processes associated with the concept development phase of the project planning process.

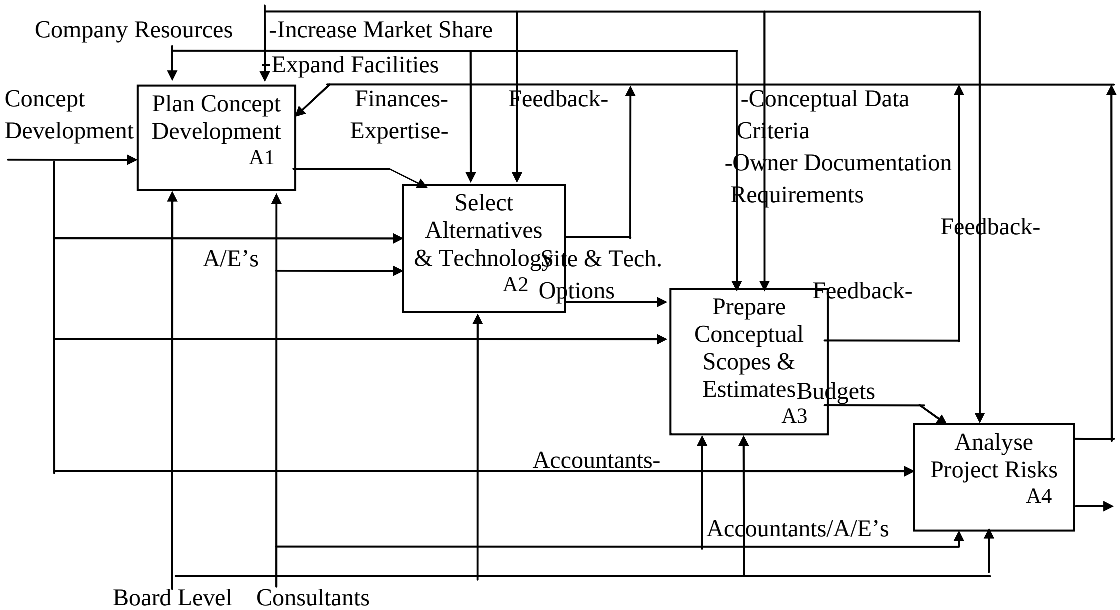

Figure 6. Simplified Example of First Level IDEF-0 Diagram - Concept Development

This first level diagram can be further decomposed to represent in greater detail the individual functions identified. At a later date the research will use these draft diagrams to plan a test program to utilise I.T. to communicate specific information, be it management, project, technical or general, in the required formats and detail, between parties within the project planning process.

SUMMARY AND CONCLUSIONS

This paper has critically examined the construction project planning process and identified need for change within specific areas of that process.

Literature review, case-study analysis, extensive industrial interviews and the ISF initiative identified that many of the problems encountered during the construction phase of a project were actually initiated during the front-end phase of the project planning process. Poor client briefs, pre-project planning and uncoordinated design all contribute to overall poor project performance. Manufacturing product development techniques have proven success in the pre-planning phase of product manufacture.

This paper reviewed the product development process as used in the manufacturing sector to identify potential processes which may be transferable into construction practice and aid the development of a generic construction process protocol. Not all phases of the manufacturing product development process will be transferable and further analysis of manufacturing management techniques is necessary. Also, this paper identified that the complex information-flow-pattern during the project planning process would benefit from better co-ordination through the application of I.T.

Achieving the 30% cost savings implied by Sir Michael Latham (Latham 1994) may be attainable if the incorporation of specific concurrent engineering practices found in the manufacturing sector's product development processes could be applied within the construction project planning process. Thus to achieve such savings and promote improvement within the planning process, an accurate generic model of the actual total construction process is required. Through collaborative action with industry practitioners, under the auspices of the ISF it is intended to develop a generic construction process protocol that will be capable of providing the foundation for real, demonstrable improvements to the project planning process.

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