Design-Management and Planning for Photovoltaic Cladding Systems within the UK Construction Industry.

An Optimal and Systematic Approach to Procurement and Installation of Building Integrated Photovoltaics – An Agenda for the 21st Century.

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Review of IDEF Modelling Technique and Language

8.1 IDEF Background

The Integrated Definition (IDEF) Standards provide technique for functional and information modelling. These techniques are widely accepted in the government and commercial sectors. IDEF0, the standard for function modelling, is widely applied to the analysis of business processes. IDEF1X, the standard for information modelling, is primarily used for logical database design. Work continues on both standards to improve their current functional specification.

IDEF originate back in the 1970's under the US Air Force Program for Integrated Computer Aided Manufacturing (ICAM). Two of the techniques developed for this program were IDEF0, used to produce function models and IDEF1, used to produce information models.

In 1983, the US Air Force Integrated Information Support System program enhanced the IDEF1 information modelling technique to form IDEF1X (IDEF1 Extended), a semantic data modelling technique. Currently these techniques are widely used in both the government and commercial sectors, supporting modelling efforts for a wide range of enterprise and application domains

Integrated Definition for Functional Modelling (IDEF) is a graphical approach to system description. It is based on the Structural Analysis and Design Technique (SADT). The US Airforce Programme for Integrated Computer-Aided Manufacture (ICAM) standardised and made public a subset of SADT, called IDEF.

8.2 Introduction to IDEF Modelling

The desire of the US Airforce to reduce cost and lead times by assisting the aerospace industry in its modernisation efforts is evidenced in is many 'Tech Mod' (Technical

Modernisation) Programs. A similar goal, but using an industry-wide target rather than individual companies, was established under the ICAM (Integrated Computer Aided Manufacture) Program. In ICAM, the goal was to develop 'generic subsystems', which could be used by a large number of companies to provide a significant upgrade to the industry as a whole. These 'subsystems' provide support for common functions such as management of information, shop floor scheduling and materials handing.

During the 1970's, the US Air Force Program for ICAM sought to increase manufacturing -productivity through systematic application of computer technology. The ICAM program identified the need for better analysis and communication techniques for people involved in improving manufacturing productivity

As a result, the ICAM program developed a series of techniques known as the IDEF (ICAM Definition) techniques, which included the following

- IDEF0, used to produce a 'functional model'. A function model is a structured representation of the functions, activities or processes within the modelled system or subject area.
- IDEF1, used to produce an 'information model'. An information model represents the structure and semantics of information within the modelled system or subject area.
- IDEF2, used to produce a 'dynamic model'. A dynamic model represents the time-varying behavioral characteristics of the modelled system or subject area.
- IDEF3, used to produce a 'process model'. A process model helps document and analyse the processes of an existing or proposed system. It provides guidelines and a language for information capture. It helps users capture and organise process information for multiple downstream uses.

In 1983, the US Air Force Integrated Information Support System program enhanced the IDEF1 information modelling-technique to form IDEF1X (IDEF1 extended) technique, a semantic data modelling technique.

In 1991 the National Institute of Standard Technology (NIST) received support from the US Department of Defense, Office of Corporate Information Management, to develop one or more Federal Information Processing Standard (FIPS)

In 1992, at the request of the USA Department of Defense, the NIST agreed to investigate the possibility of issuing one or more Federal Information Processing Standard (FIPS) Publications for modelling techniques. To fairly choose a possible-modelling technique for standardisation, NIST established the following evaluation criteria. This technique needed to be well established and in the public domain. A neutral group had to be identified as controlling the techniques, and training for the techniques must be available from multiple sources.

NIST then published an announcement in the Commerce Business Daily containing a brief explanation of their intention and the list of evaluation criteria. After reviewing various replies to the announcement, the modelling techniques suggested were reviewed for compliance with the published evaluation criteria. As a result of the review, the IDEF0 and IDEF1X modelling techniques were chosen for standardisation. The IDEF User Group was then contracted and agreed to work with NIST in the development of the FIPS.

The original Air Force ICAM documents were chosen as the baseline documents for this effort. For nine months members of the IDEF User Group from both the public and the private sector, along with NIST personnel, worked to transform the ICAM documents into an acceptable form for publication as Federal Information Processing Standards (FIPS). When this work was completed the draft FIPS for IDEF were circulated through the normal FIPS development review channels and many additional comments were received. These additional comments were evaluated and, where appropriate, included in the development of the final FIPS documents.

In August 1993 the draft FIPS for IDEF0 and IDEF1X were forwarded from the Computer System Laboratory at NIST to the Secretary of Commerce for final review and signature. On December 21, 1993, Secretary of Commerce Ronald Brown approved IDEF0 and IDEF1X as Federal Information Processing Standards. IDEF0 was assigned FIPS Publication number 183 and IDEF1X was assigned Publication number 184.

The primary objectives of the IDEF standards are:

1. To provide a means for completely and consistently modelling the function (activities, actions, processes, operations) required by a system or enterprise, and the functional relationship and data (information or objects) that support the integration of those functions, http://nemo.ncsl.nist.gov/standsp/blp.html;
2. To provide a modelling technique, which is independent of Computer-Aided Software Engineering (CASE) methods or tools, but which can be used in conjunction with those methods or tools;
3. To provide a modelling technique that has the following characteristics

- Generic: for analysis of systems of varying purpose, scope and complexity;
- Rigorous and precise: for production of correct and usable model;
- Concise: to facilitate understanding, communication, consensus and validation;
- Conceptual: for representation of functional requirement rather than physical or organisational implementation;
- Flexible: to support several phases of the lifecycle of a project.

8.3 IDEF0 Concept

A model is a representation of a set of components of a system or subject area. The model is developed for understanding, analysis, improvement or replacement of the system. Systems are composed of interfacing or interdependent parts that work together to perform a useful function. System parts can be any combination of things, including people, information, software, processes, equipment, products, or raw materials. The model describes what a system does, what controls it, what thing it works on, what means it uses to perform its functions, and what it produces.

IDEF0 is an engineering technique for performing and managing need analysis, benefits analysis, requirement definition, functional analysis, system design, maintenance and baseline for continuous improvement. IDEF0 models provide a "blueprint" of functions and their interfaces that must be captured and understood in order to make systems engineering decision that are logical, affordable, integratable and achievable. The IDEF0 model reflects how system functions interrelate and operate just as the blueprint of a product reflect different piece of a product fit together. When used in a systematic way, IDEF0 provides a system engineering approach to:

- Performing system analysis and design at all levels, for system composed of people, machines, materials, computers and information of all varieties- the entire enterprise, a system, or a subject area;
- Producing reference documentation concurrent with development to serve as a basis for integrating new system or improving existing systems;
- Communicating among analysts, designers, users, and managers
- Allowing coalition team consensus to be achieved by shared understanding;
- Managing large and complex projects using qualitative measures of progress;
- Providing reference architecture for enterprise analysis, information engineering and resource management.

8.4 IDEF0 Models

This section of this chapter discusses the basic elements of the IDEF0 modelling technique, identifies the basic components of syntax (graphical component) and semantics (meaning), specifies the rules that govern the use of the IDEF0 technique and describes the types of diagrams used. Although the components of syntax and semantics are very highly interrelated, each one is discussed separately without regard for the actual sequence of construction.

8.4.1 Use of IDEF0 Model

IDEF0 was created as a high-level method for analysing complex systems. This technique is used in the early stages of problem definition. It was originally developed as a means of depicting manufacturing processes. To day its applicability has extended beyond manufacturing and it is being widely used in the analysis of business processes, Stuart (1995).

One key benefit of the IDEF0 technique is that it provides a mechanism for communicating complex concepts. It provides a simple syntax of boxes and arrows allowing users to use their time more productively. Time can be dedicated to analysing the system and not on learning the technique.

8.4.2 IDEF0 Graphical Construction

IDEF0 is a graphical language, which defines functions and their interfaces within the context of a system. Each IDEF0 model is composed of a series of hierarchical diagrams that display increased level of detail. A diagram captures the functions and functional interfaces of the system at a particular level of detail. Each diagram of the model contains boxes and arrows. The boxes depict the system functions and the arrows represent data or objects related to those functions, figure 7.1.

Each side of a function box has a standard meaning in terms of the relationship between the box and arrow. An arrow may be input, control, output, or mechanism. Arrows connected to the left side of a function box are input. Input arrows are transformed by the function into outputs, which exit the right side of the function box. Control arrows enter the top of the box. These arrows specify the condition required for the function to produce correct outputs, figure 8.1.

Mechanism arrows are connected to the bottom of a box. A mechanism arrow may be depicted as an upward or downward pointing arrow. An upward pointing arrow identifies the means by which a function transforms the input into output. A downward pointing arrow or call arrow is used for inter-model connecting. A call arrow indicates that the decomposition at the present level of abstraction is complete by further details can be found within lower level models. A call arrow is a pointer to those lower level models or sub-models.

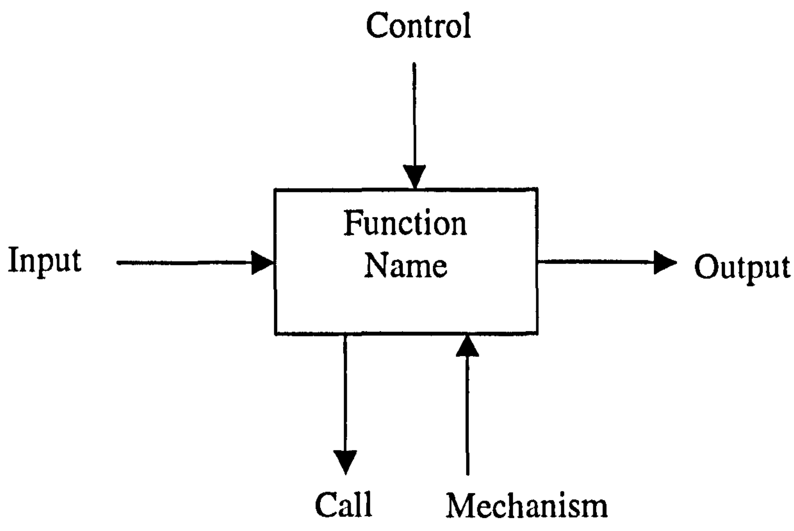

Figure 8.1: ICOM Arrows

8.4.3 IDEF0 Decomposition of Functions

An IDEF0 model consists of a series of diagrams organised in a hierarchical manner. The topmost diagram of a model is referred to as the A-0 Context diagram. This diagram contains only one function box with two brief statements providing the models purpose and viewpoint. The purpose describes why the model is being created. The viewpoint provides the perspective the author is using to construct the model.

The function defined on the A-0 diagram is decomposed into its major sub-functions. This breakdown diagram is referred to as the A0 diagram. Any function defined on the A0 diagram can then be further decomposed thus creating additional diagrams. This decomposition will continue until the author of the model reaches the desired level of detail. When a function is decomposed into its major sub-functions, the diagram defining the detail is referred to as the child diagram for that function. All created child diagrams must contain at least 3 and no more than 6 sub-functions. The diagram that contains the functions that was decomposed is referred to as the parent diagram.

8.4.4 Linking IDEF0 Function to Diagrams

IDEF provides a reference notation for tracking decomposed functions to particular diagrams. A box number and node number identifies functions on a diagram. Node numbers are normally formed by appending the box number to the node number of the diagram on which that box appears. The child diagram contains the decomposition of a parent box. For example, figure 8.2, an IDEF0 diagram with node number A23 contains 4 function boxes. Box 4 on this diagram has the node number of A234, if box 4 is decomposed. The diagram node number for the child diagram is also A234.

This notation provides the basis for presenting the decomposition of a model I a node tree structure. The node tree is a useful means for understanding the breadth and depth of information represented in a model.

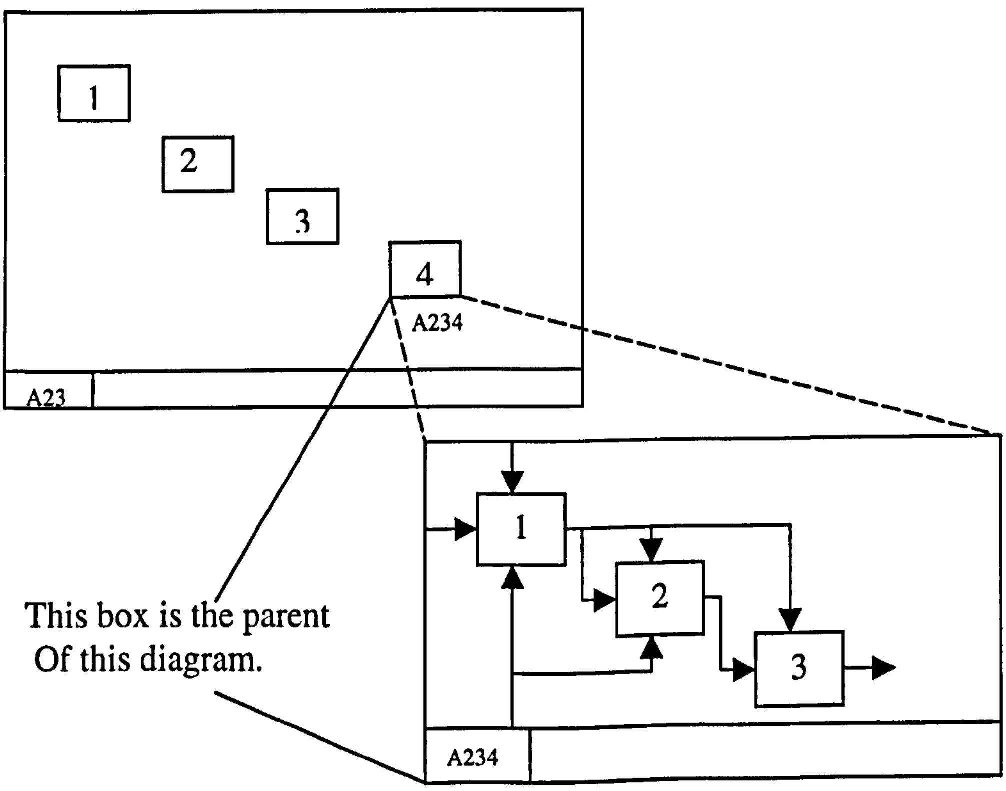

Figure 8.2: Decomposition of an Activity box into a Child diagram

8.4.5 Arrow Bundling and Decomposition

The arrow on a diagram represents the input, controls, output and mechanism (ICOMs) interfacing with a function. Arrows can be viewed as conduits containing other arrows. An arrow segment bundled with other arrow segments can break out revealing more detail where appropriate. In IDEF0 this is referred to as forking. In addition, arrow segments may also be grouped together (joined) to create a more general category. This allows the modeler to capture the appropriate level of abstraction.

8.4.6 Linking Arrow Across Diagrams

Arrows segments may also play multiple roles within a model. For example, an output arrow of one function may serve as an input arrow to another function. It becomes difficult to track arrows as they change roles across diagrams. IDEF does provide a notation for tracking arrows used on different diagrams within a model. This is accomplished by using ICOM codes.

As a function is decomposed, arrow segments may carry down to the child diagram. The arrows associated with the decomposed function may be assigned an ICOM code depending on the particular role the arrow plays. For example, figure 8.3, if one input arrow, two control arrows, and one output arrow are to be carried down to the child diagram then these arrow segments would be assigned the code I1, C1, C2 and O1.

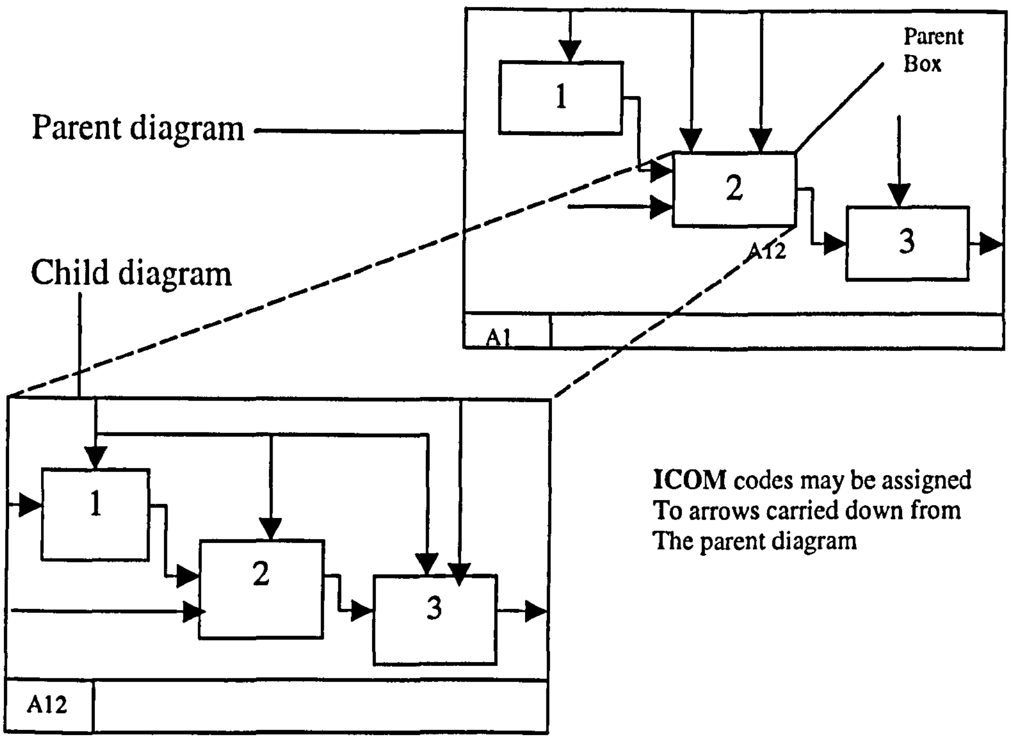

Figure 8.3: ICOM code assigned to arrows carried down from parent diagram.

8.5 Summary Box and Arrow Semantic Rules

IDEF0 supports function modelling, other specifications are as follows, Laamane (1994):

1. A box shall be named with an active verb or verb phase
2. Each side of a function box shall have a standard box/arrow relationship:
    - Input arrows shall interface with the left side of a box.
    - Control arrows shall interface with the top side of a box
    - Mechanism arrows (except call arrows) shall point upward and shall connect to the bottom side of the box.

3. Arrow segments, except for call arrows, shall be labeled with a noun or noun phrase unless a single arrow label clearly applies to the arrow as a whole.
4. A "squiggle" shall be used to link an arrow with its associated label, unless the arrow/label relationship is obvious.

5. Arrow labels shall not consist solely of any of the following terms: function, input, control, output, mechanism, or call.

8.6 Child Diagram

The single function represented on the top-level context diagram may be decomposed into it's major sub-functions by creating its child diagram. In turn, each of these sub-functions may be decomposed, each creating another, lower-level child diagram. On a given diagram, some of the functions, none of the functions or all of the functions may be decomposed. Each child diagram contains the child boxes and arrows that provide additional detail about the parent box, figure 8.4.

8.7 Parent Diagram

A parent diagram is one that contains one or more parent boxes. Every ordinary (non-context) diagram is also a child diagram, since by definition it details a parent box. Thus a diagram may be both a parent diagram (containing parent boxes) and a child diagram (detailing its own parent box). Likewise, a box may be both a parent box (detailing its own child diagram) and a child box (appearing on a child diagram). The primary hierarchical relationship is between a parent box and the child diagram that detail it, figure 8.4.

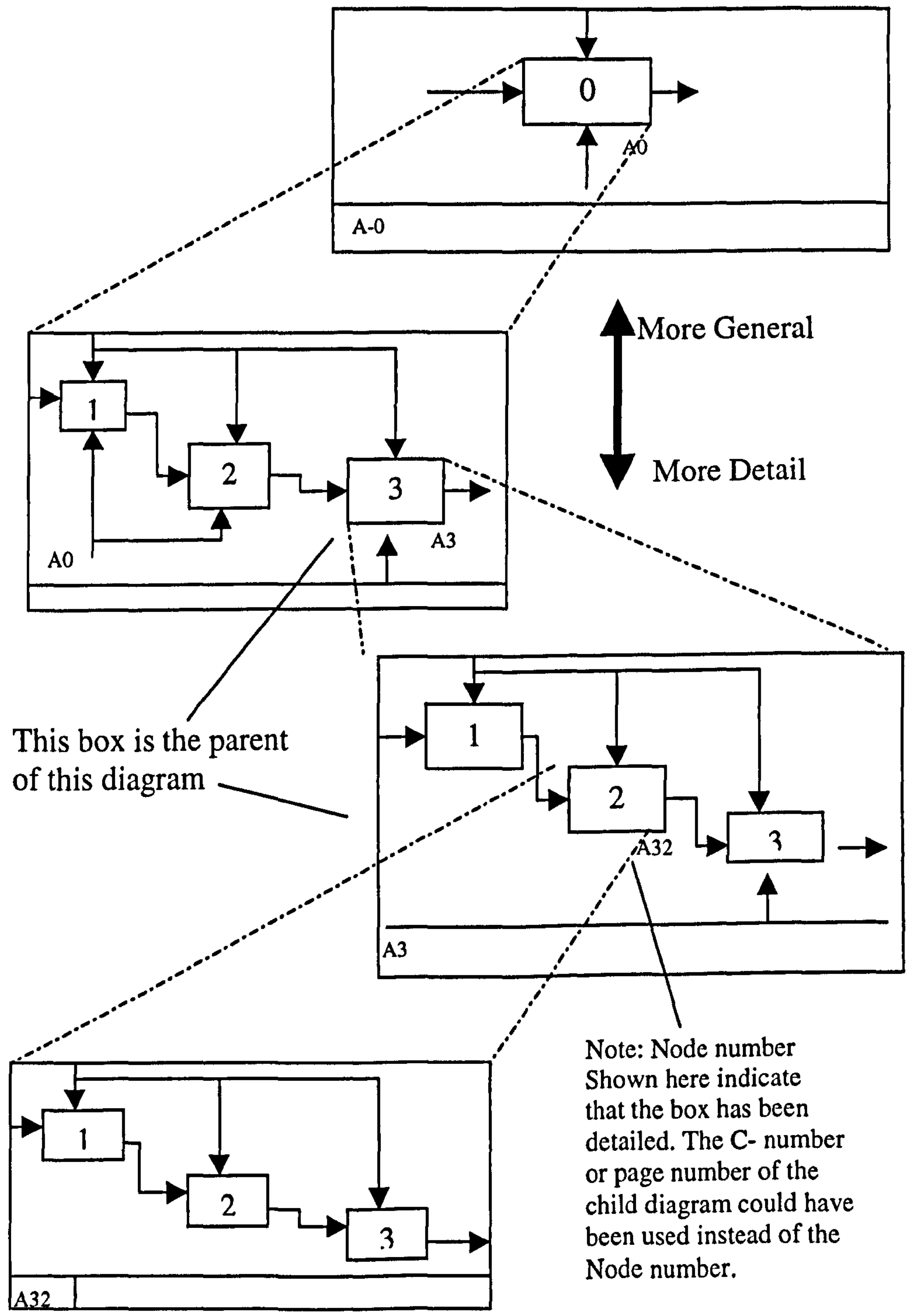

Figure 8.4: Decomposition Structure.

8.8 For Exposition Only Diagrams

For Exposition Only (FEO, pronounced fee-oh) diagrams shall be used where additional level of supplementary knowledge is required to adequately understand specific areas of a model. Supplementary detailing should be limited to what is needed to achieve the stated purpose for a knowledgeable audience. A FEO diagram need not comply with IDEF syntax rules.

8.9 Some Outstanding Issues of IDEF0

Even though a tremendous effort was put forth to publish IDEF0 as a standard, work is still ongoing concerning this standard. Issues still need to be resolved in order to completely and unambiguously specify this technique. For example, it is still unclear as to the proper interpretation of a fork arrow.

Another issue currently opened for discussion is the limitation on the number of boxes permissible on a child diagram. The standard states that no more than six boxes are allowed. Practitioners are divided on the importance of this rule. Some feel that it is critical to the meaning of IDEF0. In order for this language to handle complex issues, systems must be broken down into manageable components. Others feel that this rule is too limiting. They feel that now, with automated tools and the power to isolate and highlight, that rule no longer applies. The complexity of a system can still be represented and communicated with more than six boxes.

A formal language specification is being developed for IDEF0. This work is critical in assisting in the identification of ambiguities, which must be resolved in order to strengthen the IDEF0 technique. It will also provide a solid foundation for possible extension to the current specification.

8.10 IDEF3

IDEF3 is designed to assist those engaged in capturing and analysing the vital processes of an existing or proposed system. Guidelines and simple-to-use graphical language structure to aid users in successfully capturing and organising process information for multiple downstream uses. IDEF3's unique design includes the ability to capture and structure descriptions of how a system works from multiple viewpoints, thereby enabling users to capture information conveyed by knowledgeable experts about the Behaviour of a system rather than directing user activity toward constructing engineering models to approximate system Behaviour. This feature is among the central characteristics distinguishing IDEF3 from alternative offerings. As an integral member of the IDEF family of methods, IDEF3 works well in independent applications or in concert with other IDEF methods to identify and develop the vital process of a business, http://www.idef.com/complete_reports/idef3/IDEF3_TOC.html

The notion of a scenario or story is used as the basic organising structure for IDEF3 Process Descriptions. A scenario can be though of as a recurring situation, a set of situations that describe a typical class of problems addressed by an organisation or system, or the setting within which a process occurs. Scenarios establish the focus and boundary to describe what they know in terms of an ordered sequence of activities within the context of a given scenario or situation. Scenarios also provide a convenient vehicle to organise collections of process-centered knowledge, http://www.dtic.mil/c3i/bpred/0050/index.htm

The primary role of a scenario is to bind the context of an IDEF3 Process Description. It is important to name the process description appropriately. Scenario names often take the form of an imperative – verb or verb phrase or indeed a verb that functions like a noun. A well-chosen scenario name will ensure that the users of the description make the appropriate association with the real-world situation being described. Correctly identifying, characterising, and naming scenarios is a necessary step to creating process-centered IDEF3 Process Descriptions.

This section of this chapter briefly introduces the description representation concepts and syntax available in the two types of IDEF3 schematics.

IDEF3 Process Schematics are the primary means for capturing, managing, and displaying process-centered knowledge. These schematics provide a graphical medium that helps domain experts and analysts from different application area communicate knowledge about processes. This includes knowledge about events and activities, the objects that participate in those occurrences, and the constraining relations that govern the behaviour of an occurrence.

A process-centered description is constructed systematically, using the basic building blocks of the IDEF3 schematic language, linked together in different ways. These building blocks have specific semantics associated with them. They are used to represent certain kinds of activities or relations in the real world. A detailed specification of these blocks is discussed later.

8.11 IDEF3 Process Centered View

In IDEF3, boxes represent types of happenings. Such happenings are referred to by the neutral term 'Units of Behaviour' (UOB). Each UOB box represents a real – world process. The information recorded about a UOB includes:

- A name (often verb-based) that indicates what the UOB represents
- The names of the objects that participate in the process and their properties;
- The relation that hold between the objects.

The arrows (called links) connecting the boxes in figure8.5 indicates the precedence relationships (or more generally constrains) that hold between the processes being described. Thus, an instance of the UOB at the source of a link would complete before an instance of the UOB at the end of the same link starts.

In figure 8.5, the UOB labeled 'D' would complete before the start of the UOB labeled 'E'. The small box containing the "X" denotes a 'Junction'. A junction is a point in the process where a process splits into multiple paths, or where multiple paths merge. Junctions represent constraints (or the effects of constraints) of the 'activation logic' for the process. The first junction in the figure below indicate that only one path will be taken in an activation of the described process

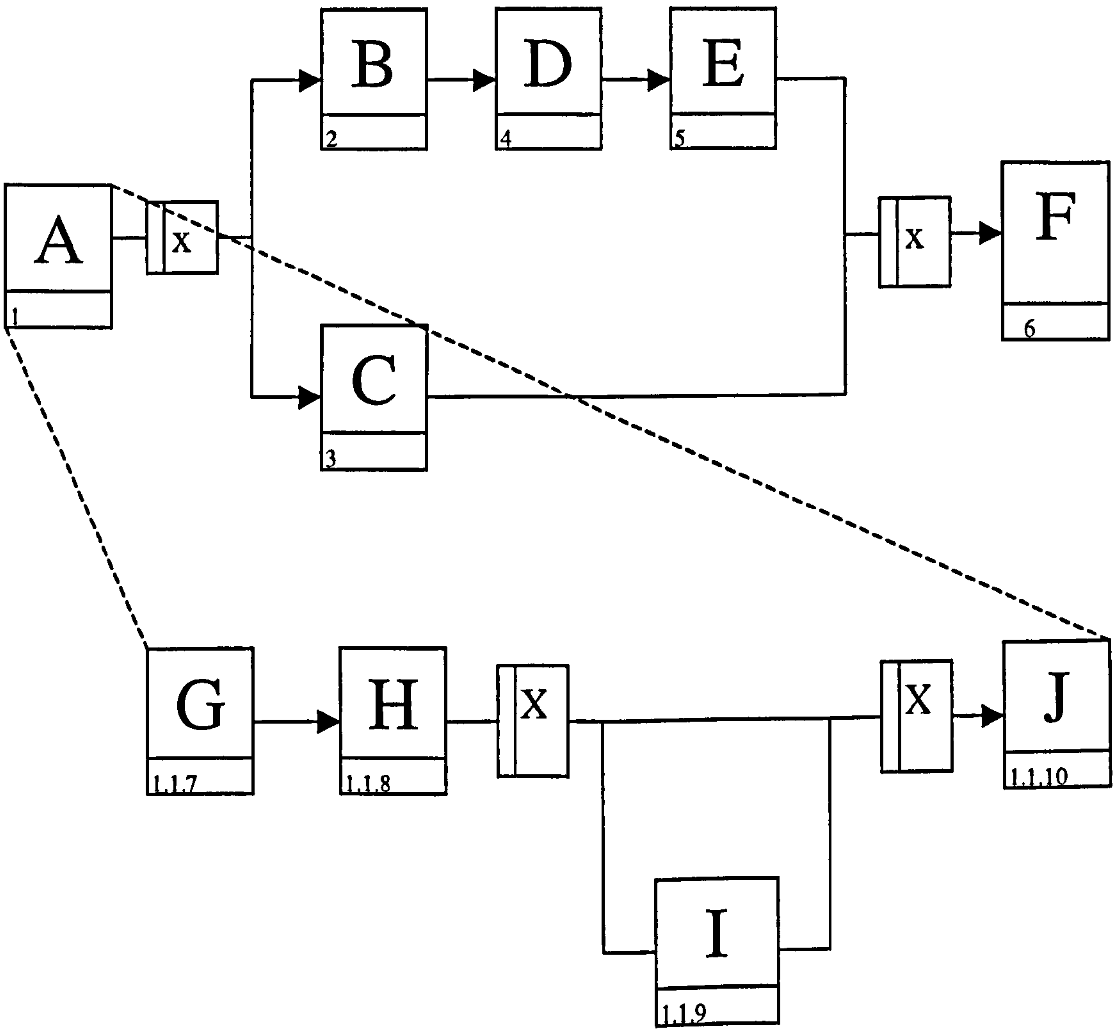

Figure 8.5 IDEF3 Process Schematics

The IDEF3 method allows users to capture descriptions all varying levels of abstraction by providing a mechanism called 'decomposition'. Decomposition provides a means of organising a more detailed description of a UOB. The decomposition schematic follows the same syntactic rules as those for a scenario and is created using the same IDEF3 elements. A UOB can have any number of different decompositions, all on the same level. The use of more than one decomposition for the same UOB is for the purpose of representing different points of view or providing greater details of the processing relating to the UOB.

The UOB labeled ‘A’ in figure 8.5 has been decomposed into UOBs 7 through 10. The number in the lower-left corner of UOB box 7 through 10 include a reference to UOB 1 (the first digit) and the decomposition (decomposition 1 of UOB 1). This is illustrative of the IDEF3 numbering scheme, which allows explicit traceability between levels of detail in the description.

The Process Schematic in Figure 8.5 represents a ‘process-centered view’. This view focuses on assertions about the processes that occur and their ordering. Sometime it is convenient to organise the description of a situation from an ‘object-centered view’ (where a participating object or set of objects is the focus of attention).

8.11.1 IDEF3 Object Centered

IDEF3 Object Schematic captures, manages, and displays object-centered description of a process. Information about how objects of various kinds are transformed into other kinds of things through a process, how objects of a given kind change state through a process, or context-setting information about important relations among objects in a process.
An object is any physical or conceptual thing that is recognised and referred to by participants in the domain. It also has to be recognised as a part of their description of what happens in their domain. Correctly identifying, characterising, and naming objects is a necessary step in the creation of object-centered IDEF3 Process Description. Object names are often nouns or noun phrases that may not be coupled with a state descriptor.
Object Schematics may be developed in the context of a single scenario, thus characterising the state transitions traversed by participating objects in an occurrence of

the scenario. These schematics, called Transition Schematics, allow users to specify the rules that govern the transitions between object states in a scenario occurrence. Alternatively, Object Schematics may evolve in a more opportunistic fashion, capturing descriptions of objects, object states, and their transitions across multiple scenarios. Object Schematics developed in this fashion make no attempt to define the structure for object state change behaviour in a scenario occurrence. This cross-scenario Object Schematic development approach is often useful when exploring what object-centered process information merits a more detailed focus or when attempting to discover context-setting information about the object encountered in a description. Object Schematics may be distinguished from the more specialised Transition Schematic (and Enhanced Transition Schematics) by the absence of a context-setting scenario. Generally speaking, IDEF3 Object Schematic is developed to provide an object-centered description of a particular process or scenario. Transition Schematics therefore tend to dominate the attention of those developing IDEF3 Object Schematics, Mayer et al (1995)

The schematic in Figure 8.6 below represent an Object Schematic a scenario derived from a business owner's description. This example illustrates a Transition Schematic since it characterises the nature and structure of the object state transition for occurrences of the "Order Material 'A'" scenario.

A key document in this process is the Purchase Request (PR) form. This form is eventually transformed into a Purchase Order (PO) via 'Order Material -A' process. A circle containing the name of an object represents an object of a certain kind. These labeled circles are known as kind symbols. A certain kind of object being in a certain state is represented by a circle with a label that captures both the kind itself and a corresponding state, thereby representing the type (or class) of objects that are in that state (within a given process).

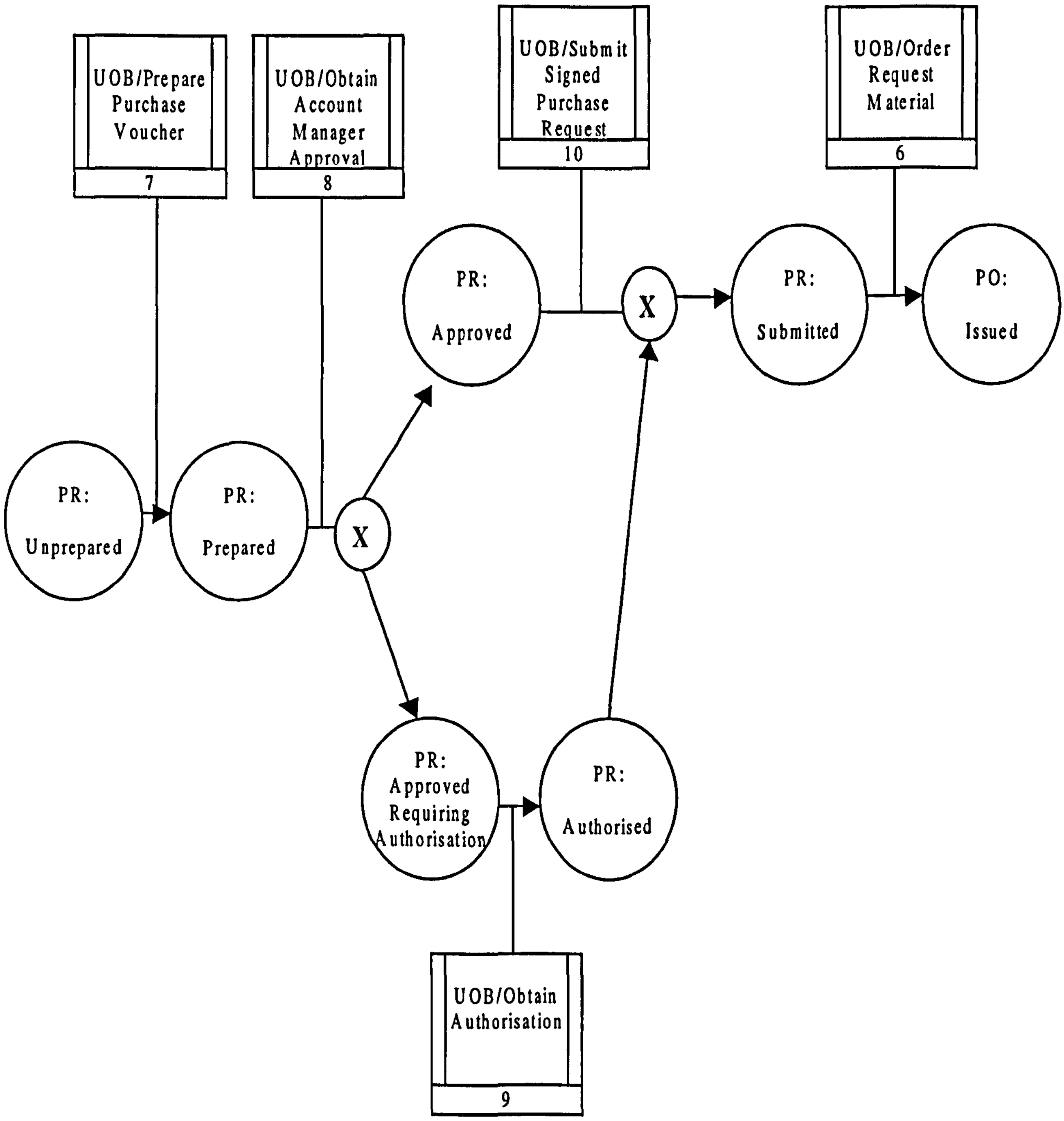

Figure 8.6: IDEF3 Object-Oriented Transition Schematic

An approved Purchase Request (PR) would be indicated by the label, 'PR: approved' an Authorised PR by 'PR: Authorised' e.t.c. Though a real-world object often evolves through a continuum of states, an Object Schematic focuses on those distinguished states of particular interest to the domain expert. The transition arcs (arrows with triangular filled –in heads) connecting the circles symbolise a 'state transition'-the activity of changing from one state to another. The condition that establish when an object is in a given state, how it exists a state, how it can transition between states, and how it can enter a new state are recorded on a special form. The banded boxes linked to the arrows (called referents) are aids to describe the relationships between object states, and UOBs, scenarios, or other Transition Schematic that participate in a scenario occurrence. In Figure 8.6, during the transition of the object 'PR' from its state of having been prepared for review by Account Manager (PR: prepared) to an approved state (i.e., PR: approved or PR: approved requiring authorisation), the process represented by the UOB 'Obtain Account Manager approval' must initiate and complete. The transition junction containing an "X" (for exclusive) indicates the choice of exactly one path among several possible paths in an occurrence.

Figure 8.6, indicates that Purchase Request transition from an 'unprepared' to a 'prepared' state and from a 'prepared' state to either an 'approved' state or an 'approved requiring authorisation' state. If the Purchase Request requires authorisation, it will transition to an 'authorised' state before transitioning to a 'submitted' state. Otherwise, it will transition directly to the 'submitted' state. After the Purchase Request reaches the 'submitted' state, the objects will transition to an 'issue' Purchase Order. Attaching appropriately labeled referents to the Object Schematic indicates UOBs scenarios and other Transition Schematics that participate in a transition between states. The relative positioning of referents on the Transition Schematic indicates the order in which they occur. The position of the UOB 'Prepare Purchase Request' in figure 8.6 indicates that it initiates and completes before all other UOBs referenced by the schematic in an occurrence of the scenario.

It is interesting to note that among the possible state transitions represented, none reflect a failed request. This is simply because the original dialog contained no information about such situations. This is a key point in the use of IDEF3. IDEF3 is intended as a mechanism for structuring the assertions made by the domain expert. It does not force the completion of partial information with 'modelling' assumptions. The schematic in figure

8.6 may be embellished to include additional context-setting information –hence an enhanced Transition Schematic.

8.12 Basic Elements of IDEF3 Process Description

IDEF3's realistic approach to process modelling has made it a popular method for modelling "what if?" scenarios prior to discrete-event simulation. A high-level process is composed of several tasks made up of individual activities. IDEF3 recognises this multilevel approach to process modelling through "decomposition". This means that high-level processes can be decomposed into their constituent activities to demonstrate the real-world complexity of a seemingly simple process.

IDEF3's multifaceted approach encourages the modelling of multiple perspectives. For instance, the "request material process". From the manager's perspective, the process may seem simpler than it is. However, buyers or clerks who must order the material may not understand how their activities fit into the process as a whole. IDEF3 captures and reconciles both perspectives to achieve the truest possible representation of how the actually works.

It also accounts for random behaviour and its effect son a process and associated costs. If a company needs an order quickly, and it orders directly from a supplier without bidding the order, it likely will impact cost. A simulation model based on IDEF3 can account for this randomness. Also, simulations based on IDEF3 process model can rapidly determine the effect of shared resources on process costs. If one employee is required to perform two concurrent activities, simulation can determine the best way for that employee to accomplish both tasks.

IDEF3 can also model from an object-centered perspective through object state transition network (OSTN) descriptions-as discussed earlier. Similar to the resources captured in IDEF0, which enable an activity, objects associated with a process are captured in IDEF3. For a request for material process, the object may be the material request (paper form) that proceeds through stages before becoming a purchase order. Certain tasks, such as obtaining signatures, may have to be performed.

By modelling from the perspective of the object – in this case, the material request/purchase order-managers can determine not only what form the material request takes throughout the process, but also the resources required to change the request to an order. With this knowledge, discrete-event simulation and activity-based costing techniques can help managers get a handle on the expenses associated with the request at each stage in its development.

Together, IDEF3's process-and- object-centered perspectives provide a complementary modelling and analysis environment. IDEF3 takes the knowledge capture in IDEF0, supplements it with owner's real world knowledge of how a process works, and produces accurate, robust process scenarios, which feed directly into simulation environments, http://www.idef.com/articles/inside-the-process/Inside-the-process.html

IDEF3 modelling techniques accomplishes the following:

- Objectively models how processes work;
- Captures timing and decision logic of processes;
- Provides realistic models for simulation;
- Manages complex models through multiple levels of abstraction; and
- Models from both a process- and an object-centered perspective.

8.13 Summary on IDEF Methodology.

Software based on the IDEF methods can speed up the enterprise engineering process. It worth while mentioning that not all activity and process modelling software available support IDEF methods.

Activity-modelling software can graphically present activities, their relationships to one another, and the object associated with each. Reworking how activities relate to one another is as easy as drag-and-drop with some packages. Activity-based costing information can be assigned to activities and their objects with such software.

Some process modelling software generates code to run discrete-event simulation software. By running "what if" discrete-event simulations, a management team can see how the redesign will impact the company prior to implementation. Working in the background, the best IDEF-based software minimises the amount of IDEF expertise end users must have to successfully use the software while providing a structured, logical and comprehensive environment for modelling and analysis.

" Just as CAD tools have improved the speed and quality of hardware design and manufacture, these computer-aided enterprise engineering tools will enable the quick and precise design, testing, and implementation of business process changes". According to Frank Boydstun, program manager on a number of process improvements projects for the U.S. Air Force. ' IDEF-based model make it possible to flex the entire enterprise to find the best solution to a particular problem', Manufacturing Systems: Information Technology for Manufacturing Manager (March 1997), pp. 70-75.

Systems Architect, a software-modelling environment, supports IDEF methods- has been used in this study to carry out all modelling exercises. Function determination and optimisation was be carried out using IDEF0 whilst IDEF3 takes the knowledge captured in IDEF0, supplements it with PV cladding systems design and installation processes – real world knowledge of how the process works. It is hoped this will produce accurate and robust process scenario, which will feed directly into "what-if and to-be" simulation scenarios.
IDEF methodology has been used in this research to capture the functional activities and processes as obtained within the UK construction industry, conventional cladding sector and BIPV cladding sector. This is hoped, would provide a framework for the optimal re-engineering of the design-management and installation planning of BIPV systems.

Overview of UK Design-Management Practices

9.1 Introduction to Pilot Study

A pilot study was carried out, followed by more detailed case studies. The main study in this section was conducted following an intensive literature review. The pilot studies commenced by sending a out a questionnaire in September 1997 to 100 UK consultants and contractors selected at random from a Chartered Institute of Building (CIOB) and Royal Institute of British Architects (RIBA) Directory of Practices (1997). Letters were subsequently sent to those companies who responded to the questionnaire and were prepared to assist with the survey (46%). This was followed by a number of interviews; formal discussions and project analysis, which included site visits. The pilot survey was undertaken so as to achieve the following objectives:

- Assessment of the current practices in designs, estimating, planning and installation of conventional as well as Building Integrated Photovoltic (BIPV) cladding systems.
- To understand the different ways the participants function and how information is generated. The assessment will also give indication of the processes, the important disciplines involved, and unveiling the overlapping areas in design, specification estimating, planning and installation activities. This, is believed, will help eliminate duplication of functions, rework, and other wasteful activities within existing processes. Re-engineering in this domain would eliminate this arbitrariness, and provide a framework for information sharing in this domain.
- To enable the professionals in the various companies involved in the studies to assist in effecting changes to the flaws in existing processes and then assessing the effect the improved or redefined process will have on the various organisational operations. Other purposes are to enable these companies to assist in the validation of the system framework designed and assessing the performance of the redefined or improved process in design, planning and installation BIPV cladding systems.

9.1.1 The Case Studies

The case studies were conducted with companies involved with complex conventional/ advanced cladding system and (or) Building Integrated Photovoltaic cladding systems, design, planning and installation. Details of the case studies may be found in the appendix A, B and C.

A total of 12 projects, 25 consultants and contractors, took part in the studies. Eight of them involved the installation of complex or advanced conventional cladding systems, whilst the other four involved installation of BIPV cladding systems within the UK. Details of some of these projects can be found in the case studies in Appendix B and C.

9.2 Design, Planning and Installation of BIPV within Convention Building Projects

More often than not, Building Integrated Photovoltaic Cladding Procurement and Installation is a sub-function/ process of a building construction project/ process. As a result this section reviews the design, planning and installation of photovoltaic cladding system as an integral part of a typical building construction exercise.

Literature review indicates inconsistent processes and sub-processes within the UK construction industry as a whole. (Thompson (1997), Tah (1997), Franks (1998)). Flaws and rigid functional barriers are driving the industry through radical changes, with the prime objective to enhance information sharing and exchange, Frucher (1996), Thompson (1998). In the effort to effect such changes in the design-management and installation processes, an analysis of the process in this domain is undertaken. This is the first part of the process re-engineering approach for both the 'initial analysis' and developing 'innovative changes' to the process. The first phase of this approach focused on the critical analysis of the existing design, planning procurement, and installation activities. This is aimed at revealing the flaws and arbitrariness in existing processes.

The basic technique used to carryout the analysis is the modelling approach, and the basis for the selection of a modelling technique is discussed in chapter 8. Based on the modelling requirements, the problem characteristics and the various applications of the modelling methodology discussed in chapter 8. IDEF0 models were used as the technique to illustrate the processes. This included the analysis of the functions, information flow, as well as the implementing mechanisms in the design right up to the installation activities. The notation for the IDEF0 model is shown in figure 9.0. Details of IDEF0 syntax and semantics are discussed in detail in chapter 8.

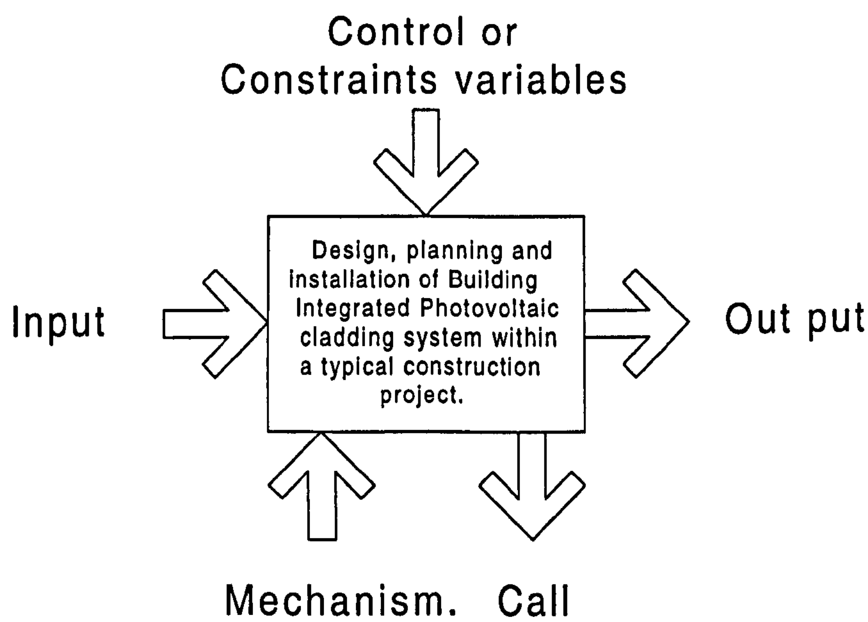

Figure 9.0: IDEF0 Contextual Notion for High Level Functional Model (A-0)

The two primary model components shown in the diagram are:

- The functions in the design and installation of BIPV system, within a wider construction project, are represented by boxes, which may contain names and alphanumeric digits.
- Arrows represent the data and object that interact with these functions.

The classes of arrows entering the boxes on the left are transformed by the function into output. These arrows are referred to as *inputs*. The class of arrows leaving the boxes, associated with the right side, represents *outputs*. The *Control Arrows* are the class of arrows that express the IDEF0 control or constraints. They also represent the conditions required to produce the correct output. These arrows are associated with the topside of the IDEF0 box. The Mechanism arrows are the class of arrows that express IDEF0 Mechanism. They are associated with the bottom of the IDEF0 box and represent the means used to perform the function. A type of mechanism arrow that enables the sharing of detailed information between models is indicated in figure 9.0-as Call Arrow. In IDEF modelling, the overall function can be summarised by a parent IDEF0 model, which illustrates the primary functional activities, the inputs, outputs, control variables, as well as the mechanism. An example is shown in figure 9.2, illustrates the top level IDEF0 model and shows the functions and basic variable of existing-design, planning, construction and management processes.

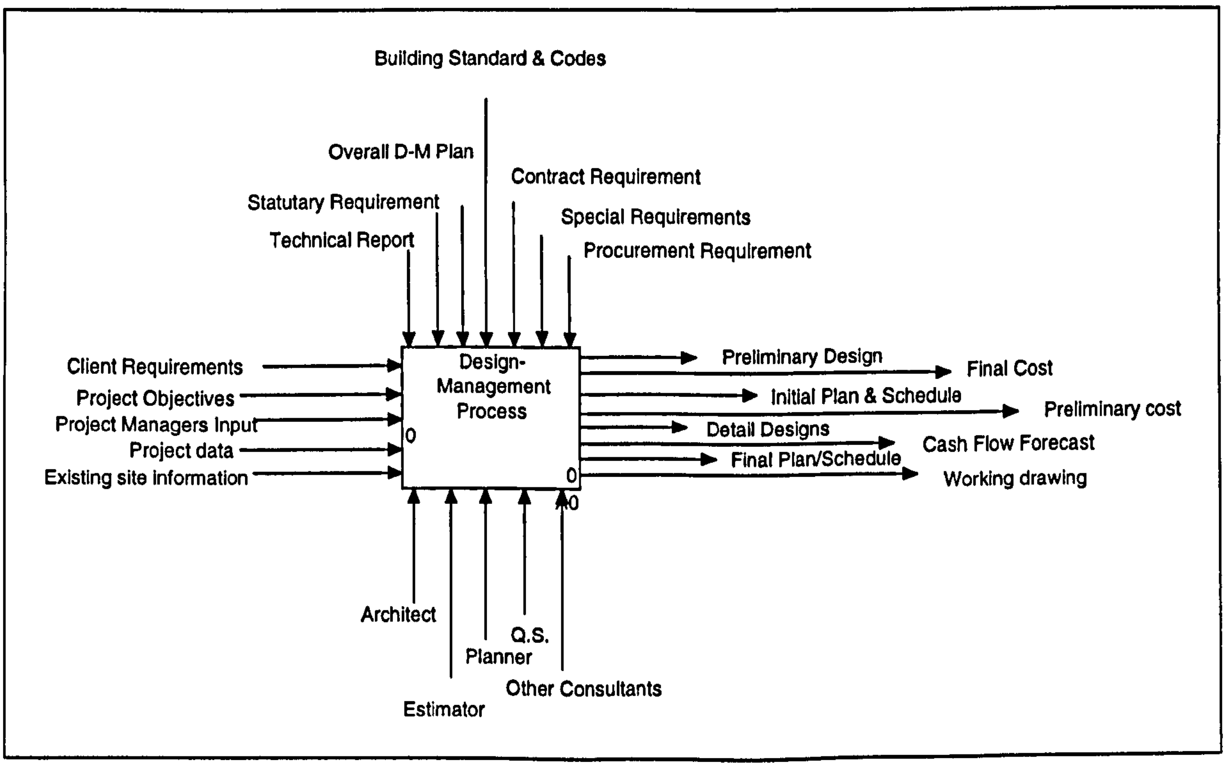

Figure 9.1 an IDEF0 Parent Model of the Design-Management Planning and Construction process (A-0).

The IDEF0 model shown in figure 9.1 provides a 'blue print' of functions and their interfaces, as well as the decision making mechanism of the architect, engineers, planner and estimator in the design-management process. As part of the main characteristics of the IDEF0 modelling technique, the functional model in figure 9.1 can be decomposed to provide a more detailed activity application model. This illustrates the main stages in the design-management process of large or complex projects. The design planning and installation of cladding systems is a sub-function of the above holistic process.

Using the IDEF0 modelling facilities, the main stages in design-management can be grouped as follows:

- The design phase
- The planning/ scheduling phase
- The cost estimating phase
- The construction/ installation/ site operation phase

9.2.1 Overview of the Building Design Phase

The function at this stage varies with the type of procurement method being used for the project delivery. However, the sequence of activities in design-management carried out in this work follows the general practice of the UK construction industry. The functions take account both architectural and structural requirements of projects that involve the installation of large or complex cladding systems.

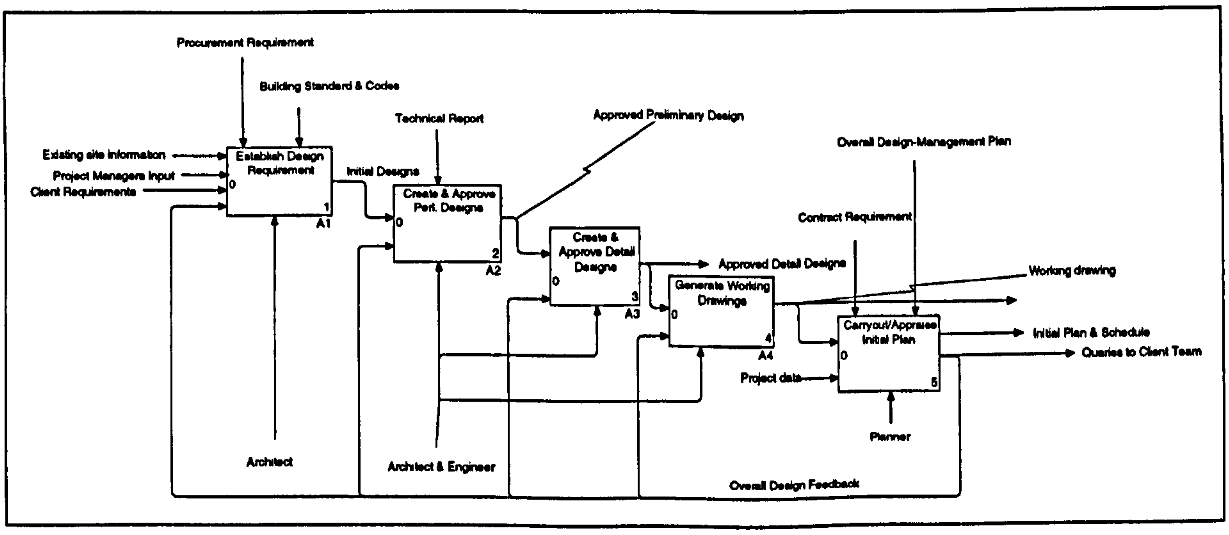

Figure 9.2: IDEF0: the Existing Design – Management Process (A0).

9.3 Establishing Design Requirement

The initiation of the building process starts with the 'Establish Building Design Requirement'. The sequence of activities includes initial briefing, carrying out feasibility studies on client requirement, which includes preliminary site investigations, and establishing funding arrangement. The next stage, in the process, is the development of the clients brief into a more robust and comprehensive statement of the client's requirement.

The Construction Design Management (CDM) Regulations, a new and important variables in current construction processes, is also used as a guide in specifying the safety and regulatory criteria for the construction design, management and production. The sub-function of Establish Building Design Requirements is shown in figure 9.3. Inferring form the diagram, which replicate existing practice of the UK construction industry, the decision-making mechanism is based on the sole responsibility of the architect or the designer. The output at this stage becomes the input for the "Create and Approve Preliminary Design" stage.

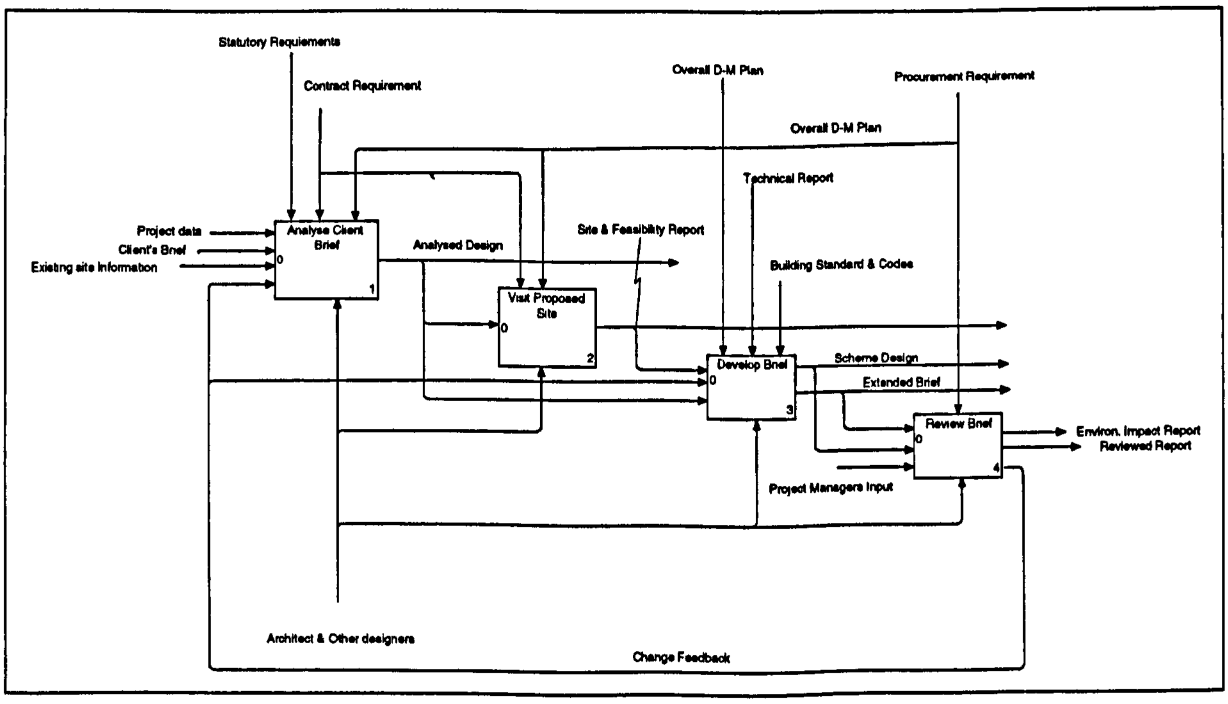

Figure 9.3: IDEF0 Model – Establish Building Design Requirement Stage. (A1)

9.4 Create and Approve Preliminary Designs

The functional process, " Create and Approve Preliminary Design" is the second main activity in the project design processes. It is comprised of the further development of the client's brief into preliminary architectural and structural designs of all the building elements (including the cladding system design) as shown in figure 9.4. Inferring from this diagram, which represents the preliminary design process in practice. The activities follow rigid sequential functions and numerous phasing. The details of these characteristics are illustrated with the IDEF0 modelling decomposition structure as shown in figure 9.4. The diagram provides more detailed information of functional processes at the " Create Preliminary Design Stage". Inferring from figure 9.4 the activities at this stage starts with the "Develop Preliminary Architectural Design" as the initial sub-functional process and uses the 'Client Brief' and 'Schematic Design', which are part of the output of the 'Establish Building Design Requirements' stage as the main input variables.

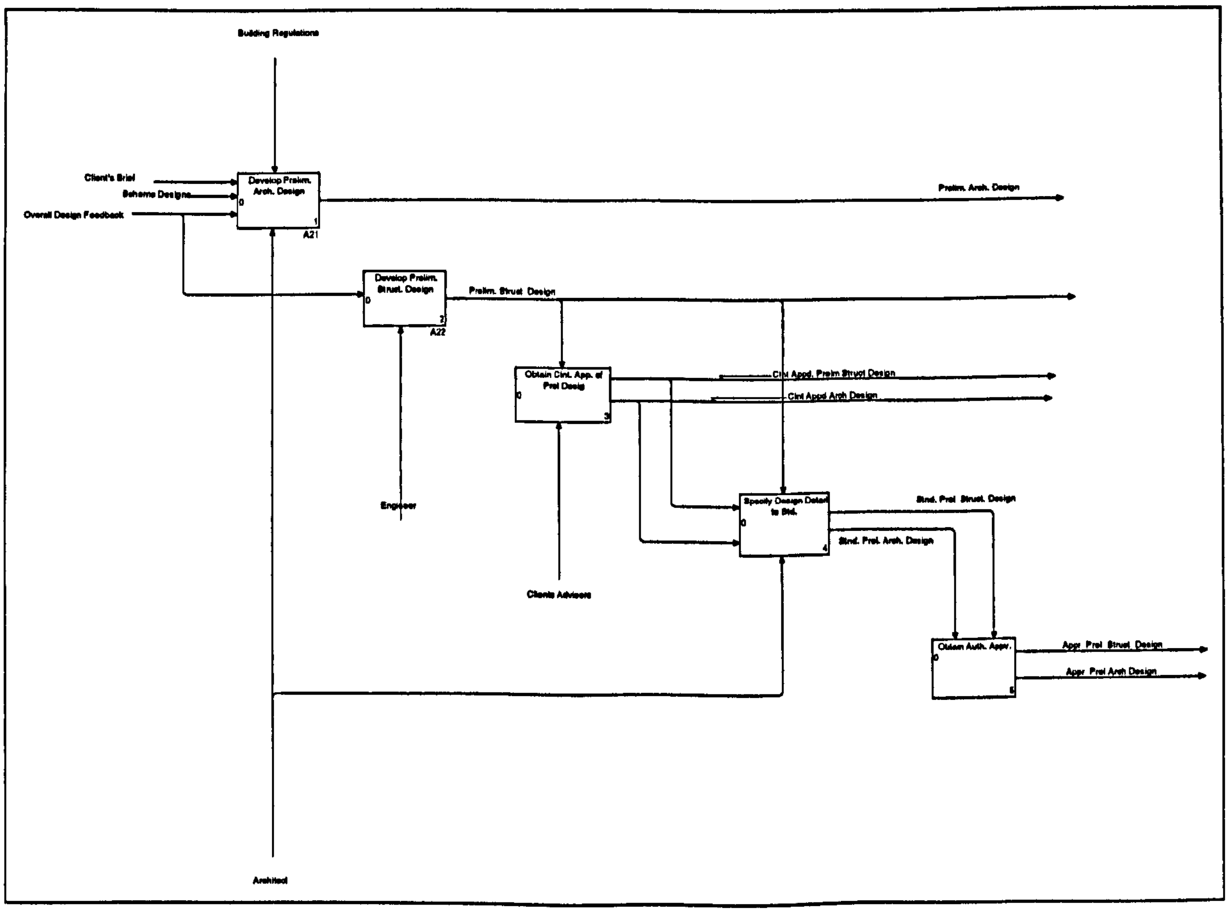

Figure 9.4: IDEF0 Model – Create and Approve Preliminary Building Design Stage (A2)

Using the decomposition structure characteristics of the IDEF0 model the sub-functional activities at the Develop Preliminary Design stage expanded to give clearer information of the processes at the Develop Preliminary Architectural Design Diagram as shown in figure 9.5. The variables and the sub-functional activities are illustrated in figure 9.5. The output of the Develop Preliminary Architectural Design stage becomes the input for the Develop Preliminary Structural Design stage as shown in figure 9.6. The sub-function activities include the following: Generate Framing Plan, which involves the layout of the framing plan, indicating the position of structural members; Selecting Structural Sizes, which assign members sizes and type to the framing plan. The interface between the selected framing scheme and the proposed cladding system, to be installed, is also considered at this stage. In the Review Structural Scheme, the preliminary structural design is assessed as part of the feedback analysis exercise. The output of the activities at the Preliminary Design stage consists of the Preliminary Architectural Design and Preliminary Structural Design, respectively. This goes for the clients' approval. If successful preliminary design goes to the building authorities for approval in conformity to the statutory and building regulations and if not, it goes through an iterative process until the desired results are achieved.

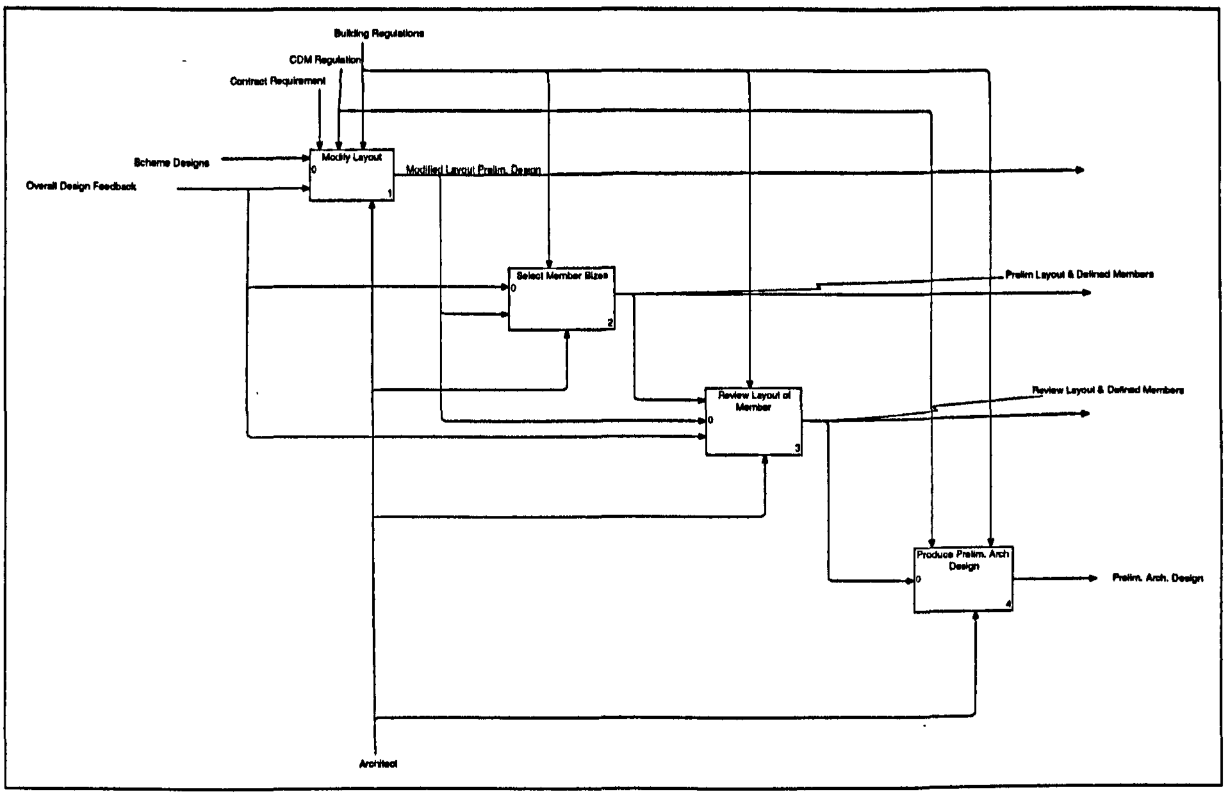

Figure 9.5: IDEF0 Model – Child Diagram – Preliminary Architectural Design Stage (A21)

Inferring from figure 9.5 and 9.6 respectively, which are generic representations of current preliminary design practices. The activities tend to follow a rigid and sequential process, which bring about a longer overall design period than is necessary. Furthermore, the flows of information between parties operating in such a rigid sequence shown in the preliminary design stage tend to become tenuous and sometimes lead to errors, rework, and duplication, Franks (1991), Anumba et al. (1996). All these affect the interest of the parties involved and the project as a whole suffers as a consequence.

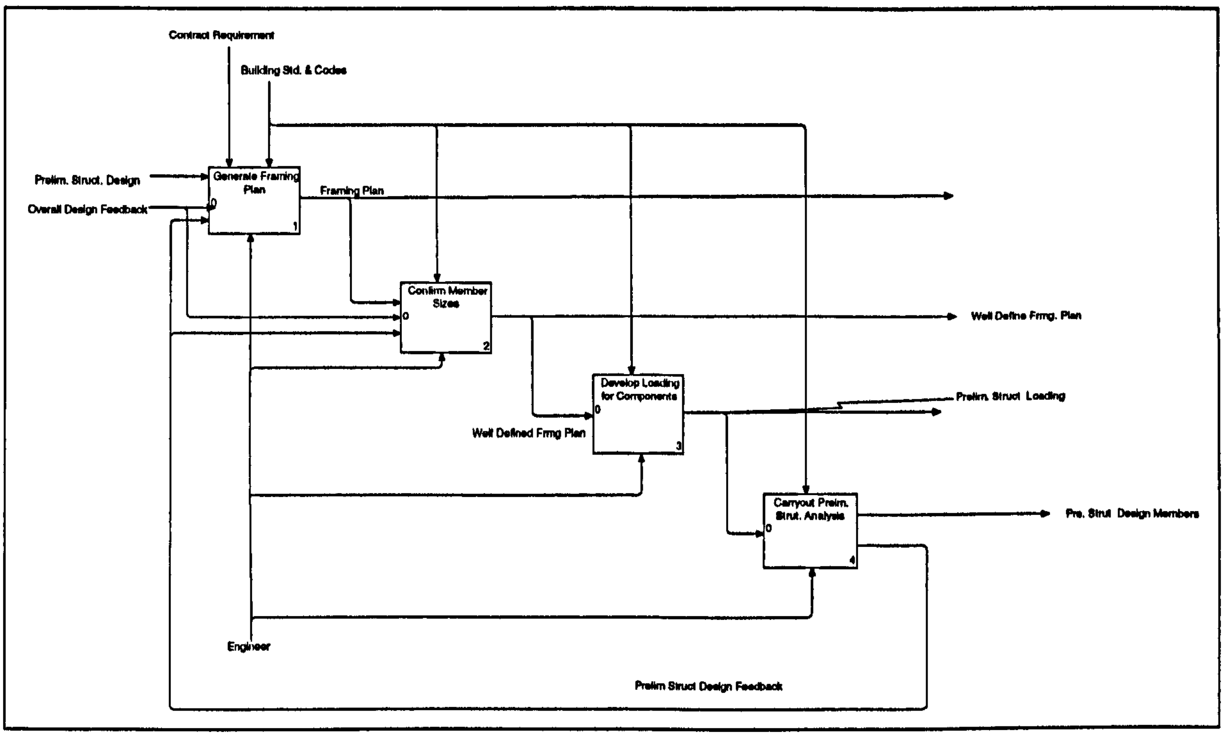

Figure 9.6: IDEF0 Model, Child Diagram – The Preliminary Structural Design Stage (A22)

The next stage after the approval of the preliminary designs is the Develop and Approve Detail Design processes.

9.5 Develop and Approve Detail Designs.

The development of detailed designs comprises of both architectural and structural designs. This entails the detail initiation, designing, specification and confirming the sizes of the various structural members and building elements. The functions involved are illustrated with the IDEF0 model in figure 9.7. The parent diagram illustrated the activities of the Develop and Approve Detail Design stage. The sub-functional processes involved the detail design of both structural and architectural members. This is followed by the "Check Suitability of Design Members function".

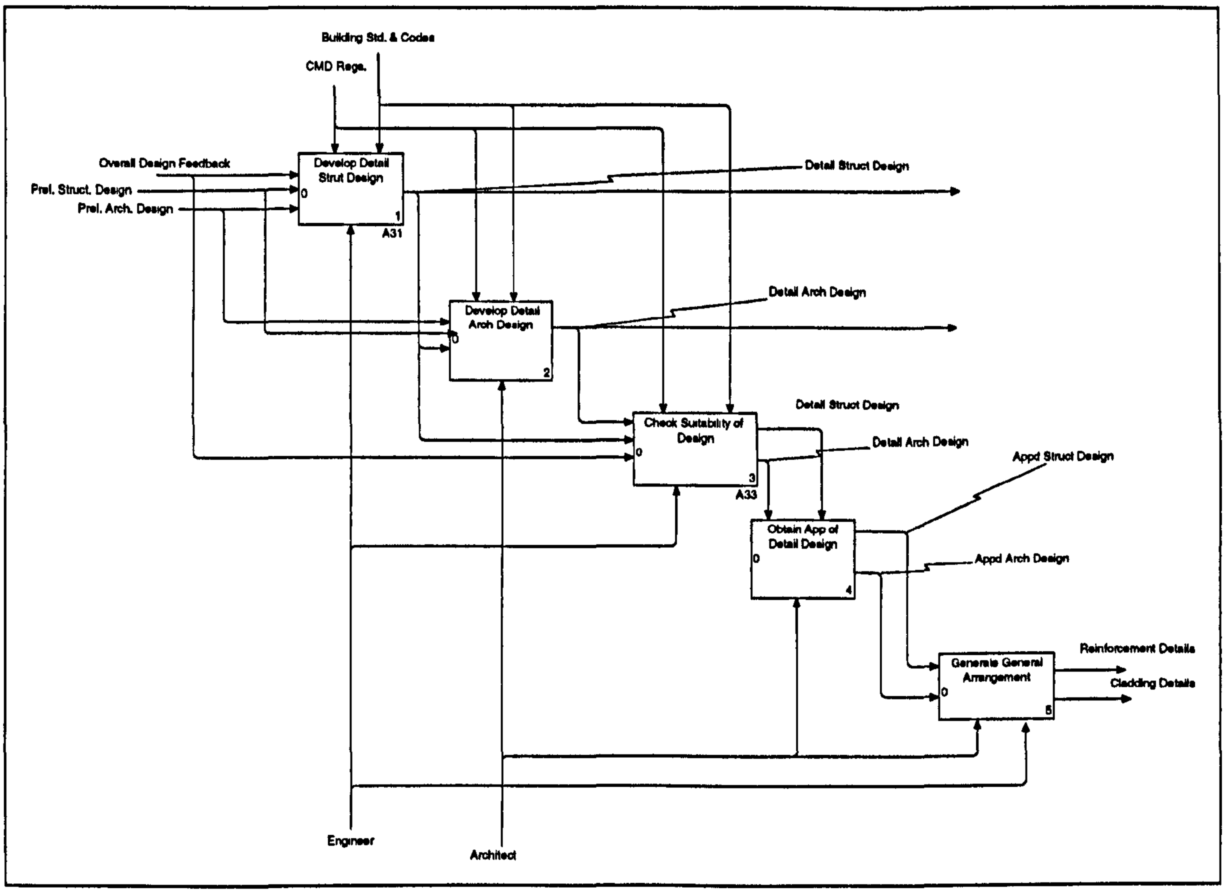

Figure 9.7: IDEF0 Model, Parent Diagram – Develop & Approve Detail Design Stage (A3)

The next functional activity is the Obtained Client Final Approval for the detail designs followed by the 'Analyse Results' function. Details of sub-functional activities of the Develop of Detail Design in terms of conventional cladding systems design, specification, fabrication and installation within the context of a typical construction project was discussed in chapter 6 and is expanded upon in the next section.

9.5.1 Develop Detailed Structural Design.

The first sub-functional process in the Detail Design stage is the 'Develop Detail Structural Design' this encompasses the support and framing structure of building cladding system. The activities involved are - 'Review Structural Analysis' which assesses the design loads with respect to the structural design development plan, the analysis feedback and the design criteria. These variables produce models, which generate structural representative models from the Preliminary Structural Scheme; Generate Basic Load Cases, which assesses the design loads and create appropriate load cases for each of the building element. The Load Case Combination sub-functional process is a multiple combination of the load cases, which are used in the analysis of the whole structural work. The variable to perform the sub-functional activities at this stage are shown in figure 9.8

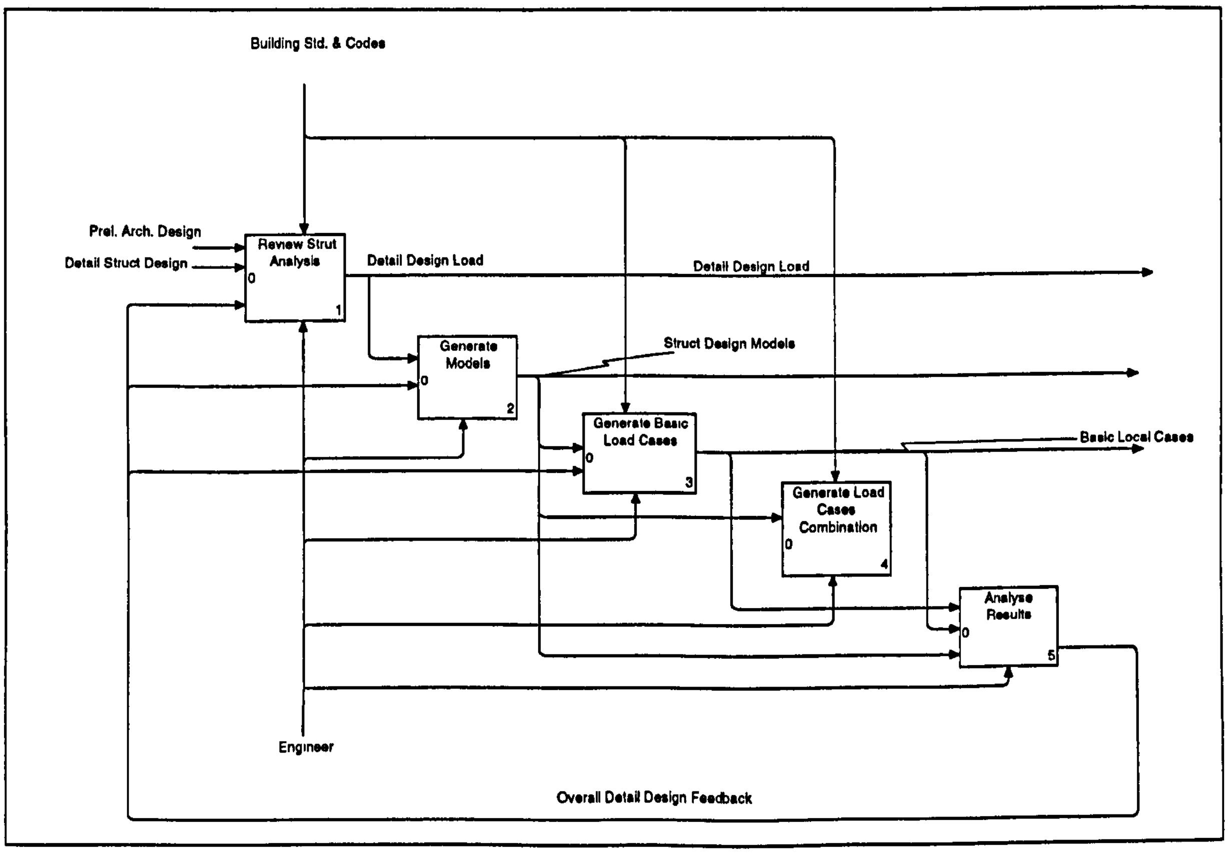

Figure 9.8: IDEF0 Model, Child Diagram – Detail Structural Design Function (A31).

The output for the Load Case Combination and the Model Generated are used as the input for important sub-functional activities in the detail structural design stage.

9.5.2 The Analyse Result Stage

The 'Analyse Results' function used the combination of the 'Basic Load Cases', the 'Structural Models', and the 'Load Case Combination' as the inputs. The control variables are the Building Standards & Codes, CDM Regulations and the Design

Requirements. The outputs are the Analytical Results - the results of the structural analysis, the Overall Structural Design. The overall structural design provides the relevant information about the structure to the design team, whilst the Analysis Feedback provides the all feedback data after the analysis had taken place. This provided the means to review the detail structural design and further provided the input for the detail architectural design.

9.5.3 Develop Detailed Architectural Designs

The activity of the 'Detail Architectural Design' encompasses the use of design continuity feedback to monitor both space and building element. This is to ensure that the entire design stay within the bounds set by the detail development plan. Detail Designs involves identifying and collating all relevant information on each design element from both the architectural and structural analysis. Checking Suitability of Designed Members - the next parent functional activity, follows the sub-functional process. This function uses the individual information for each design element to check for suitability.

9.5.4 Check Suitability of Design Members

The overall detail designs are checked in terms of their sizes, positions, as well their structural integrity, guided by the detail design development plan and building standards. This includes the required concrete strength and reinforcement characteristics as well as suitability of steel structural frame and its impact on all aspects of the overall design. An important aspect of this function is illustrated with an IDEF0 model in figure 9.9. This exercise is aimed at ensuring that the overall design fits the client's final requirements.

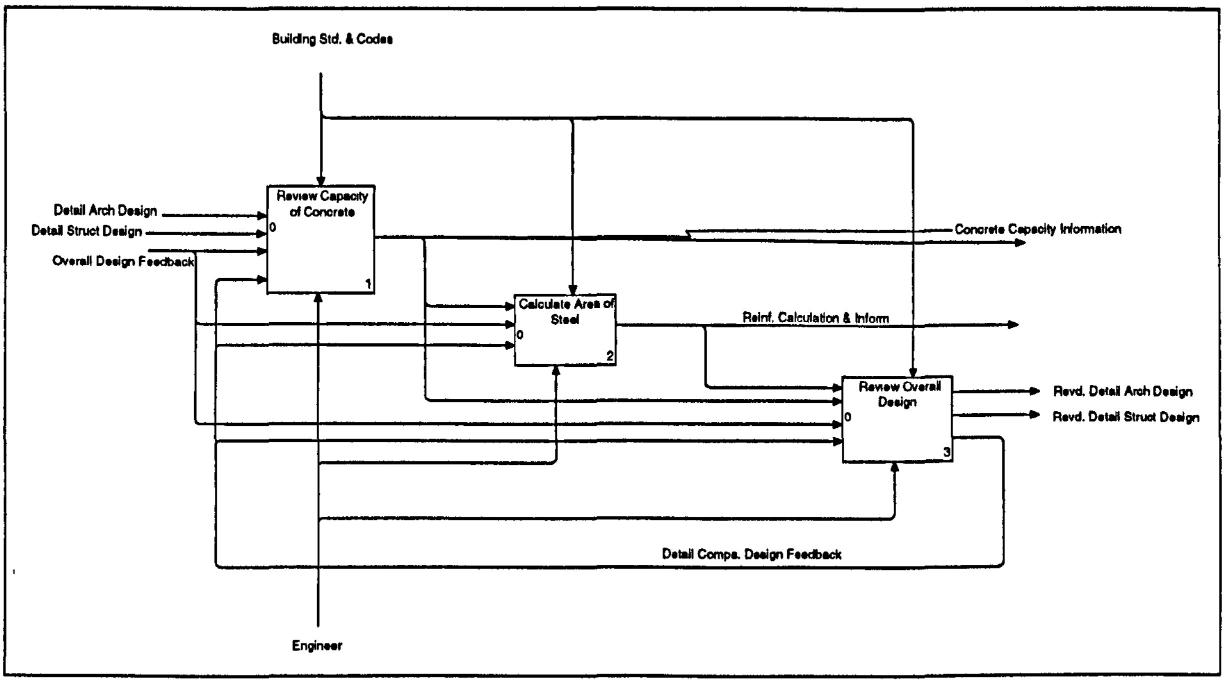

Figure 9.9: IDEF0 Model: The Check Suitability of Detail Design Stage (A33).

Inferring form figure 9.9, the outputs include the Reinforcement Schedule, which provides the area of reinforcement required, its grade, length, lap length as well as the link spacing; the concrete information, which provided the grade, maximum aggregate size, admixes required in the case of steel structures RSJ specifications. Others outputs are the Review Detail Design (structural & architectural) as well as the detail component design feedback, which provides feedback route for both concrete and reinforcement data to be modified. This stage involves a constant review of the effect of the framing structure, floor plate design (steel or concrete) on the proposed cladding system configuration, components and methods of assembly/installation. The reviews of detailed design results (structural & architectural) are passed on to the client for approval. The changes required are made and the results passed on to the next stage – ' Generate Working Drawings'.

9.5.5 Analyse Detailed Design & Produce Working Drawings

The "Analyse Detail Design and Produce Working Drawing" stage is the last functional process in the design phase of the entire traditional design-management process after the client's approval of the detail designs with or without changes as shown figure 9.10.

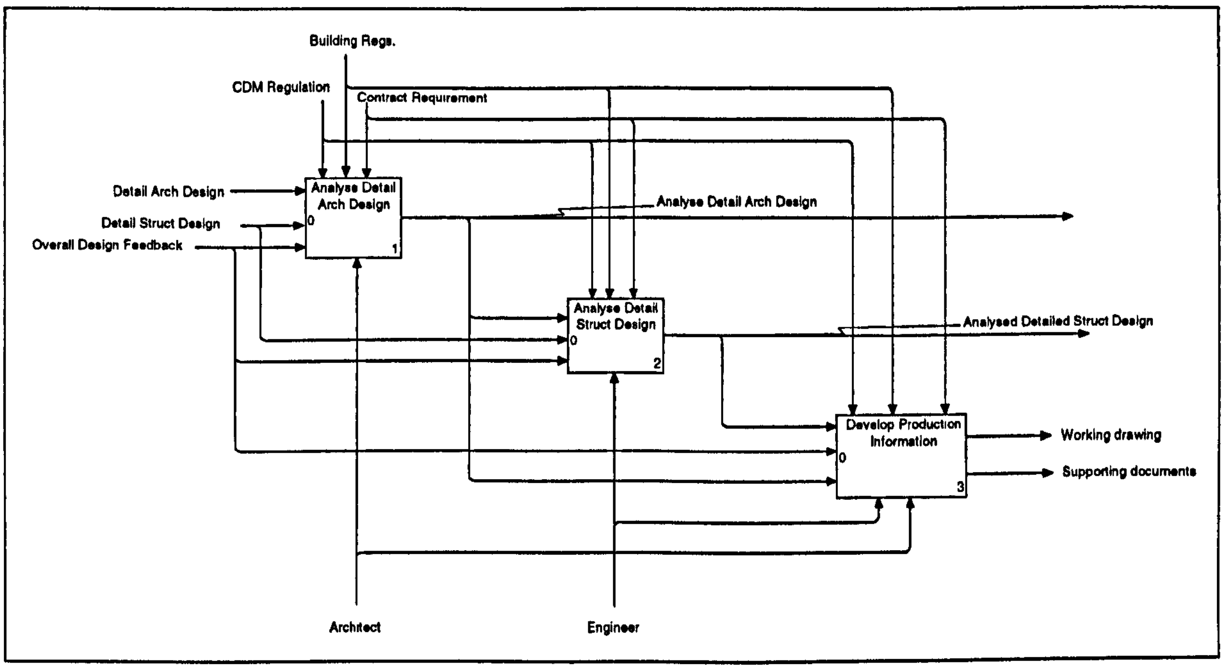

Figure 9.10: IDEF0 Model Produce Working Drawings Stage (A4).

The working drawing and the supporting documents including detail specifications become the input variables for the Planning/ Scheduling phase discussed in the next section.

9.6 Overview of the Planning/ Scheduling Phase

Project planning discussed in this chapter refers to construction project planning and scheduling, and the process is defined as the means to assign time and resources (plant, labour and materials), to design (architectural & structural) and construction in order to achieve the execution of a project in a time-cost effective way. It is argued in current practice that planning is an intrinsic part of estimating process, whether it is undertaken by an estimator or by a planner acting in support of the estimator, McCaffer et al. (1991), Aouad et al. (1994). Planning forms a major constituent of construction management processes, which include the overall planning, control, monitoring and co-ordinating of a project. It reflects the multi-dimension of the nature of construction projects and covers the major parts of the life cycle of a project – project life cycle. Some researchers, Kezner (1989), Kahkonen (1991), hold the view that project planning is a separate function which merely abstract ways of asserting planners organising and documenting their thinking and assumptions, communicating all these to people who are responsible to put such plans into action. Planning includes any and all activities needed to create a project plan. This includes the scope definition, scheduling, costing, staffing and so on. In order to minimise complications the concept of planning presented in this chapter, planning is limited to planning / scheduling activities which consists of the following functions

- Project Scheduling – which produces an estimate expression of when the different phases of a project and activities of each phase start and finish with resulting project schedule, shows when the project is to be completed - in the case of a building, when the project will be handed over. The other aspects discussed below are placed under cost estimates and they are:
- Project Budgeting – which includes project cost estimation
- Financial Planning – which covers plans of the project finance and estimating of residual profit.

The Planning/ Scheduling phase is the next main functional activity after the generation of the working drawing. The planning phase is defined by Louler and Tucker (1988), as a multi-tasks process involving planning/ scheduling / preparation activities in a continuous and iterative process, where decision making is needed at all times. The processes involved in planning preparation can be grouped into five main stages, such as:

- Carryout initial appraisal
- Create initial plan
- Analyse initial plan
- Improve initial plan
- Process final plan

Using the IDEF0 modelling methodology the sequential functional activities at the planning stage grouped above can be shown as in figure 9.11, where the first parent functional activity is the Initial Plan Appraisal. The purpose of the initial overall appraisal function is to assess and highlight any high value areas, or any particular problems with the designs and (or) the contract documents, which require special attention.

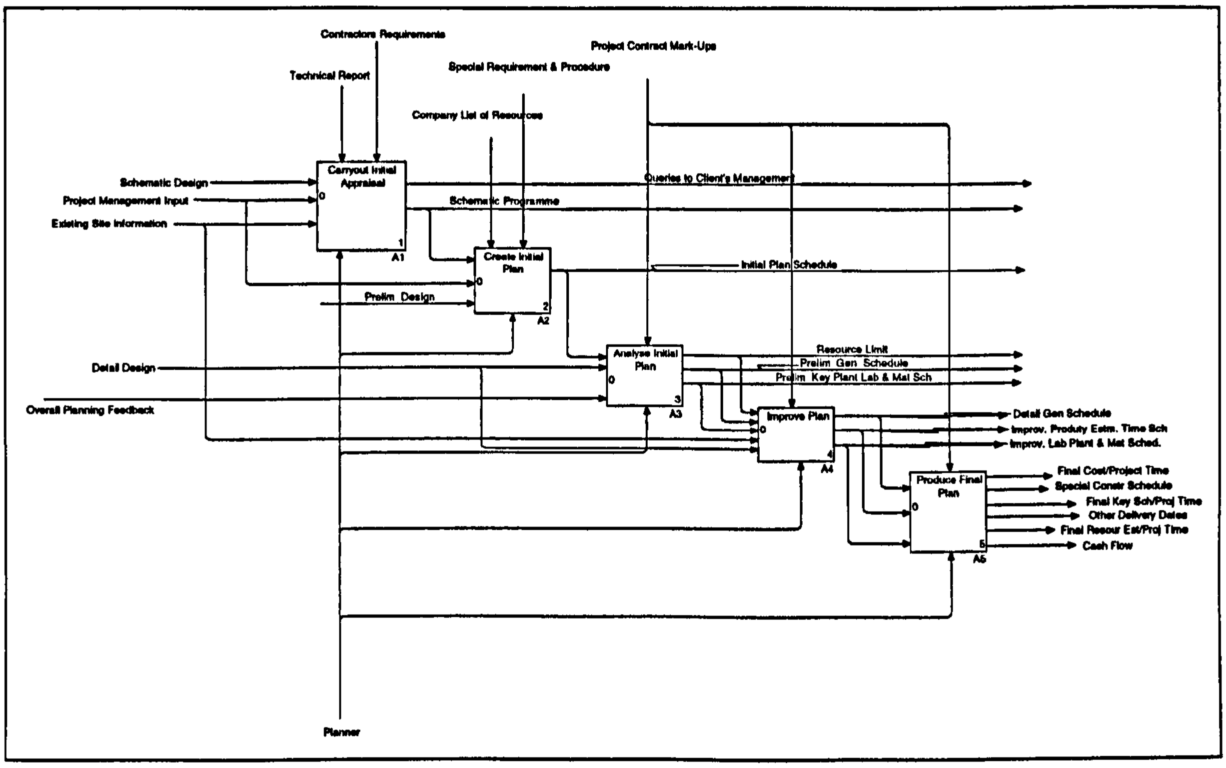

Figure 9.11: IDEF0 Model, Parent Diagram – Project Planning Stage (A-0).

9.6.1 The Initial Appraisal (Plan)

The functional activities within the project planning process are discussed in this section. The Initial Appraisal at the plan stage is the first logical step in the production of a project plan / schedule, and it includes the identification of other possible alternatives methods of construction. Other purposes of Initial Appraisal are to enable other important activities such as the analysis of the principal quantities of work; the items to be sub-contracted and the key delivery dates for materials to be assessed and passed on for quotations. It is also a means to assess whether there is a case for considering design alternatives or alteration to temporary works. The sub-functional activities and the variables needed to perform these sub-functions are shown in figure 9.12.

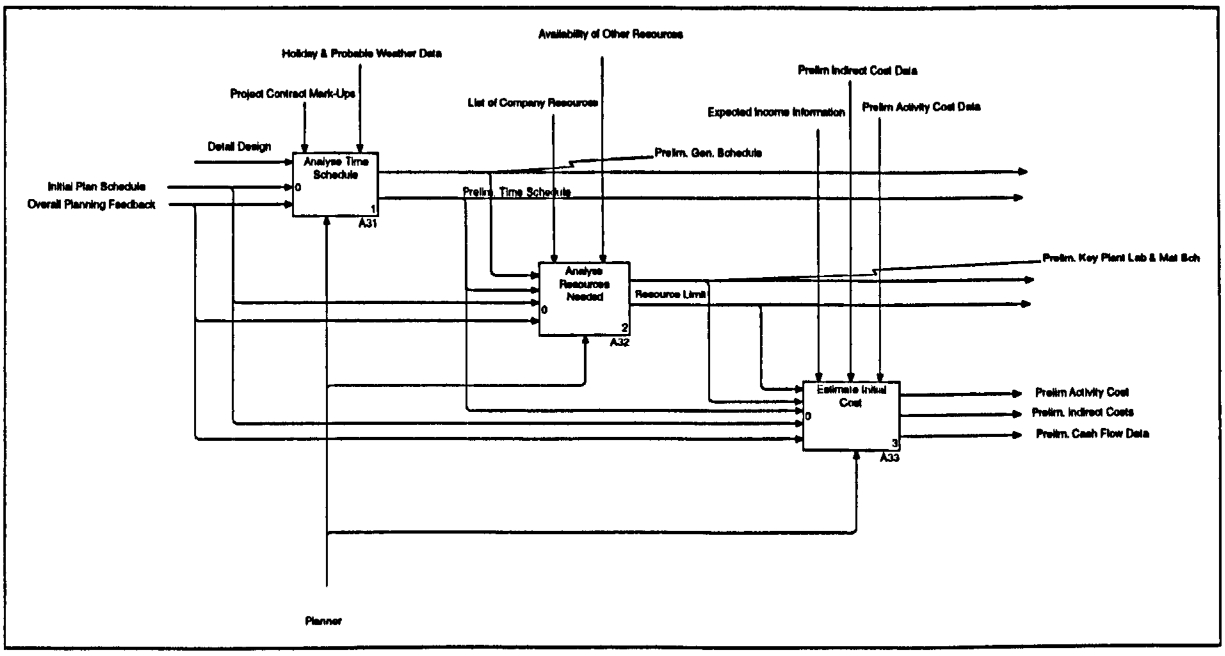

Figure 9.12: IDEF0 Model, Child Diagram, Initial (Plan) Appraisal Function (A1).

The output of the Initial Appraisal function becomes the input and control variables in the next functional stage, which is Create Initial Plan, discussed below.

9.6.2 Create Initial Plan

The activity at the Create Initial Plan Stage is the second parent function in project planning. It is divided into 5 main formation processing requirements, which are:

- Creation of Activity Lists
- Analysis of Dependencies
- Definition of Sequence of Activity
- Definition of Overlap Activity
- Levelling of Activities

9.6.3 Creation of Activity List

The creation of activity list is the first sub-function of the Create Initial plan process where effective decision making about the sequence and flow of work from one section to the other are carried out. It also forms the basis of planning of the sequence of the building process. The variables required to perform the sub-functions are shown in figure 9.13

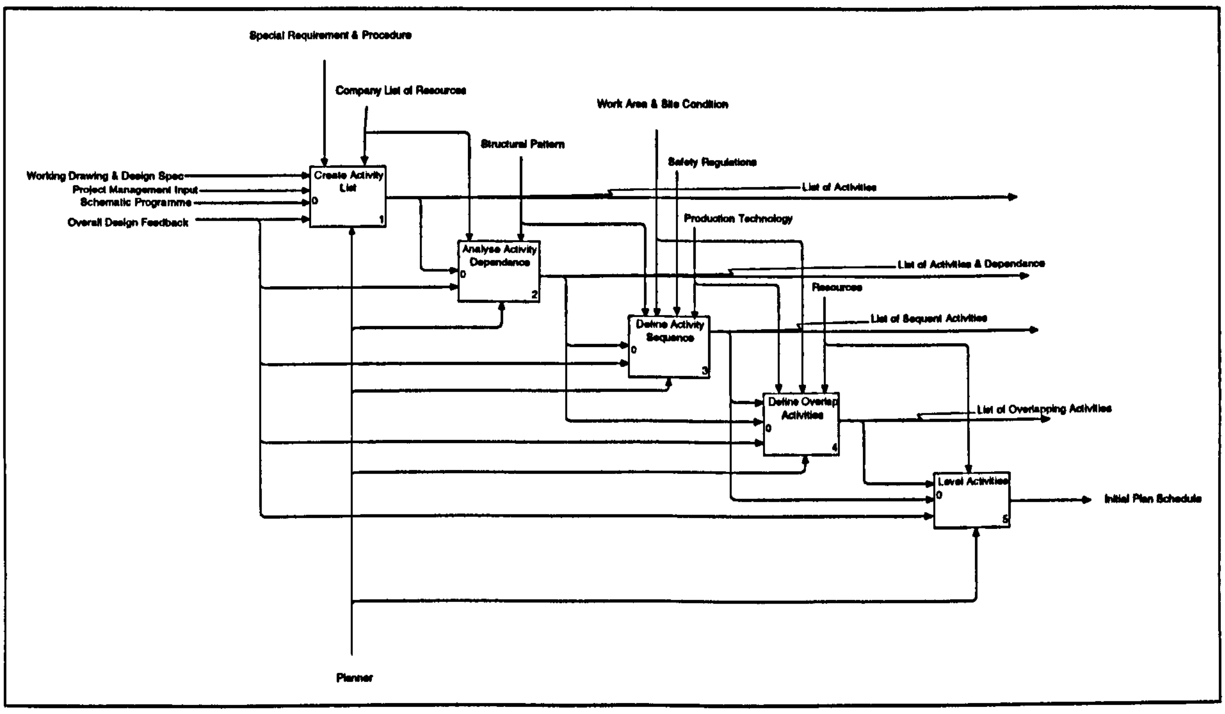

Figure 9.13: IDEF0 Model – Create Initial Plan Stage (A2)

In most companies, the output of this function also forms the basis for the preparation of material orders. It further acts as planning reminders and in some cases as operational control factors. The Activity List – the output data, is the input data for the 'Analysis of Dependencies Stages'.

9.6.4 Analysis of Dependencies

Analysis of Dependencies is one of the very important sub-functional activities in project planning which relies mostly on the expertise of the planner when the conventional method of planning is employed. Important variables required to perform this sub-function are illustrated in figure 9.13. The Analysis of Dependencies involves a top-down and bottom-up approach, controlled by factors such as site conditions, location, sequence and overlapping activities. These factors influence the planner's decision, Kahkoen (1990), Sher, (1995). Inferring from figure 9.13. The typical factors that affect the planner's decision on sequence of individual project activities are mainly structural. However, in a study carried out as part of this research, safety, production technology and site condition was found to have some influence on the planner's decision. Resources, work area, safety and production technology can influence the planner's decision on individual overlapping activities, Kerzner (1989). The output at the Analysis of Dependencies Stage is a list of activities with dependencies between them. This output can then be grouped into two categories:

- Definition of the sequence of activities
- Definition of overlap activities

The functions of the Analysis of Dependencies stage produces a list of sequence activities and a list of overlap activities respectively.

9.6.5 The Definition of Sequence and Overlap Activities

The Definition of Sequence Activities involves the analysis of the activities of the project, which are required to operate in sequence, Lock (1994). In this process, information of the sequence of activities is influenced by the method of construction and material characteristics. An example of such sequence of activities is the erection of a column on a floor slab followed by the beam and subsequently the floor on the upper level and then the cladding system. Other examples of the influence of material on the sequence of activities are shown in the use of concrete and steel frame structures, Thompson (1992). The examination of possible overlapping activities comes after the definition of the sequence of activities. The definition of overlapping activities is also influenced by effective utilisation of resources. In some cases, the same gang of workmen can carry out a preceding activity (such as wall priming) and succeeding activities (such as painting). In this case, such activities can overlap Kahkonen (1991). Activity dependencies, which influence both the definitions of sequence and overlap activities, as shown in figure 9.13, can cause certain quantitative constraints between two activities.

9.6.6 Levelling of Activities

This is the critical analysis of both sequence and overlap activities using the effective application of resources as a tool to achieve the best result. It critically reveals the best of the two options (sequence and overlap) and set work priorities which depend on effective use of resources. It also analyses the probable delays that may arise and at the same time suggest the best optional activity (sequence or overlap). During levelling, the use of alternative processes due to site conditions and change of resources can bring about the best option. On one of the projects reviewed during the course of this research, the same gang of workmen carried out the wall surface finishing and wall painting. The project planner had overlapped these activities on the bases of resources.

In current practice, changes in activity dependencies are brought about as a result of the use of dynamic factors (such as resources). These changes are then fed back into the functional process cycle as illustrated in figure 9.13; the whole process is repeated. This sometimes creates a repetitive function and duplication of efforts, which may led to inaccuracies and mistakes. In a continuous and iterative process, the output of the function of Levelling of Activities which is part of the Initial Plan then becomes the input for the creation of the Initial Resource Schedule and Initial Time Schedule respectively. These are both referred to as the Initial Plan.

9.6.7 Analyse Initial Plan

The Analysis of initial plan is the third parent function process of the overall project planning phase. The process is carried out in the three following main sub- functional stages:

- Time Analysis – this function produces some input data for the resources and cost analysis.
- Resource Analysis – this function covers the analysis of the needed resources for the project and at the same time produces input data for the cost analysis.

- Cost Analysis – this consists of activity cost estimation, indirect cost estimations and cash flow analysis.

The functional activities and the variables of the Analysis of the Initial Plan are shown in figure 9.14.

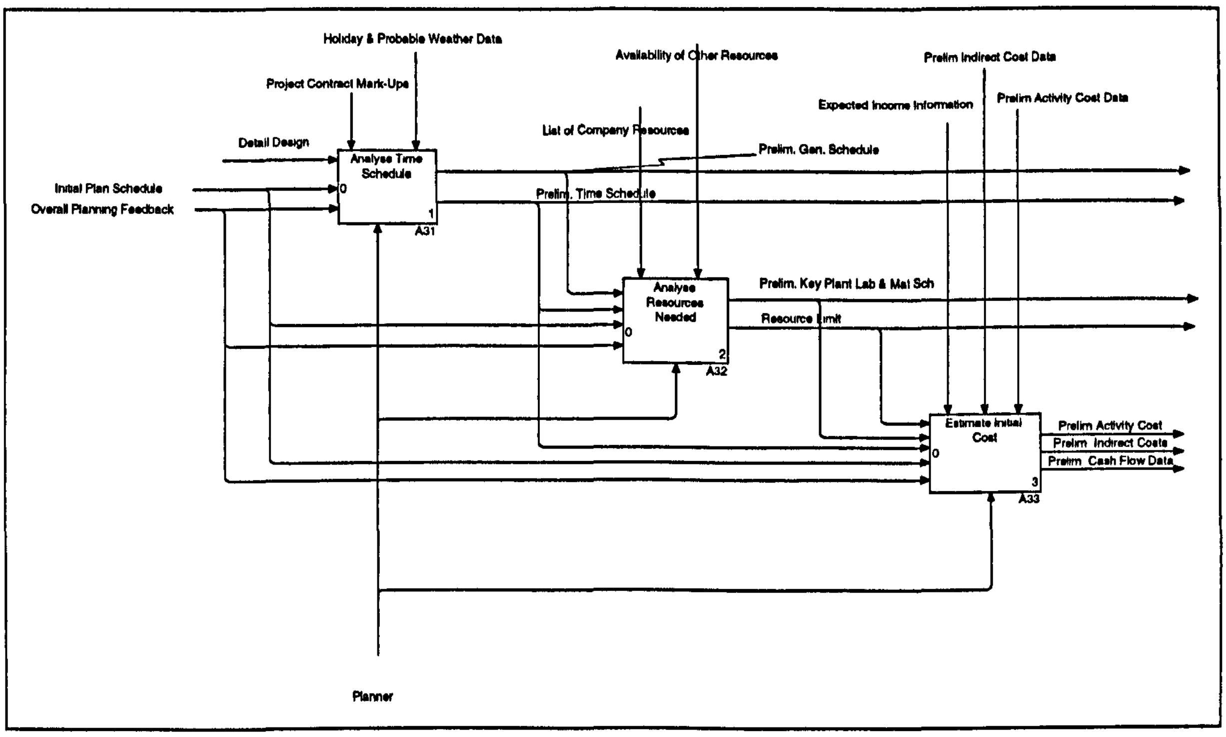

Figure 9.14: IDEF0 Model of the Analyse Initial Plan Stage (A3)

Figure 9.14 also illustrates the sub-functional processes at this stage, which follow a rigid sequence. The details of these functional stages are discussed below.

9.7 Time Analysis

The first sub-functional process of the Analyse Initial Plan function involve the Analyse Time Schedule and it incorporates the estimation of the start and finish time of each activity. The variables needed to perform the Time Analysis sub-function are shown in figure 9.14 to include the following:

- Design drawings
- Design specifications
- Unit time (could be in days, weeks or months)

- Initial plan data
- Levelling activity data.

The control variables include the holiday dates, probable weather information and the production technology. The output variables include the initial workday schedule, the initial calendar day schedule, and the initial productivity time schedule. These become part of the input data required to carry out the function at the 'Analyse Resources Needed' stage. Using the IDEF0 modelling technique as shown in figure 9.15 additional details of the analyse time schedule function can be summarily divided into three main area:

- Estimation of activity time
- Estimation of production time in workdays weeks or months
- Estimation of production time in calendar days, weeks or months

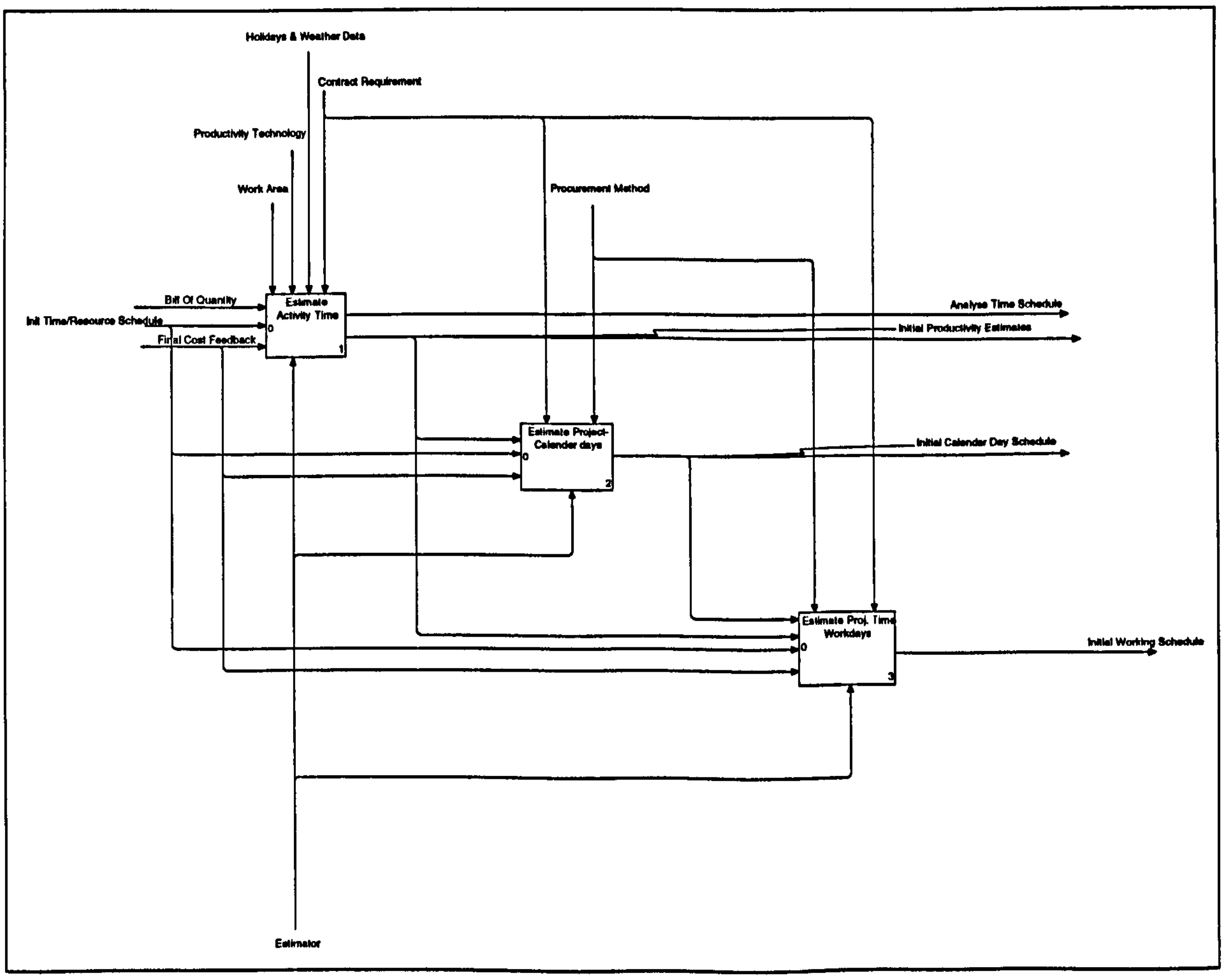

Figure 9.15: IDEF0 Model, Child diagram of the Analyse Time Schedule Stage (A31).

Figure 9.15 further shows the sub-functional activities of the Time Analysis stage including the variables to perform each of the sub-functions. In the construction industry, weather conditions, such as those in winter, can clearly have effect on the generation of construction activities. Similarly productivity technology can affect activity time schedule of a project. The process therefore involves the determination of the amount of work needed to be carried out in each activity of the plan using the above mentioned variables to control the sub-functions. In most cases this phase of work depends on the expertise of the planner and the functions involves the re-discovering of some of the data already obtained by the estimator if such function are separated, McCaffer (1991), Sher et al. (1995).

9.7.1 Estimate Project Time

Project time can be estimated in either workdays or calendar days and the process involves calculating the start and finish times for each activity. Analysis of 'Activity Dependencies' is an essential information required during this process. In calculating activity times in calendar days, the project start and finish dates are taken into account in relation to the project contract requirement. The details of the processes involved in carrying out these activities are shown in figure 9.15. Contract requirements are very essential in the generation of construction time functions, which also act as control. The 'Estimated Project Time' is constrained by factors such as holiday dates and other dates when staff will be unable to work. The scheduling in 'calendar days' show dates when individual activities and the overall project start and finish, whilst the project time in working days inclusively indicates the holidays where workers are not supposed to work. The output of either initial calendar days or workday's schedules becomes the input data for resource analysis.

9.7.2 Resources Analysis

Resource analysis is one of the most important phases in planning activities. It is the second sub-functional process at the Analyse Initial Plan Stage and the sub-processes involved are divided into three main areas as follows:

- Allocation of resources to activities
- Calculation of resources needed
- Analysis of limits of resources, which include evaluation of other options

Figure 9.16 illustrates the variable needed for the functions of 'Resources Analysis'. Inferring from figure 9.16, the Analysis of Resources involves detailed allocation of resources to the listed activities, calculation of the resources needed and assessing the limits to the use of the selected resources. The use of other optional resources is also analysed at this stage. An example of the functions of the analysis of resources is illustrated with the analysis of reinforced concrete members, where the initial work begins by assessing the periodic needs of resources for concrete work during the project span. Analysis of the required resources is then carried out at this stage. The next stage is a comparison of the amount of resources available with the project resource required. In such analysis, many considerations are given to the possible use of other options such as site or imported mix.

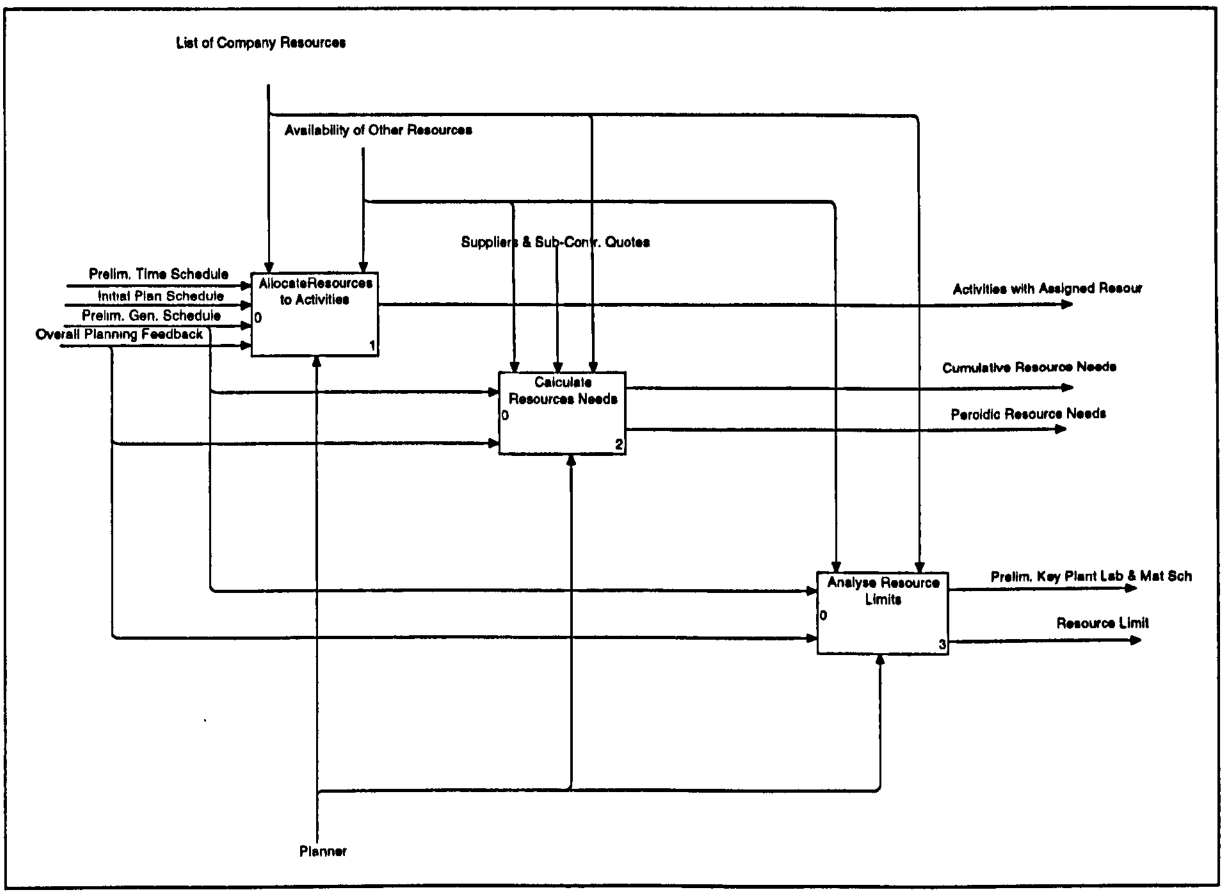

Figure 9.16: IDEF0 Child Model of the Analyse Resources Needed Stage (A32).

Whatever the outcome of the analysis, the output of the 'Analysis of Resources. Limits include the key labour, plant and material schedules. These play a major role as the main input data for the cost analysis function. In general practice, there is duplication of efforts by the planner in carrying resource analysis. This is because, the estimator carries out the same function when the two functions (estimating and planning) are not fully integrated. In this case, the planned use of the plant and labour resources is priced in total to be checked against the labour and plant total cost calculated by the estimator, McCaffer, (1991), Sher (1995), Thompson et al.(1996).

9.7.3 The Cost Analysis

The Cost Analysis function in planning is classified by many practitioners, Newton (1990), McCaffer et al (1991), Lover et al (1995), as the most data intensive process which duplicates the functions of the estimator. In general practice, the amount of overlap in function at this stage, between planning and estimating depends on the degree to which the two functions have diverged and also the type of procurement method being adopted. However, the separation of the two functions brings about the duplication of efforts at the cost analysis stage in estimating and planning phases respectively. The process, at this stage, covers the activity cost estimation, the indirect cost estimation and the general cash flow analysis. The variables required to perform these sub-functional activities are illustrated in figure 9.17. Inferring from this diagram, the 'Analyse Costs' function involves the estimation of the activity cost. This process uses the activity cost data, which includes item build-ups, labour rates, materials and plant prices. The estimator rediscovers these data - as part of the basic information requirements for cost estimation exercise. This results in duplication of effort by the estimator in cost estimating processes. The output of this functional activity is the 'Activity Costs', which becomes an input for the second sub-function activity - the 'Estimate Indirect Cost' of the project. In the estimating of indirect cost sub-function process, the input are, the labour schedule and the indirect cost data, which includes the insurance to cover the operations of the site, the management cost, temporary works, utility costs (electricity & water) site plant and equipment. Other variables are shown in figure 9.17. The third functional activity of the 'Cost Analysis' stage is the 'Calculate Cash Flow'. This shows the balance between the project income and expenses, Khosrowshahi (1991). The input data for the 'Calculate Cash flow' are Indirect Costs, Activity Costs and the Overall Planning Feedback. In calculating the cash flow, it is usually deemed that the project's income covers the projected expenses during the lifetime of the project. The cash flow sometimes shows whether it would be necessary for the infusion of extra capital into the project. Despite the involvement of a lot of routine calculation at this stage, experience suggests that there may be problems during the project implementation stage.

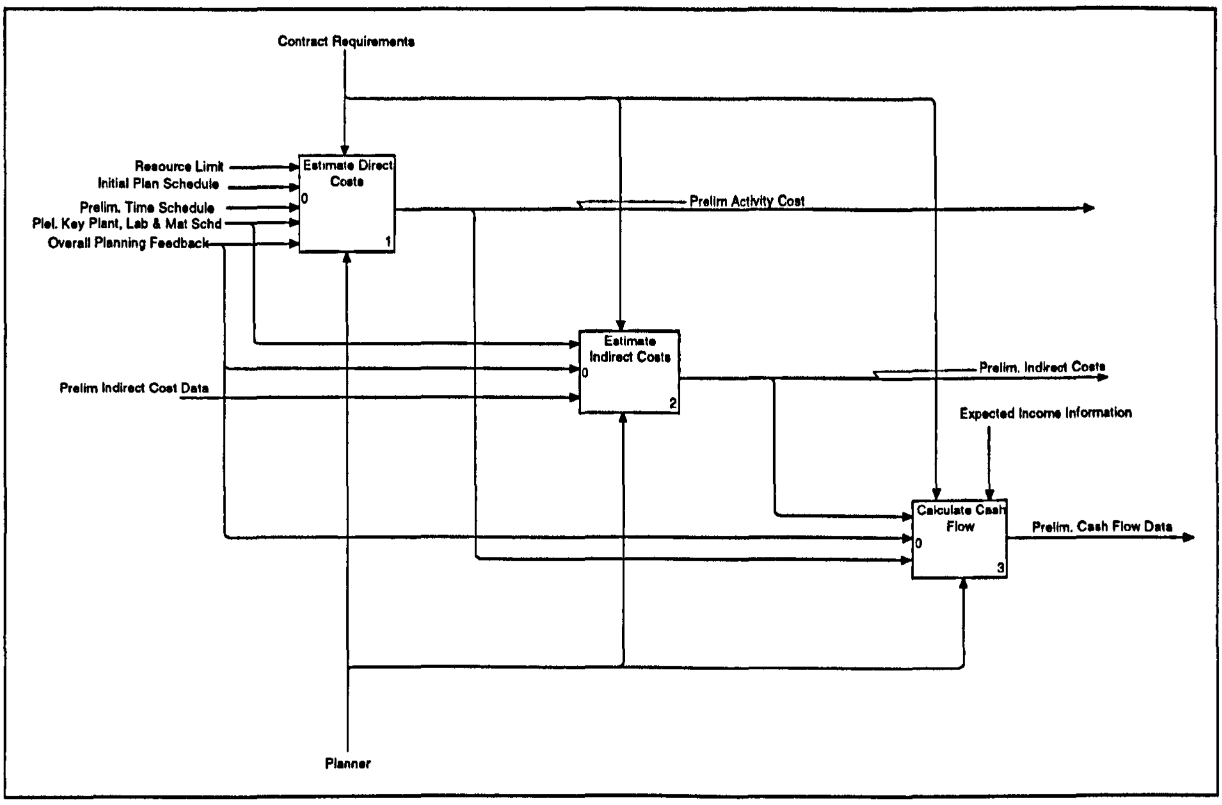

Figure 9.17: IDEF0 Model Estimate Initial Cost Stage (A33)

9.7.4 Improve Plan

The main objectives of the Improve Plan function in project planning, is to speed up the activities by effectively utilising limited resources available to achieve a minimum total cost at a reasonable minimum time. The Improve Plan functional activities can be sub-grouped into three areas. They are as follows:

- Resource scheduling
- Re-assessment of project time
- Resource levelling

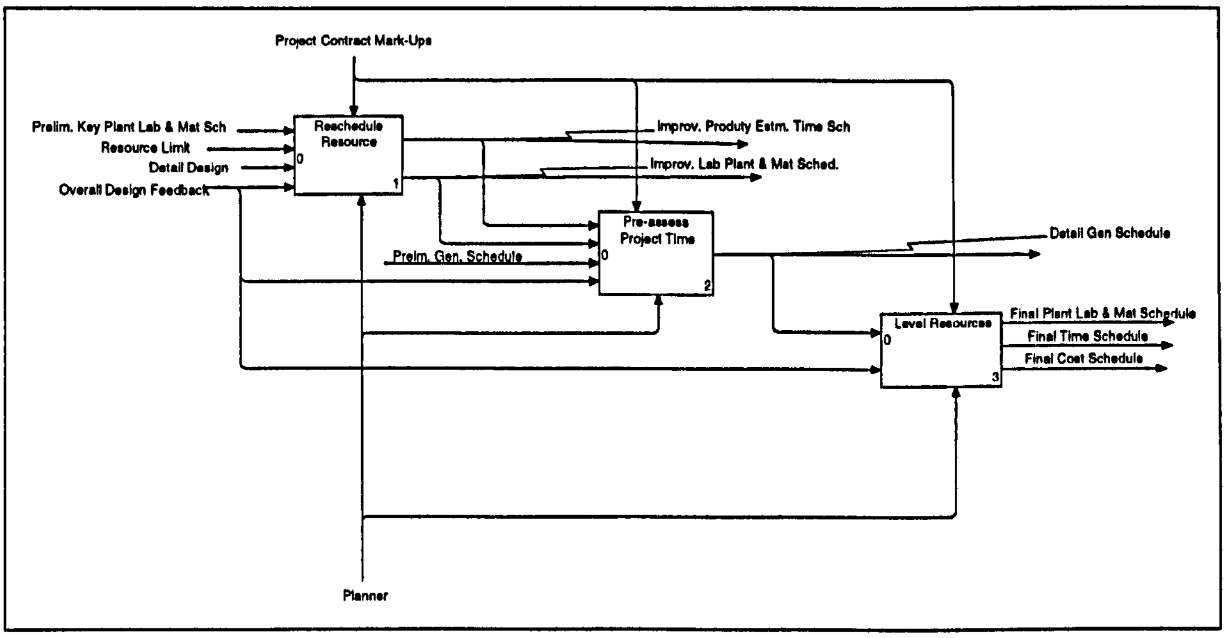

Figure 9.18: IDEF0 Model of the Improve Plan Stage (A4)

Figure 9.18 illustrates the decomposition structure of the Improve Plan and some of the associated variables. The model shows the stage by stage process of the Improve Plan. The first sub-functional process, that 'Resources scheduling' and sub-functional processes are discussed below.

9.7.5 Resources Scheduling

Resources Scheduling described in this section in relation to current UK practices is the effective allocation of available resources to project activities and then re-scheduling the plan in order to speed up the project within a reasonable minimum period. In practice, this process requires the expertise of both the estimator and the planner to handle the resources-cost-time solution since the activities overlap when separated McCaffer (1991). The variables for these sub-functional processes are shown in figure 9.19.

9.7.6 Re-assess Project Time

The re-assessment of the project time is the process of re-examining the project allocated time in a more speedy and time-cost effective way, such that, the project can be completed reasonably earlier than the initial project time plan. In practice, speeding up the project has serious repercussions on the project resources, the project cost as well as the cash flow. The procedure used in achieving this task requires a "synergistic" approach in addition to the expertise of the project planner and estimator, McCaffer (1991). Re-assessment of project time requires a careful assessment of the working situation, the contract requirements and available resources. In terms of resources, it is always advisable to find out whether speeding up the project will require an increase amount of resources at least working overtime. This should be assessed against other options, such as, maintaining constant resources, but run extra shifts.

Whatever option available to the planner to achieve the suitable activities towards project acceleration, this should be evaluated against the project schedule, the cost estimate, and finally the effect the acceleration time will have on the cash flow. The next sub-function in the Improve Plan Stage is the Resources Leveling function.

9.7.7 Level Resources

Resource levelling is the process of altering the activities of planning within reasonable resource limits in order to achieve a better distribution of resources for the project implementation. In practice, it is the optimisation of project resources to speed up the project within a minimal additional cost. The process involves a careful change of start and finish time without seriously affecting the completion date. Based on the results of projects studies and interviews carried out as part of this research, levelling of resources, in the UK construction industry, involves temporary increase and decrease of labour, plant resources and working conditions in an effort to achieve higher productivity without serious cost implications. Resource Levelling is a major sub-functional activity in the Improve Plan stage and requires a considerable amount of experience and co-ordination skills. Resource Levelling dominates all the activities in the Improve Plan processes and is characterised by a complex problem-solving procedure, Kahkonen et. al, (1991).

Resource Leveling has been carried out in the past by planners based on their skills and expertise and experiences, using trial and error methods. The functional activities at the Improve Plan stage replicates some of the functions in the Analyse Initial Plan stage, discussed in chapter 10. A Literature survey reveals algorithms currently under development and other combinatorial methods/techniques been used to handle adequately problems in the Improve Plan stage, Kahkonen et. al (1991). Some of these approaches include heuristics, linear programming, branch and bound and most recently fuzzy logic and fuzzy set theory based decision support systems.

These initiatives have contributed to the achievement of high level of performance in projects planning. However, the problems of repetitive functions, duplication of activities, and rework in planning still remains. In this research, proposed solutions with regards to project involving BIPV cladding systems installation are discussed in chapter 10 and 11.

9.7.8 Process Final Report

The processing of final report is a routine procedure of translating building plan/schedule into other forms of reports. The reports take various forms, such as, tables, graphical output, such as, histogram, graphs and bar charts. In project planning, three main reports are mostly processed, based on three main functions-as follows:

- Processing final time report
- Processing final resource report
- Processing final cost report

These three main groups of information for report processing are shown in figure 9.19. The information is grouped so as to facilitate the processing of other reports that might be required – for instance the material order and delivery dates. Inferring form figure 9.19, the first sub-functional activity of the 'Process Final Report' is the 'Process Final Time Report' stage.

9.7.9 Process Final Time Report

The Final Time Report provides the start and finish times of the various project activities. The outputs are classified in various forms by their purpose and formats. In general, they are produced in schedule form – as follows: Final General Schedule; Final Project Schedule and Other Periodic Schedules, McCaffer (1991), Kahkonen et. al,(1991). Some of these reports take different formats, which include the following: Bar charts – simple or linked; Activity List – which show the activities start and finish dates; the Network Analysis – which are the smaller self contained steps used in creating the network activities in a more experimenting nature in sequence. The stage-by-stage sub-functional process of the Process Final Report is shown in figure 9.19.

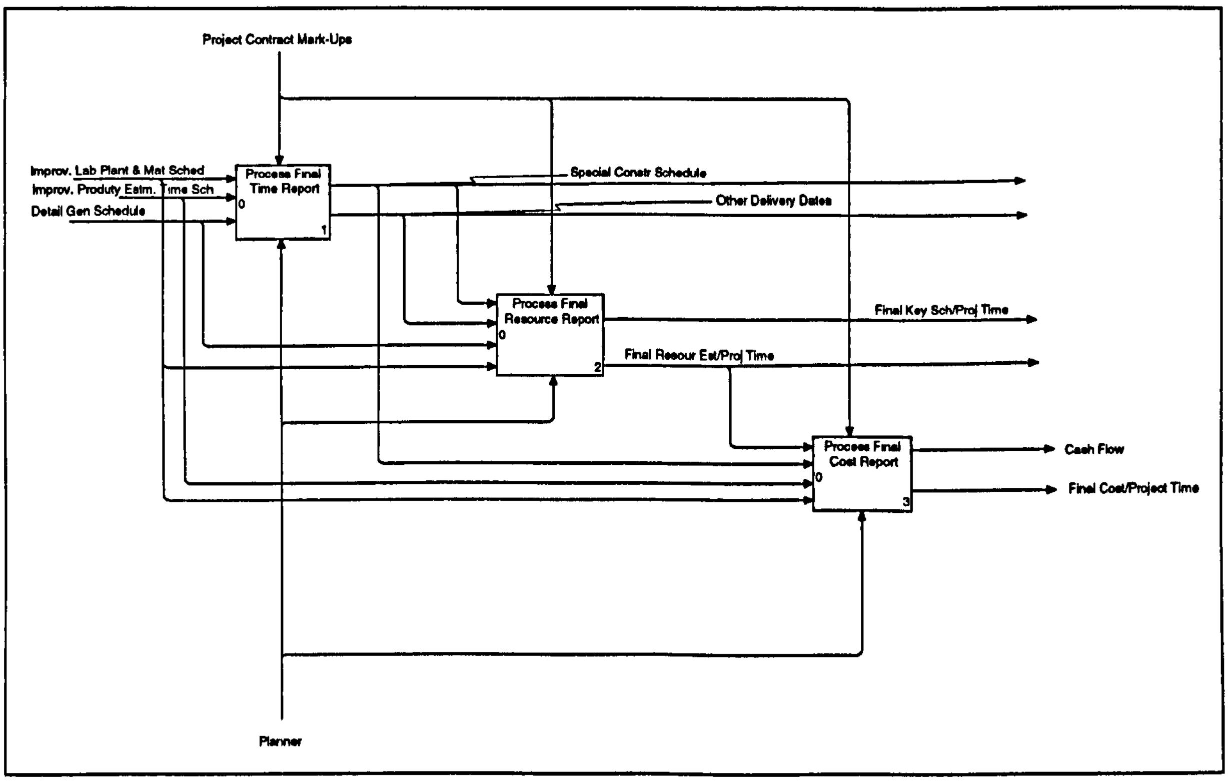

Figure 9.19: IDEF0 Model of the Produce Final Plan Stage (A5)

9.8 Process Project Final Report

The Final Report gives the key resources required during the project period. These form the basic information requirement for the final project schedules and assist planners to decide on the labour, plant, and material needs of the project. Finally it assists in the processing of the final cost report of a project.

9.8.1 Process Final Cost Report

The Process Final Cost Report is schedules process, which combines both the cost and time element. It illustrates a cumulative total project cost against project time, which are mostly used on major project for the control of the entire project. In most cases, the output includes cost/project time and a cash flow. The shortcoming and limitations of this process include duplication of function and re-discovery of information already acquired by other members of the design-management team. The next parent function activity in the design-management and planning process after the planning/scheduling stage is the cost estimating stage.

9.8.2 Overview of the Cost Estimating Phase

Estimating is the process of assessing the cost of a project. In most cases, the preparation of estimates for major projects is heavily influenced or dominated by planning and preparation of the construction methods and programs, McCaffer et. al. (1991). The processes use in carrying out estimating and planning activities, be it traditional method or the use of computers for estimating works on projects, follow the stage by stage functions illustrated with an IDEF0 model in figure 9.20. Inferring form the model in figure 9.20, the activities in the cost estimating phase which is a representation of the information gathered form the pilot studies are groups into five main stages. The are: Initial Cost Appraisal, Development of Method Statement, Estimating Preliminary Costs, Estimating Final Costs, and Preparation of Final Cost Report. These activities replicate the current practices of the industry and comparing them with the parent model in the planning phase, chapter 9.20, they show great signs of duplication of function between these two phases. Similarly there is a repetitive effort to exchange information between the estimating and planning phases. An analysis of the flaws in the poor interface between the estimator and the planner is unveiled, using SA\BPR business process re-engineering approach in chapter 10. Detail of IDEF syntax and semantics were discussed in chapter 8.

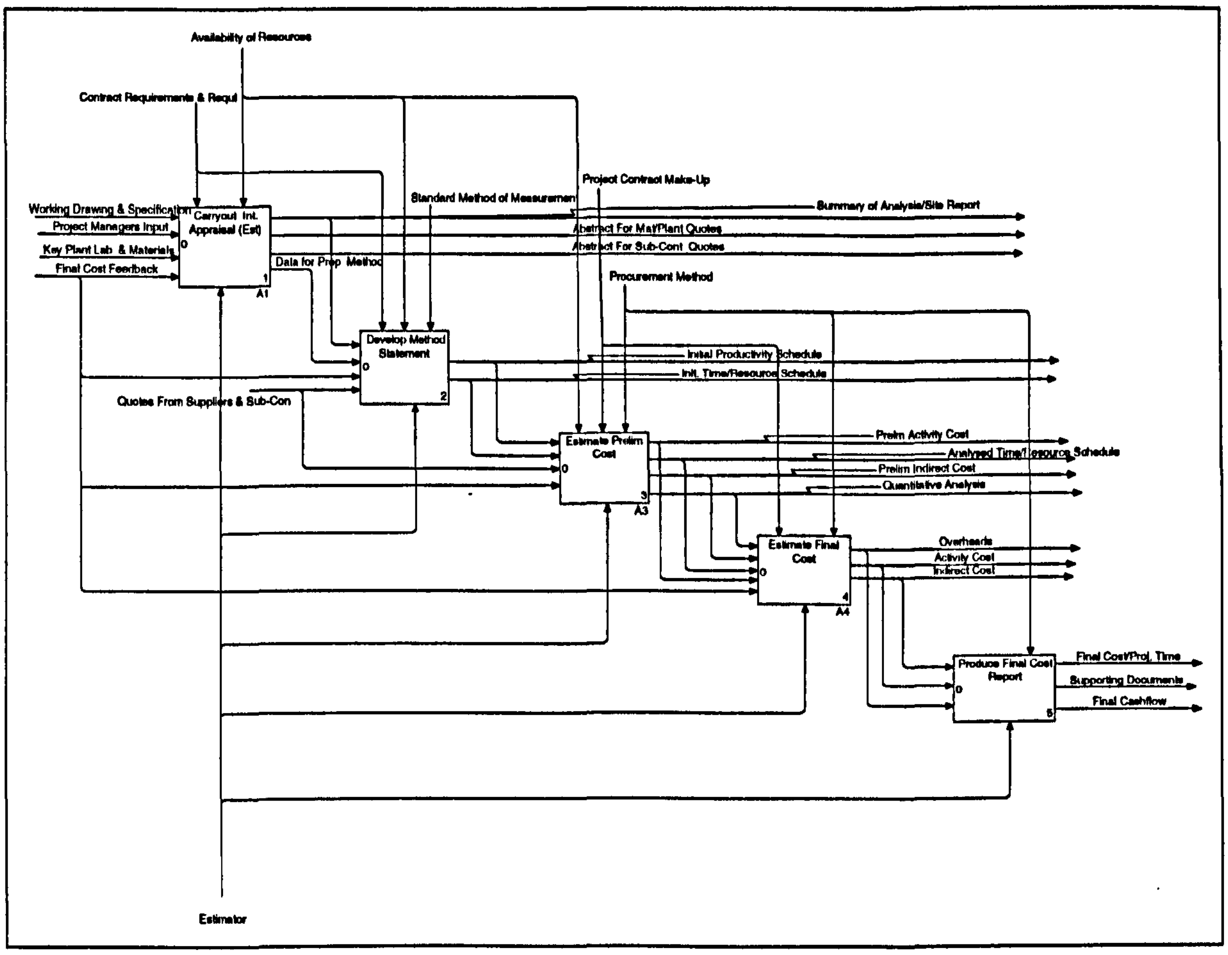

Figure 9.20: IDEF0 Parent Model of the Cost Estimating Processes (A-0)

In this process the repetitive way information is generated by participants; the overlapping, and the duplication of areas in design, planning and cost estimating is unveiled.

9.8.3 Initial Cost Appraisal

The purpose of the initial cost appraisal function is to highlight any high value areas or any particular problem of the contract documents. This includes working drawings, specification and plan/schedule, which require special attention. Initial Cost Appraisal is the first logical step in producing a cost estimate and it includes the identification of other possible alternative methods of construction. Other purposes of Initial Cost Appraisal is to enable the following to be established:

- The principal quantities of work
- An appropriate estimate to be carried out
- The items to be sub-contracted to be extracted
- The materials for which quotation are required
- The key delivery dates
- Whether there is a case for considering design alternatives or alteration to temporary works.

The variables needed to perform the functional activities at the Initial Cost Approval stage are illustrated in figure 9.21.

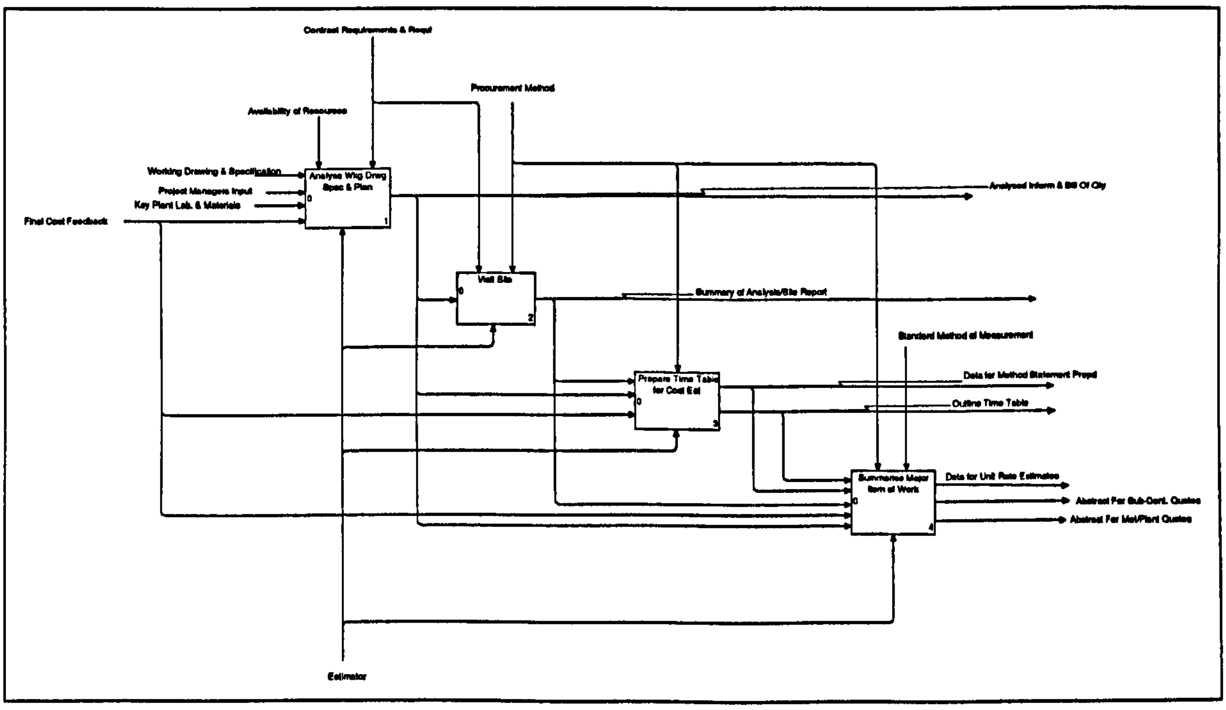

Figure 9.21: IDEF0 Model, the Initial Cost Appraisal Stage (A1)

9.9 Analyse Working Drawings Specification & Plan

The first sub-function activity at the initial cost appraisal stage is the Analysis of the Working Drawing Specification and Plan/Schedule. It involves a thorough examination of contract documents including the working drawing specifications and plan/schedule by the estimator whereby, all queries concerning the project are highlighted. These collate with other queries raised by the planner and other members of the contractor's team who also examine the contract documents. In practice the performance of this sub-function duplicate the functions of the planner at the initial appraisal stage when the two functions - estimating and planning are separate with or without the close liaison between the to personnel. These results into the re-discovery of information already obtained by the planner during the estimating process. The duplication of efforts is minimal in other cases where the estimator is responsible for his own planning, McCaffer et. al. (1991). The next stage of the Initial Estimating Process is the Site Visit.

9.9.1 Site Visit

The next sub-functional process at the initial cost appraisal stage is the site visit which determines problems on site, the possibility of temporary design works, and the need for changes in the original design. The other purpose of the site visit is to provide an opportunity for the examination of the general locality, as well as establish the extent of other building works in the area. Other important information to be ascertained during the site visit is as follows:

- Position of the site in relation to road, rail, and other public transport facilities
- Topographical details of the site, including notes of trees and site clearance required.
- Any demolition work or temporary works needed
- Access points to the site and any restraints on layout that have been considered including temporary roads
- Ground conditions and water table; facilities in the area for disposal of spoil
- Existing services, water, sewer, electricity, overhead cable etc
- Any security problems; the need for hoarding etc labour situation in the area.
- Location of nearest garages, hospitals, police and cafes in the area
- Restraints imposed by adjacent building and services i.e. space available for tower cranes, overhanging etc.
- Other works currently in the area or shortly to start.

- Availability of space for site offices, canteen, stores, toilets, and storage or any special difficulty that might be encountered during the construction process.

From the site visit, a detailed report giving all the information from the above mentioned site conditions is made. This information also form part of the input for the cost analysis. It also forms part of the basis of discussion during the estimation visit to the project by the consulting team which include the consulting engineer, the architect, the service engineer and sometimes the quantity surveyor. Another importance of the visit to the consulting team by the estimator is to present the queries to the team and also to meet the personalities who will subsequently be involved with the project. In practice the performance of these activities duplicates the function of the planner when there is separation of the estimating and planning function. This also brings about rework and rediscovery of information already obtained by the planner during the estimating processes. The output of the 'Site Visit' takes the form of a report and serves as input for the next sub-functional activity- the Preparation of Timetable for Cost Estimates and Summary of Major Items of Work respectively. As illustrated in figure 9.20, the output of the Initial Cost Appraisal is the input for the next parent functional activity in the Cost Estimate stage, which is Develop Method Statement.

9.10 Develop Program & Method Statement

Develop program and Method Statement is a sub-functional process, which describes how the entire work of the project will be executed, giving the details of the type of labour and plant required, Sher (1995). The preparation of the method statements provides alternative methods of construction, which are considered together with alternative sequences of work and site condition, Oteifa et al 1991. In practice, the separation of estimating and planning functions, at this stage, brings about rediscovery of information and rework, McCaffer et al (1991). The influence of planning on the estimating processes, at this stage, is also dependent on the alternative methods used in carrying out the estimating process. From a survey carried out as part of this study, there is evidence to suggest that the type of estimating method used for a project depended on the type of project and level of estimates required. In all the methods studied the duplication of effort varied with the degree of separation of planning and estimating functions. The other type of estimating method which shows significant signs of duplication is the "unit rate" estimating based on assumed or collective product rates. Other factors which contribute to the higher level of duplication of effort between the estimator and the planner at this stage are the project size, the project complexity, and the procurement method adopted for the project delivery, Sher (1995). The procurement method used for a project affects the contract conditions and also has great influence on planning and estimating activities. The functions of Program and Method Statement can be divided into four main functions:

- Creation of Activity List
- Definition of Sequence
- Overlap Activities
- Leveling of Activities

In a nutshell, this sub-function replicates the Create Initial Plan in the Planning phase. In addition to producing the work breakdown structure, the Develop Program and Method Statement provides the initial productivity schedule and the Initial time/resources schedule required in the Estimating Preliminary Cost stage.

9.11 Estimate Preliminary Cost

Estimate Preliminary Project Cost is the main parent functional process of the overall project Cost Estimating phase. The process at this stage is argued to be one of the most duplicated functions in design – management process. It is carried out in for main sub-functional stages as follows:

- Quantitative Analysis – this function analyses the quantities of materials, attendance and other input form suppliers and data from subcontractors
- Time Analysis- this function produces some input data for the resources and cost analysis.

- Resources Analysis – this function covers the analysis of the resources required for the project and also serves as an input data for the cost analysis function.
- Cost Analysis – covers the activity cost estimation, i.e. the indirect cost estimates as well as Cash Flow Analysis.

9.11.1 Quantitative Analysis

'Quantitative Analysis' at the Cost Estimating stage is the critical assessment of the quantities of material required quotations received, checking to ensure that materials to be supplied, by the supplier, comply with the specifications. Similarly, the activity of the Quantitative Analysis stage ensures that the requirements concerning fixed or fluctuating prices are complied with. Other sub-functional activities at this stage are to ensure that the checked materials will be available to meet the construction program requirements. The output of the Quantitative Analysis stage is used as the input for the next sub-functional activity, which is the Analyse Time Schedule.

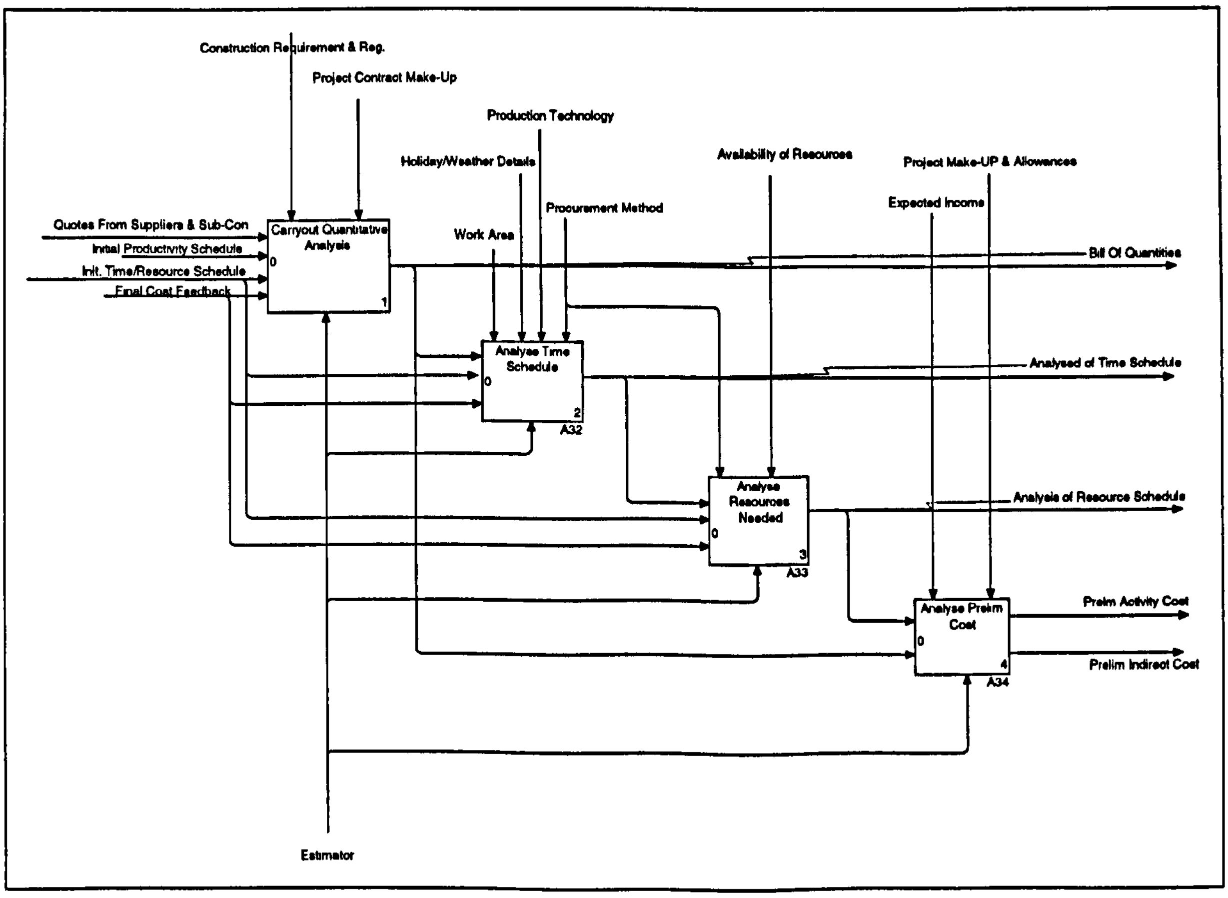

Figure 9.22: IDEF0 Model of the Estimate Preliminary Cost Stage (A3)

The Analyse Time Schedule sub-functional activity is the second important process in Estimate Cost Function, as identified by this study. This sub-functional activity duplicates some of the functions in Analyse Initial Plan in project planning. The functions incorporate the estimation of the start and finish time of each activity. The variables required to perform the Analyse Time Schedule function are shown in figure 9.23. This functional process can further be elaborated upon using the decomposition structure of IDEF0 to provide a supplementary information of this stage. The Analyse Time Schedule functional process can be summarily divided into three main areas such as:

- Estimation of activity time
- Estimation of production time in workdays, weeks or months
- Estimation of production time in calendar days, weeks or months can be provided.

Estimate Activity Time – in estimating process, be it operational, spot item, unit rate approach or the combination method, project time can form one of the most important constituents in cost assessment. It can be estimated in either workdays or calendar days and the process involves calculating the start and finish times for each activity. Also based on the type of procurement method adopted for the project delivery, this sub-functional process can duplicate the function in project planning.

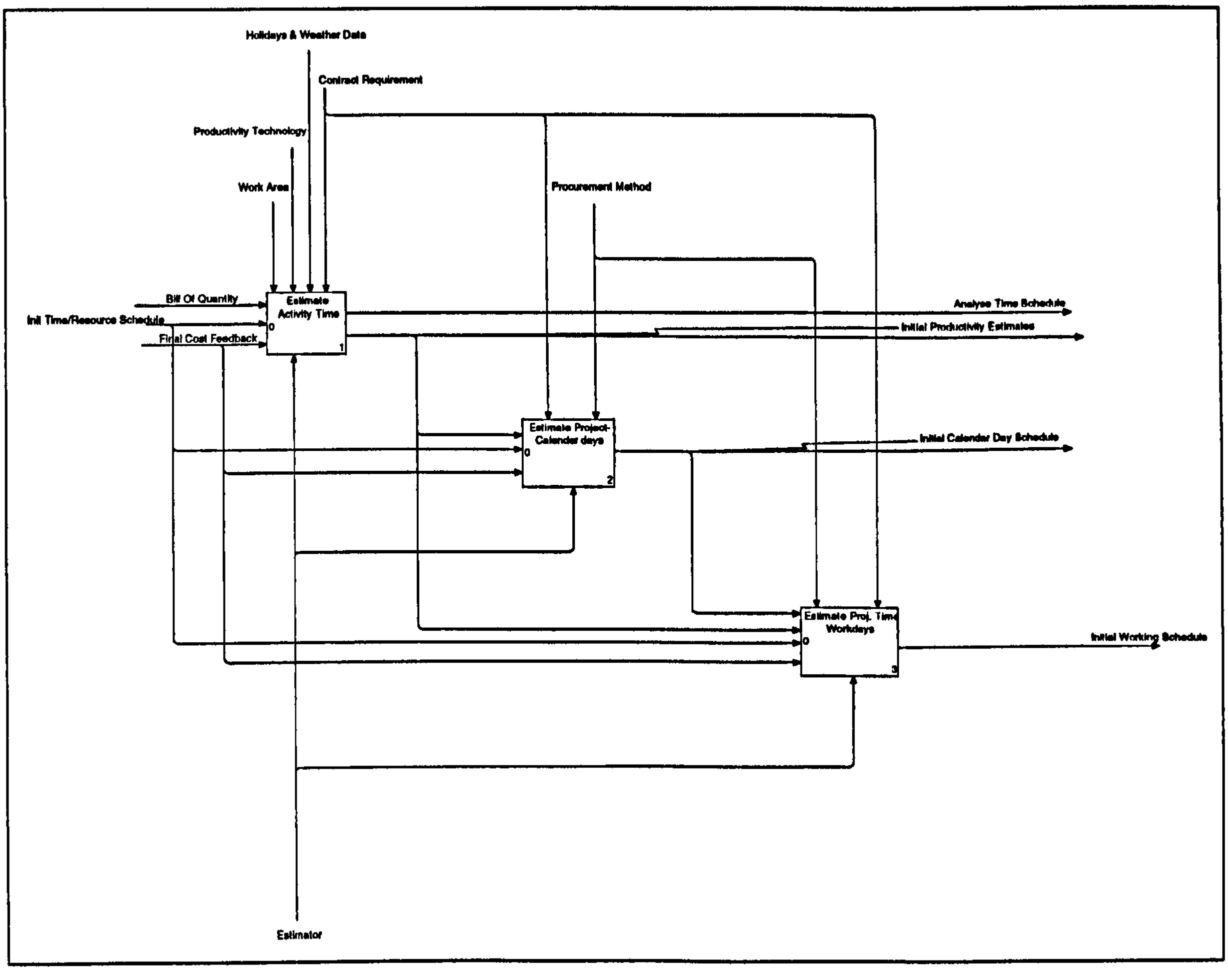

Figure 9.23: IDEF0 Model - Child Diagram of the Analyse Time Schedule Stage (A32).

The output of the Analyse Time Schedule function, now becomes part of the input data required to carry out the functions at the 'Analyse Resources Needed', and the 'Analyse Cost' stage respectively.

9.11.2 Analyse Resources Needed

Resources Anlysis is one of the most important phases in project management. The functions of analyse resources needed is very implicit, in the sense that it is essential in both planning and cost estimating activities without any formal definition of its functional boundaries. 'Analyse resources needed' is a major sub-functional activity in the in the Estimate Cost stage, where either the cost data or the output rate / the production times method is used to produce direct cost rates for bill items. The activities in these sub-functional processes can be divided into three main areas such as:

- Allocation of resources to activities
- Calculation of resources needed
- Analysis of limits of resources (which includes evaluation of other options).

Figure 9.24 illustrates the important variables needed to carry out the sub-functional activities at this stage.

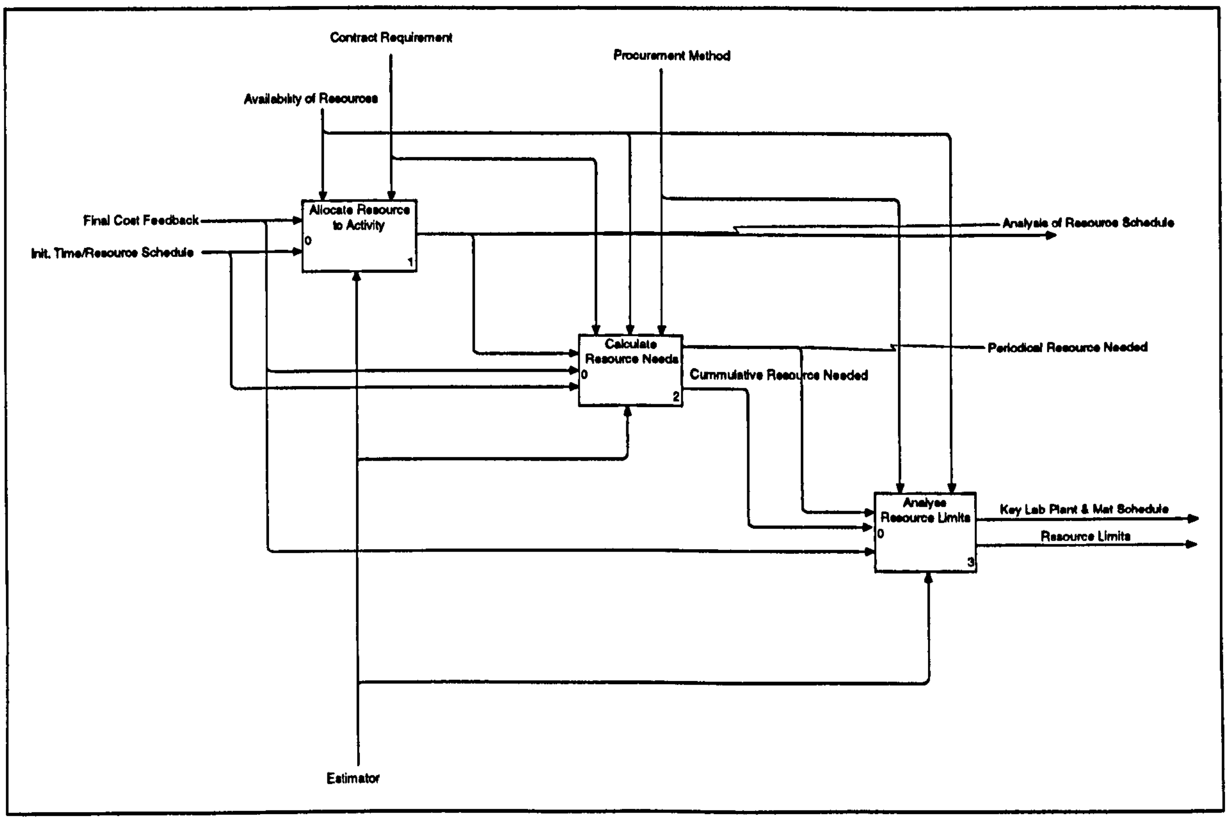

Figure 9.24: IDEF0 child diagram of the Analyse Resource Needed Stage (A33).

In general, the analysis of resources needed involves detailed allocation of resources to the listed activities, and assessing the limits of the selected resources and the associated cost implications. The assessment and use of other optional cost-effective resources are also analysed at this stage. The output data serve as an input data for the Cost Analysis function. In practice, there is duplication of efforts and rework in carrying out the functional activities at this stage. The same function is carried out by the planner (in the Analyse Resource stage in figure 9.16) when the estimating and planning functions are not fully integrated or operate with poor co-ordination, McCaffer (1991).

9.12 The Analyse Preliminary Cost Stage

The Preliminary Cost Analysis function in estimating may assume a variety of forms. These may include the composite net unit rate approach; the spot item approach; the extension of bill of quantity approach; the operational estimate approach; the prime cost approach or the combinatorial approach. The combinatorial method uses a combination of cost data and production times to produce direct cost rates for group of bill items, Ashworth et al (1993); McCaffer et al (1991); Lover et al (1995). In bring this work closer to current practices unveiling some of the duplication of functions between estimating and planning processes, the combinatorial approach is adopted at this stage. The model of the process, at this stage, replicates the general practice in the UK construction industry- a great degree of overlap occurs in functions between planning and estimating. However, the amount of overlap of functions and the repetitive effort used to acquire information depends on the degree to which the two functions have diverged. The details of the sub-functional activity and the variables at this stage are illustrated in figure 9.25.

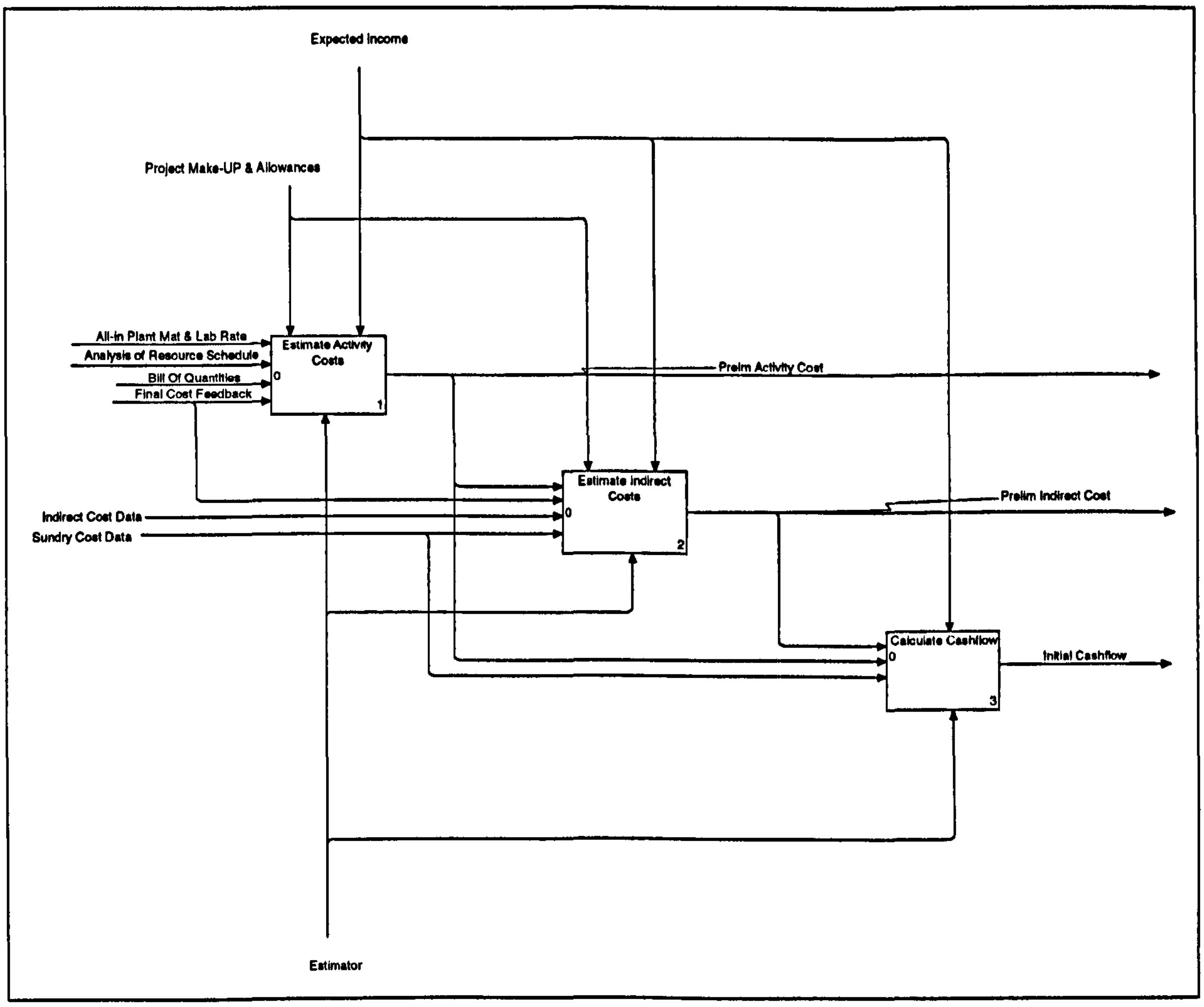

Figure 9.25: IDEF0 child diagram of the Analyse Preliminary Cost stage (A34).

The diagram in figure 9.25 shows the parent functional activities at this stage, which are grouped into three main parts, as follows:

- Estimate activity cost
- Estimate indirect cost
- Calculate cash flow

9.13 Estimate Final Cost

The final cost provides the cumulative total cost of the project consisting of the Net Activity Costs and Site Overheads or Indirect Costs which includes the cost of Attendance. All these costs constitute of the Construction Costs. The Construction Costs together with the General Overheads constitute the Net Project Cost, McCaffer et al (1991). The components for the Estimate Final Cost stage are illustrated with an IDEFO model diagram in figure 9.26. Base on the survey carried out as part of this research, figure 9.26 is a representation of current practice within the UK construction industry. The Net Project Cost together with the risk and profits for the contractor constitute the tender price. This is sometimes adjusted after adjudication to become the final cost of the project.

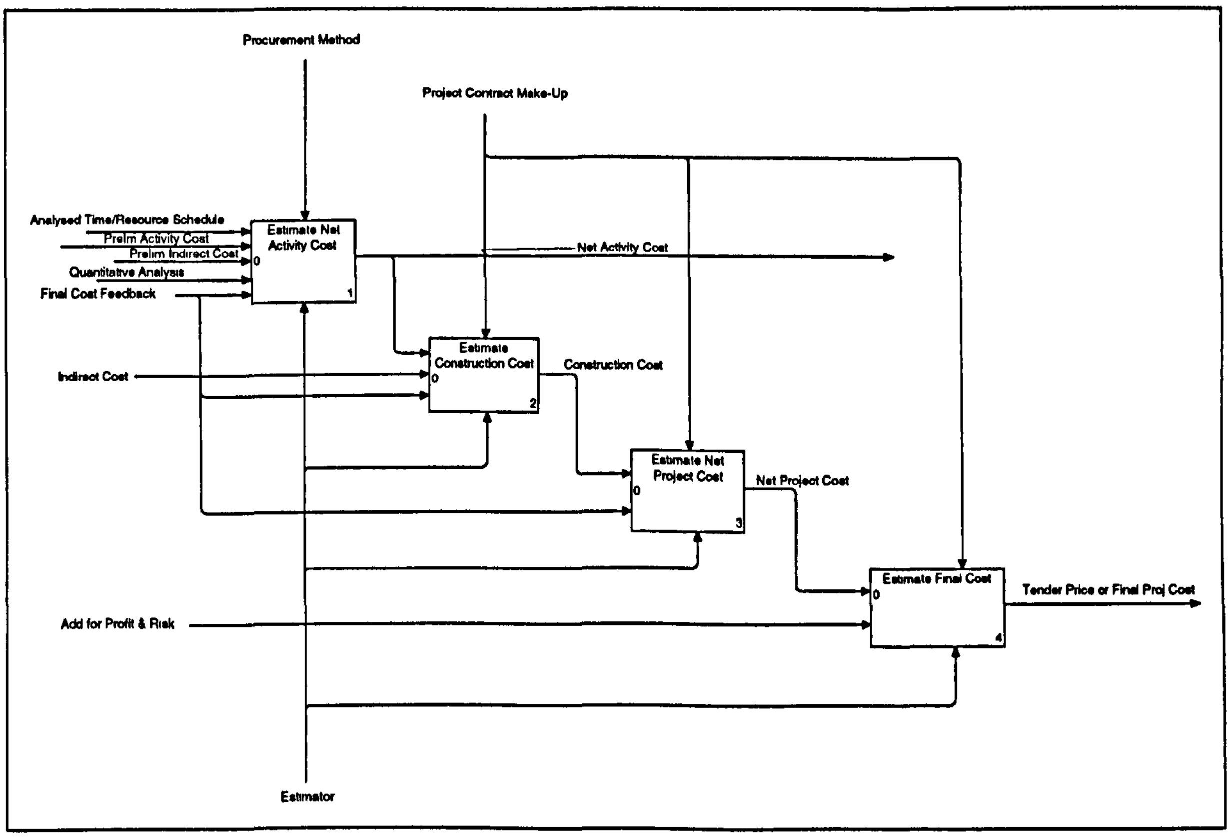

Figure 9.26: IDEFO Model of the Estimate Final Cost Stage (A4)

The next parent functional activity in the existing design management process is the preparation of Final Report.

9.14 Process Final Cost Report

The Final Cost Report process combines both project cost and time element. It illustrates a cumulative total, project cost against project time. Apart from providing the final cost and other relevant information for which a proposed project can be successively delivered, the Final Cost Report can be used as a tool for project control and monitoring activities. It is sometimes referred to as the estimators report to the project management. The final cost report consists of the cost/project time, the project cash flow, summary and analysis of other supporting documents. The report also includes the supporting quotation for domestic sub-contractors; material, plan, tender documents, and contract drawings. Project Analysis, which is part of the Final Report, includes the following:

- A brief description of the project
- A description of the method of construction
- A note of any actual risks which are inherent in the project
- The condition of contract
- Any unresolved technical or contractual problems
- An assessment of the profitability of the project
- Any pertinent information concerning market and industrial conditions
- The terms of the quotation form the accepted sub-contractors, which have been included in the estimate
- Employers special conditions i.e. bond / special insurance etc.

The supporting documents provide additional detailed information in the report and analysis. They include the following:

- Preliminary tender inquiry form
- Site visit report
- Schedule of Provisional Cost sums, Provisional sums and Day-work
- Tender program and Method Statement

- Schedule of Project Overheads
- Cash Flow Calculations.

These are pieces of information, which are submitted by the estimator to the management for adjudication.

9.15 Summary of Finding and Discussions

The analysis of design-management process discussed in this chapter reflect the overall activities in design, planning / scheduling and cost estimating in a real-world practice within the UK construction industry. The IDEF0 modelling facility of the SA-BPR CASE tool used for the analysis provided an effective tool for a better understanding of the information flow, functions and processes in project design-management. Inferring for the models representing the functional processes in design-management, the captured information reflected the diversified and complex processes characterised by 'over-the-wall' sequence of activities which tend to foster 'them-and-us' attitude between practitioners. The phases with rigid functional barriers may be attributed to the causes of conflict of operations, which lead to duplication of function and rediscovery of information already obtained by the other participants, Anumba et al (1996). In the UK construction industry, contractors are advocating for time compression in order to meet their objectives. However, the 'end-on' processes results in longer overall project period than is necessary, Frank (1998). Furthermore, the implicit functions between estimating and planning as shown in the existing design-management processes are found to be contributing to the duplication of efforts, rework and rediscovery of information. Information on design risk analysis and hazard checks, essential for the control of the design activities, do not seem to be carried out – as suggested by the findings of this research. From the finding of this research there is evidence to suggest that implicit function with rigid communication barriers in the design-management and planning phase do not allow for effective identification of design risk, which ought to be communicated to all those involved – for proper consideration and analysis of options. Similarly, implicit functions with rigid communication barriers in these processes do not allow any identified design risk to be effectively disseminated to the relevant participants for proper handling. These factors contribute to unsafe construction practices, which has plagued the UK construction industry for decades. Against this background, the need to re-engineer the design-management and planning of construction activity in line with the recommendation put forward by both the Latham and Egan report cannot be overemphasised. In order to carry out radical and innovative change to existing design-management processes, there is need to unveil the indicated ambiguities in design-management processes. This includes effective identification of the flaws in design-management processes and development of a system that would eliminate the flaws identified. The proposed system, once in place, should reflect an effective means of co-ordinating and communicates information across a multi-disciplinary team within the design-management and planning framework.

The proposed Innovative Model, bases on Business Process Re-engineering (SA/BPR) CASE tool, is discussed in the next chapter. The proposed model will form a paradigm for specification and development of an object based decision support system. The model will also serve as a framework for an optimal and systematic approach to design-management, planning and execution of a Building Integrated Photovoltic (BIPV) cladding work-packages with the UK construction industry.

Proposed Design-Management & Planning Models

10.1 Introduction to Proposed Models.

The first phase of re-engineering of the current process in design-management involved the analysis of existing practices in design, estimating, planning and construction - carried out in chapter 6, 7 and 9. Evidence suggests that current practices in design-management and construction procurement are complex. The complex processes involve a multiplicity of disciplines with diverse interests, aims and objectives. Existing processes and sub-processes are inconsistent and are being operated on an ad hoc basis, Franks (1991), Aouad et al (1994). These processes are saddled with wasteful activities, duplication of functions and rework. Waste, rework and duplication are some of the characteristics of they UK cladding industry and construction industry, Anumba et al (1996), Fluchter (1996), Ledbetter (1997). Wasteful activities consume time, effort and above all they cost money. Processes with rigid functional barriers bring about a 'them-and-us' attitude, which is widely believed to be detrimental to communication across all disciplines, Aouad (1994), Franks (1991).

The need for radical and innovative changes in existing processes cannot be over emphasised, Lover et al (1995). In order to achieve this objective, analysis of the various methodologies used in the construction industry was undertaken in chapter 9 to reveal the flaws in design-management so as to re-engineer the processes. The first section of this chapter analyses the methodology used to provide a systematic and effective utilisation of the techniques used to device an innovative design-management and planning process. The approach adopted in this chapter is quite distinct from existing re-engineering methods, which do not completely eliminate wastefulness in design-management processes, Sarkis & Lile (1995). It critically analyses each of the functions, the inputs, outputs, and mechanism involvement in existing processes, in terms of integration and implementation. Based on the integration between the activities and the information generated during the design-management and installation processed, the duplicated functions and wasteful activities are identified and eliminated. The actual innovation processes was carried out through an iterative process and in direct consultation with professionals of companies that took part in the range of surveys and case studies that were carried out as part of this research (chapter 9). More detailed information on the results and findings may be found in the appendix.

In order to assess the level of improvement that the re-engineering approach has contributed to the innovated processes, the last section of this chapter is focused on Process Based Costing Engineering, which is used as a means of bench-marking the performance of the new process. The detail of the 'innovative approach' is the subject of the next section.

10.2 The Development of the Process Innovative Methodology

Design-management, supply chain management, planning and installation of advanced cladding systems (including BIPV), within a wider construction project, is vast and difficult to understand and manage. The problem is further exacerbated, when tradition procurement methods and other similar techniques are used, Anumba et al (1996), Franks (1998).

The Process Innovative Methodology is a framework developed in the research to support process modelling aimed at identifying the ambiguities mentioned in chapters 7, 8 and 9. The development of this framework is grouped into four major stages:

- Developing the Process Planning Matrix (PPM)
- Developing the Innovative Process Matrix (IPM)
- Developing the Innovative Activities Statement (IAS)
- Developing the Enhanced Process Matrix (EPM)

All the matrices involved in this process are developed using the IDEF0 matrix facilities of the SA/BPR (System Architect/ Business Process Re-engineering) CASE tool. The innovative proposal in this research was developed from the process models representing the existing processes. However, the CASE tool has some limitations. It does not allow a matrix that provides the overview of the design-management, and planning 'functional areas' to be generated directly from the IDEF0 models. A ' Functional Area' in terms of design-management and planning is a naturally coherent grouping of the design-management functions, which utilise the information generated by the preceding or succeeding functions, FIBS-184 (1994). In order to exploit this technique to its maximum potential, the entire innovative development process is presented in an IDEF0 model shown in figure 10.1.

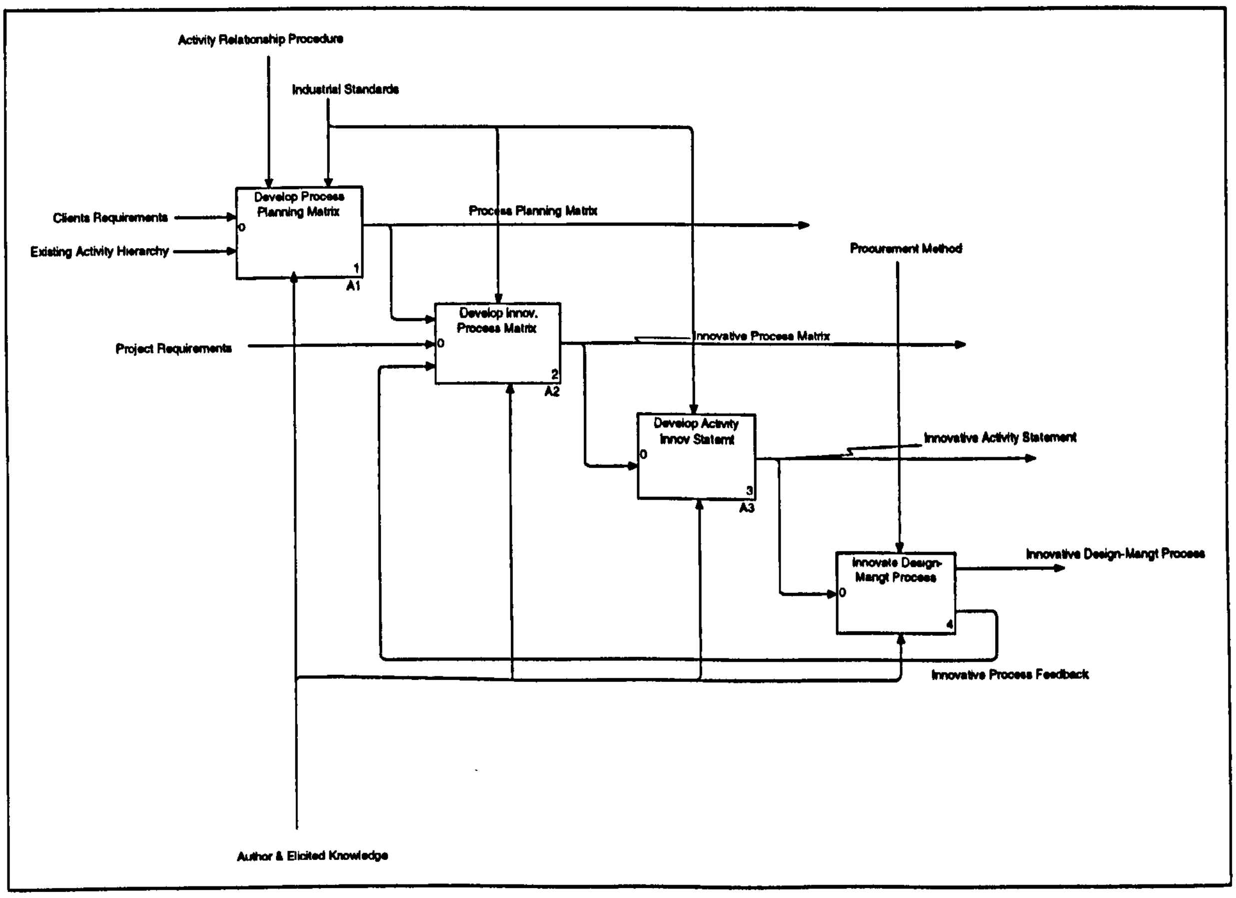

Figure 10.1: IDEF0 Model of the Innovative Development Process (IDP) (A-1)

Inferring form figure 10.1, the first functional activity of the innovative development process is the Process Planning Matrix (PPM). The PPM uses the client's requirements, client brief and existing design-management activity hierarchy as the main inputs. The other variables are illustrated in the model; the detail of this process is discussed in the next section.

10.3 Process Planning Matrix Development

The Process Planning Matrix is the first stage of the innovative development process as shown in figure 10.1. The rationale behind this development is to provide an overview of the main sub-functional activities in the entire design-management and planning processes against their respective outputs. This is a means to illustrate the areas of high cohesion between the sub-functions in the design-management and planning process. The variables required to perform the functional activities at this stage are shown in Figure 10.1. Inferring from figure 10.1. The functional activities in these processes were converted into Functional Activities Hierarchy as shown in Table 10.1, using the Activity Hierarchy tool in SA/BPR. The main aim of the Functional Activity Hierarchy is to provide an overview for the purpose of the hierarchical pattern of various overlapping functions of the participants and existing duplication of activities/functions within the existing processes. Inferring from table 10.1, the responsibilities of the participants as well as the information generated takes the form of a matrix, and its attributes are in linguistic variables (Symbols). The matrix developed also reveals some of the ambiguities in the existing processes. It also shows the importance of some of the various information generated by other functions. The outcome of the matrix provides a means to verify the effect-generated information has on other functions within the design-management and planning process. The matrix shown in Table 10.1, further reveals some of the repeated functions and outputs, in existing processes, indicated by an asterisk " * "; they include the following:

- Visit Site – carried out at the Initial Design Stage, Initial Planning Appraisal Stage and the Initial Estimating Appraisal Stage.
- Development of Initial Timetable – carried at the inception Design Stage, Initial Planning Stage and the Initial Estimating Stage; these two functions are separated.
- Major Items of Work Summary – this function is performed at both the Planning and Estimating stages

MAIN FUNCTIONS	SUB-FUNCTIONS	CONTROL VARIABLES	OUTPUT VARIABLES	RESPONSIBITY					CONTROL				
				Client	DESIGN'R (ARCH)	DESIGN'R (ENG.)	PLANNER	ESTIMATOR	Client	DESIGNS (ARCH)	DESIGNS (ENG.)	PLANNER	ESTIMATOR
Establish	A11Carryout Initial Biefing	C_1, C_2, C_3, C_4	O1	C	R	R	R	R	S	V	I	I	I
Design	A11 Analyse Brief	C_1, C_2, C_3, C_4	O1		C					S			
Require'mt	A12 Vist Site	C_1, C_2, C_3, C_4	O5 *		C	C	R	R		S	S	I	I
A1	A13 Develop Brief	C_1, C_2, C_3, C_4	O2		C	R				S	I		
	A14 Review Brief	C_1, C_2, C_3, C_4	O4		C					S	I	N	N
Create	A21 Develop Prel. Arch Design	C_1, C_2, C_3, C_4	O6		C	R	R	R	A	S	V	I	I
& Approve	A22 Develop Prel.Struct. Design	C_1, C_2, C_3, C_4	O7		R	C	R	R	A	I	S	I	I
Prelim. Designs	A23 Develop Initial Specs.	C_1, C_2, C_3, C_4	O3		C	R	R	R		S	I	I	I
Design A2	A24 Obtain Client Approval	C_1, C_2, C_3, C_4	O3, O6, O7	C					S				
Develop	A31Develop Detail Arch. Design	C_1, C_3, C_4	O9		C	R	R	R	A	S	I	I	I
Detail	A32 Develop Detail Struct. Design	C_1, C_3, C_4	O10		R	C	R	R	A	I	S	I	I
Designs A3	A33 Check Suitability	C_1, C_3, C_4	O9, O10		R	C				V	S	N	N
	A34 Oblail Approval	C_1, C_3, C_4	O9, O10						A				
Gen. Wkg	A41 Develop Working Drawing	C_1, C_3, C_4	O11		C	C	R	R	A	S	V	V	V
Drwg A4	A42 Develop Final Design Specs.	C_1, C_2, C_3, C_4	O8		C	R	R	R	A	S	V	I	I
Carryuot	A51 Analyse Working Drawings	C_2, C_4, C_5, C_8	O13				C		N	N	N	S	I
Initial	A52 Visit Site	C_2, C_4, C_5, C_8	O5 *				C	C		N	N	S	I
Appraisal	A53 Develop Init.Plan Timetable	C_2, C_4, C_5, C_8	O15 *				C			I	I	S	I
A5 (plng.)	A54 Summ. Major Items of Works	C_2, C_4, C_5, C_8	O16 *				C	R		N	N	S	V
Create	A61 Create Initial Time Schedule	C4, C12, C13	O17 *				C	R	V	I	I	S	I
Initial Plan	A62 Create Initial Resource Schd.	$C_9, C_{10}, C_{11}, C_{12}$	O18 *				C	R		I	I	S	V
A6	A63 Initial Productivity Estimate	$C_9, C_{10}, C_{11}, C_{12}$	O19				C	R		I	N	S	V
Analyse	A71 Analyse Time Schedule	$C_9, C_{10}, C_{11}, C_{13}$	O20				C	R				S	V
Initial Plan	A72 Analyse Resources Schedule	C_4, C_{14}, C_{16}	O21				C	R				S	V
A7	A73 Estimate Unit Cost	C_4, C_{12}, C_{15}	O22				C	R				S	V
Improve	A81 Re-assess Resources	C_4, C_{14}, C_{16}	O23				C	R				S	I
Plan	A82 Re-assess Proj. Time	$C_9, C_{10}, C_{11}, C_{13}$	O24				C	R				S	V
A8	A83 Level Reources	C_4, C_{14}, C_{16}	O23, O24				C	R				S	V
Pro.Rep.A9	A91 Process Report	C_2 C_4, C_{11}	O25, O26				C	R	V	I	I	S	V
Initial	A10-1 Analyse Working Drawing	C_2, C_4, C_5, C_8	13				R	C				I	S
Appraisal	A10-2 Develop Estim. Timetable	C_2, C_4, C_5, C_8	O15 *		R	R	R	C	V	V	V	I	S
A10 (Est.)	A10-3 Summ. Major Items of Works	C_2, C_4, C_5, C_8	O16 *				C	C				I	S
SiteVisitA11	A11-1 Visit Site	C_2, C_4, C_5, C_8	O5 *				C	C				I	S
A12 Method Stmt.	A12-1 Develop Method Statem't	C_2, C_4, C_5, C_8	O16 *				R	C				I	S
Estimate	A13-1 Quantitative Analysis	C_2, C_4, C_5, C_8	O27				R	C				V	S
Prel. Cost	A13-2 Analyse Time Schedule	$C_9, C_{10}, C_{11}, C_{13}$	O17 *				R	C				V	S
A13	A13-3 Analyse Resources Needs	C_4, C_{14}, C_{16}	O18 *				R	C				V	S
Estimate	A14-1 Estimate Activity Cost	$C_4 C_8, C_{12}, C_{15}$	O28				R	C				I	S
Final Cost	A14-2 Estimate Indirect Cost	$C_4 C_8, C_{12}, C_{15}$	O29				R	C				I	S
A14	A14-3 Calculate Cash Flow	$C_4 C_8, C_{12}, C_{15}$	O30				R	C	V			V	S
Pro.Rep.A15	A15- Process Report	$C_4 C_8, C_{12}, C_{15}$	O31, O32, O33				R	C	V	V	V	V	S

Key

Output		Control	Variables
O_2 =Schematic Design	O_1= Analysed Brief	C_1=Regulations	/Reg.
O_4 = Reviewed Brief	O_3 = Initial Specifications	C_2=Bldg Stand.	& Codes.
O_6=Prel. Arch Design	O_5 = Site/Feasibility Report	C_3=Contract	Requirements
O_8=Final Design Spec.	O_7=Prelim Struct Design	C_4=Overall Des.	Man. Plan
O_9=Detail Arch.Design	O_{10}=Detail Struct Design	C_5=Procuremnt	Method
O_{11}=Working Drawings	O_{12} =Ammend. & Summ Rep	C_6=Project	Special
O_{14} = List of Activities	O_{16} = Summ Major Wk Items	C_7=Safety	Regulations
O_{13}=Analyd Wkg Drwg	O_{20} = Analysed Time Schedule	C_8=Preliminary	Cost Data
O_{15}=Initial Time Table	O_{21} = Analysed Res. Schedule	C_9=Production	Technology
O_{17}=Initial Time Sched	O_{22}=Estimated Unit Cost	C_{10}=Work Area	/SiteCondition
O_{18}=Initial Res.Sched	O_{23} = Re-assess Rasources	C_{11}=Probable	Weather Info.
O_{19} = Initial Prod. Est	O_{24} = Re-assess Proj Time	C_{12}=Expected	Income
O_{26} =Final Gen Sched	O_{26} = Final Plant Lab & Mat Sche	C_{13}=Holidays	Information
O_{27} =Quant.Anal Resu.	O_{28} =Activity Cost	C_{14}=Availability	of Resour.
O_{29}=Indirect Cost	O_{31} =Final Cost/Pro.Time	C_{15}=Pro. Contr.	Mark Up
O_{30} =Initial Cashflow	O_{32} =Supporting Documents	C_{16}=Company	Resources
O_{33} =Final Cashflow			

Table 10.1: The Functional Activity Hierarchy

Legend:

C	**Control**
R	**Responsibility**
S	**Specify**
V	**Very Important**
I	**Information**
A	**Approval**
N	**Not Central**

Inferring from Table 10.1 other duplicated functions include:

- Quantitative Analysis – this function is vital for both the planning and the estimating processes and its performance is repeated when these two functions are separated.
- Time Resources and Cost Analysis – these functions are repeated in both the planning and estimating stages. Figure 10.1, shows the details of these functions and output. Some of these repeated functions are shown in the diagram to be ambiguous. However, their performance at the various functional stages is shown to have some importance

The matrix provided a means of analysing repeat functions based on their input and output as well as their importance at any particular stage. The output of the matrix in Table 10.1 reflects the client's requirements as part of the project objectives. The project requirement constituted a major input for the Process Planning Matrix development stage. In this approach, the repeated functions, the level of involvement of the participants, as well as the importance of their output were determined. The sub-processes at the development of the Process Planning Matrix stage is illustrated with an IDEF0 model as shown in Figure 10.2

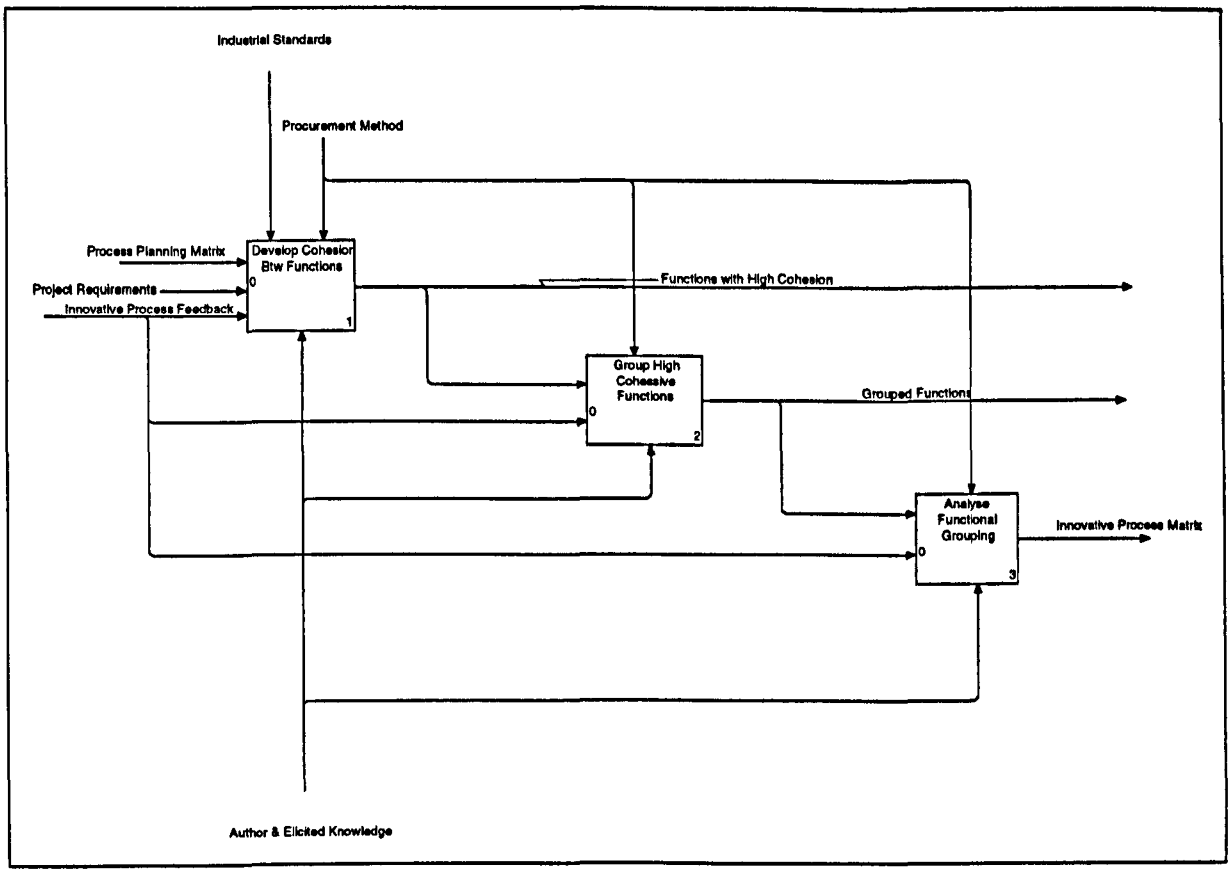

Figure 10.2: IDEF0 Model of the Develop Process Planning Matrix stage (A1)

The Process Planning Matrix is generated is shown in Table 10.2. It illustrates the fields and the factors in the matrix. The main objective of this process is to use the level of cohesion between the sub-functions, the importance of the information generated to the preceding and succeeding functions as well as the commonality of the information generated to map the sub-functions in the processes against the output. The factors, which determine the level of importance, are also shown in linguistic language (Symbol), and the output of the Process Planning Matrix becomes the input for the development of the innovation Process Matrix discussed in the next section.

10.4 Developing the Proposed Innovative Planning Matrix

The development of the innovative planning matrix is the second stage of the Innovative Development Process. The activities involved in fusing existing client's brief and the requirement are the outputs illustrated in Table 10.2 as the project requirements. The

Figure 4.0.1

Table10.2: The Process Planning Matrix

activities at this stage are illustrated with an IDEF0 model shown in figure 10.3, and the main is to develop the cohesion between functions for the actual innovative process.

Legend:

V **Very Important**
I **Information**
C **Control**
R **Responsible**

Legend for Table 10.2.

H1 Class of Cohesive Function
H2 Class of Cohesive Function
H3 Class of Cohesive Function
H4 Class of Cohesive Function

Legend for figure 10.3 and 10.4

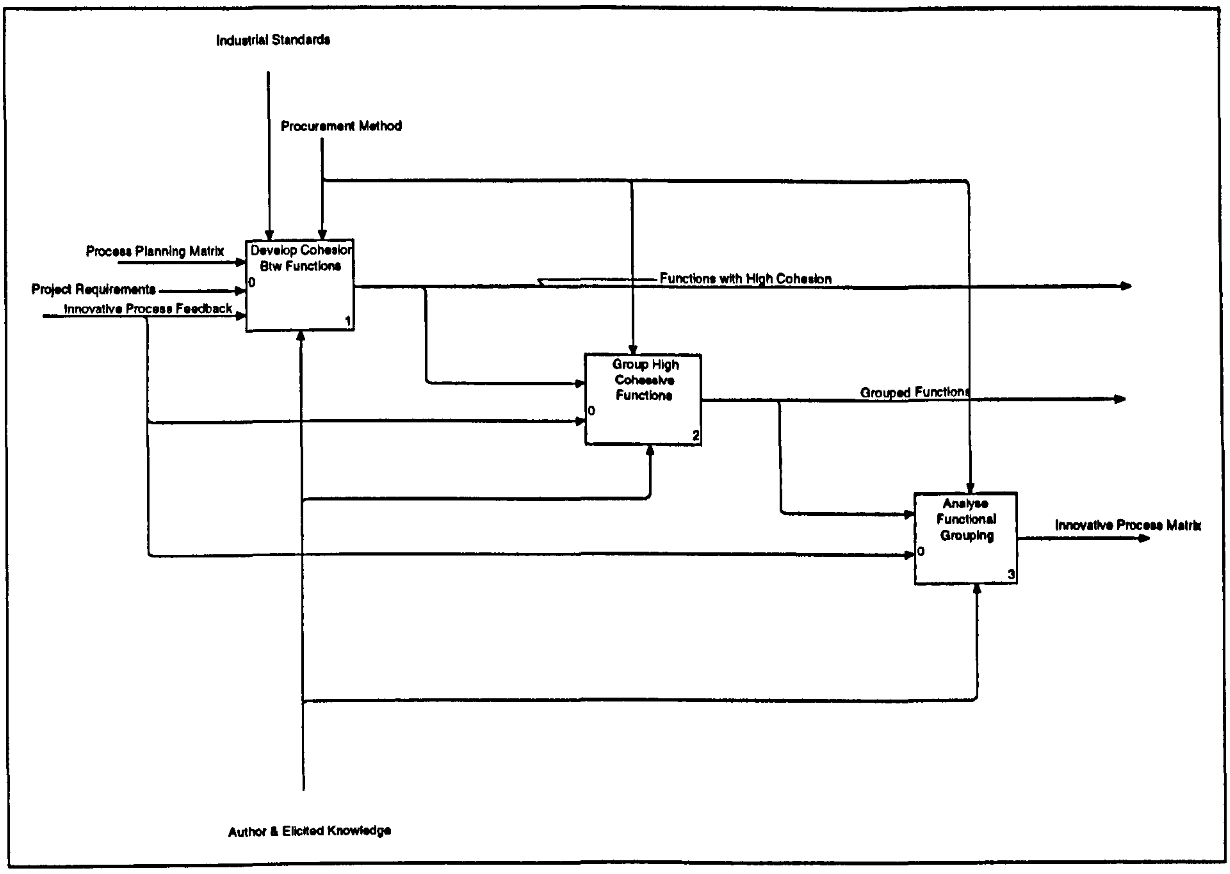

Figure 10.3: IDEF0 Model of the Develop Innovative Process Matrix Stage (A2)

The process involves the use of Activity Relationship Process to control this function where the high level functions in design-management and planning are grouped according to their importance as well as high dependency.

Other sub-functional activities and associated variables are shown in figure 10.3, depending on the type of procurement method adopted, the output which is the Innovative Process Matrix data is used by the SA-BPR CASE tool to generate the Innovative Process Matrix shown in Table 10.3. The outputs, which may vary in relation to the procurement method used, are analysed and subsequently become the input for the Innovative Activity Statement Stage discussed in the next sections.

OUTPUTS / SUB-FUNCTIONS	Overall Design Sch.	Proj. Control Authority	Project Guidelines	Project Cont. Authrity	Design Brief	Project Brief	Site & Feas. Report	Schematic. Design	Project Financial Plan	Schematic Resources	Prel. Arch. Design	Prel. Struct Design	Prel Specificationss	Approved Prel. Designs	Detail Arch. Design	Detail Struct. Design	Checked Det. Designs	Approved Det. Designs	Analy. Det Design&Specs	Working Drawings	Design Specifications	Initial Plan Time Table	Site Report	Abstracts For Quotes	Material Quotations	Plant Quotation	Sub-Con. Quotation	Initial Plan Time-Table	Initial Time Schedule	Initial Resources Schd.	Initial Productivity Estm.	Analysed Time Schedule	Analysed Res. Schedule	Estimate Initial Costs	Re-asses'd Time Sch.	Re-asses'd Resource	Levelled Resources	Final Time Schedule	Final Resou. Schedule	Final Plan Report	Analysed Drawing	Initial Estimate Plan	WBS	Initial Mat. Quantities	Initial Indirect Cost	Initial Activity Cost	Prel. Indirect Cost	Prel. Activity Cost	Total Prel. Cost	Final Indirect Cost	Final Activity Cost	Construction Costs	Net Project Cost	Cashflow Forecast	Cost Report
A1-1 Develop Overall Design Sched	H1	H1	H1																																																				
A1-2 Develop Proj Control Authority				H1																																																			
A1-3 Develop Brief					H2		H2	H2																																															
A1-4 Develop Project Brief						H2																																																	
A1-5 Develop Project Financial Plan									H2																																														
A1-6 Provide Reources										H2																																													
A2-1 Develop Prel. Arch Design											H3																																												
A2-2 Develop Prel Struct. Design												H3																																											
A2-3 Develop Init. Specs& Standards													H3																																										
A2-4 Obtain Client Approval														H3																																									
A3-1Develop Detail Arch. Design															H4																																								
A3-2 Develop Detail Struct. Design																H4																																							
A3-3 Check Suitability																	H4																																						
A3-4 Obtain Approval																		H4																																					
A4-2 Analyse Detail designs & Specs																			H4																																				
A5-1 ProduceWorking Drawings																				H5																																			
A5-2 Produce Specs & Other Docs																					H5																																		
A5-3 Develop Inital Plan Timertable																						H2																																	
A5-4 Visit Site																							H2																																
A5-5 Summ. Major Items of Works																								H2	H2	H2	H2	H2																											
A6-1 Develop Initial Time Schedule																													H2																										
A6-2 Develop Initial Resources Sch.																														H2																									
A6-3 Develop Initial Product'y Estim																															H2																								
A7-1 Analyse Time Schedule																																H2																							
A7-2 Analyse Resources Schedule																																	H2																						
A7-3 Estimate Initial Costs																																		H3																					
A8-1 Re-assess Resources Schedule																																			H4																				
A8-2 Re-assess Proj Time Schedule																																				H4																			
A8-3 Level Reources																																					H4																		
A8-4 Develop Final Time Schedule																																						H4																	
A8-5 Develop Final Resource Schedule																																							H4																
A9-1 Process Report																																								H5															
A10-1 Analyse Working Drawing																																									H1														
A10-2 Develop Initial Estimate Plan																																										H1													
A10-3 Summ. Major Items of Works																																											H1												
A11-1 Visit Site																																												H2											
A12-1 Develop Method Statement																																													H2										
A13-1 Quantitative Analysis																																														H3									
A13-2 Develop Prel. Activity Cost Est.																																															H3								
A13-3 Develop Prel. Indirect Cost Est.																																																H3							
A13-4 Develop Total Prel. Cost Est.																																																	H3						
A14-1 Estimate Final Activity Cost																																																		H4					
A14-2 Estimate Final Indirect Cost																																																			H4				
A14-3 Construction Cost																																																				H4			
A14-4 Calculate Final Const.																																																					H5		
A14-5 Calculate Cashflow																																																						H5	
A15- Process Report																																																							H5

Figure 10.3: The Initial Process Matrix.

10.5 Develop the Innovative Activity Statement (IAS)

The development of the Innovative Activity Statement is the third stage of the Innovative Development Process, it uses the output of the Innovative Process Matrix to feed the SA-BPR CASE tool which automatically clusters the high level functions into operational groups. Changes to these groupings were discussed with experts involved with the pilot studies in order to effect changes in accordance with the practices of the industry. The sub-functional activities are illustrated with an IDEF0 model in Figure 10.4.

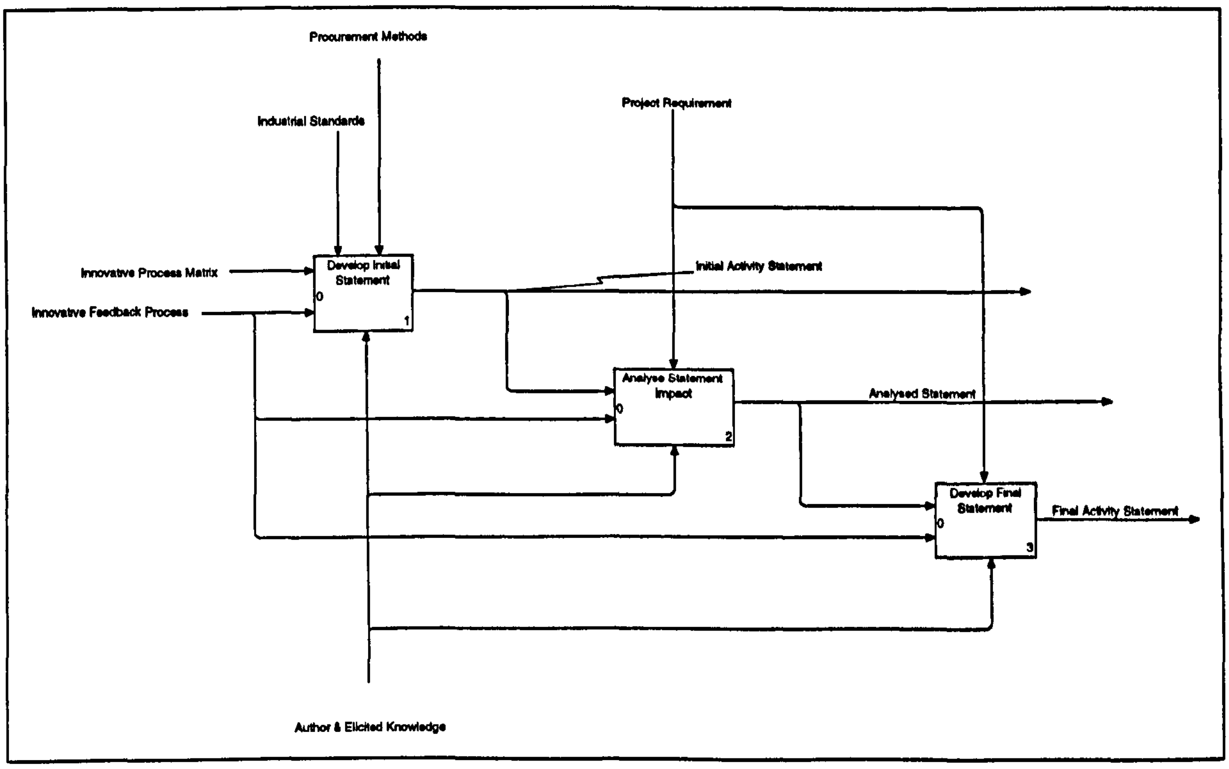

Figure 10.4: IDEF0 Model of the Develop Innovative Activity Statement Stage (A3)

Based on discussion with experts form companies involved with the studies, considerations for the development of the Innovative Statement were made. The major ones include integration perspectives, existing application implementation perspectives as well as the interaction between the processes and the information generated. The result of this approach is the suggested improvement to the Initial Innovative Activity Statement shown in Table 10.4.

SUB-FUNCTIONS \ OUTPUTS	Project Guidelines	Proj Control Authority	Project Authoris Plan	Overall Proj Dev Sched.	Project Standards	Project Financial Plan	Site & Feasibility Report	Statutory Agreement	Schematic Design	Schematic Plan & Cost	Prel. Arch. Design	Prel. Struct Design	Prel Specificationss	Prel. Plans	Abstracts For Quotes	Initial Time Schedule	Initial Resources Schd.	Prel. Estimates	ApprdPrel.Des.Plans&Est.	Detail Arch. Design	Detail Struct. Design	Detail Specifications	Material Quantities	Improvd Resource Schd	Re-Assed Proj Time Sch.	Detail Reso. & Time Sched.	Detail Estimates	Apd Det DesignsPln & Est	Anlysed Det Designs & Specs	Analysed Final Resource Sched	Final Time/Cost Sched.	Working Drawings	Design Specification	Final Plan	Final Indirect Cost	Final Activity Cost	Net Project Cost	Cashflow Forecast						
A1-1 Est. Project Specific Guidelines	H1				M	A	N	A	G	E																																		
A1-2 Est. Project Control Authority		H1	H1			P	R	O	J	E	C	T																																
A1-3 Est.Project Dev. Schedule				H1			I	N	C	E	P	T	I	O	N																													
A1-4 Define Project Specs & Codes					H1																																							
A2-1 Analyse & Plan Project & Finanaces						H2				D	E	V	E	L	O	P																												
A2-2 Carryout Site Visit & Feasibility Study							H2				I	N	I	T	I	A	L																											
A2-3 Obtain Statutory & Reg. Aggreement								H2				P	R	O	J	E	C	T																										
A2-4 Establish Project Design Basis									H2	H2			P	L	A	N																												
A3-1 Develop Prel. Arch Design											H3																																	
A3-2 Develop Prel Struct. Design												H3			D	E	V	E	L	O	P																							
A3-3 Develop Prel Specs& Standards													H3			P	R	E	L	I	M	I	N	A	R	Y																		
A3-4 Develop Prel Plans														H3			D	E	S	I	G	N	S																					
A3-5 Obtain Qoutaions															H3			P	L	A	N		&																					
A3-6Develop Initial Time Schedule																H3			E	S	T	I	M	A	T	E	S																	
A3-7 Develop Initial Resou Schedule																	H3																											
A3-8 Develop Prel Estimates																		H3																										
A3-9 Obtain Client Approval																			H3																									
A4-1 Develop Detail Arch. Design																				H4			D	E	V	E	L	O	P															
A4-2 Develop Detail Struct. Design																					H4			D	E	T	A	I	L															
A4-3 Develop Detail Specifications																						H4			D	E	S	I	G	N	S													
A4-4-1 Carryout Quantitative Analysis																							H4			P	L	A	N			&												
A4-4-2 Reschedule Reources																								H4			E	S	T	I	M	A	T	E	S									
A4-4-3 Re-assess Project Time Schedule																									H4																			
A4-4-4 Level Reources																										H4																		
A4-4-5 Develop Detail Estimates																											H4																	
A4-5 Obtail Approval																												H4																
A5-1 Analyse Detail Designs & Specs																													H5			A	N	A	L	Y	S	E						
A5-2Analyse Det Resources Sched																														H5			R	E	S	U	L	T	S		&			
A5-3 Analyse Det. Proj Time Sched																															H5			P	R	O	D	U	C	E				
A5-4 ProduceWorking Drawings																																H5			R	E	P	O	R	T				
A5-5 Produce Design Specifications																																	H5											
A5-6 Produce Final Plan																																		H5										
A5-7 Produce Final Indirect Cost																																			H5									
A5-8 Produce Final Activity Cost																																				H5								
A5-9 Produce Net Project Cost																																					H5							
A5 10 Produce Cashflow Forecast																																						H5						

Table 10.4: The Initial Activity Matrix.

In carrying out the activities at this stage, consideration was given to recommendations by NEDO in 1990, which states that it is always better to evolve around existing patterns rather than to create a completely new process which is alien and disconcertingly different from the industry's method of operation. The Functional Groupings used for the development of the Initial Activity Statement shown in Table 10.4, thus revolved around the project requirements, which were drawn from the client's brief, existing functions, as well as the other site information provided. The results of the analysis of the sub-functions in Figure 10.4 were used to produce an outline of the activity statements. They are shown in their simplest forms as follows:

- Definition of the project requirements, which includes:
  1. The establishment of Project Specification Guidelines
  2. Establishment of Project Control Authority
  3. Establishment of the Overall Design-Management Schedule

- Development of Initial Project Plan which includes:
  1. Development of Client's Brief
  2. Development of Project Brief
  3. Development of Schematic Design, Initial Plan & Cost
  4. Development of Project Finance Plan
- Development of Preliminary Design-Management Works which include:
  1. Development of Preliminary Design (Architectural & Structural)
  2. Development of Preliminary Plans and Estimates
- Analysis & Development of Production Information, which includes:
  1. Analysis of the Detail Design, Estimates and Plan
  2. Production of Working Drawings
  3. Production of Final Plan & Cost
  4. Production of Supporting Documents

The SA/BPR CASE tool was used to convert the outline activity statement into meaningful functions. The result of the entire process is then represented in a model, as shown in Figure 10.5. The innovated functional stages in the design-management processes are as follow: the Inception, Develop Initial Project Plan, Create and Approve

Preliminary Design, Estimates and Plan; Create & Approve Detail Design, Estimate and Plan; Analyse Results & Develop Production Information.

In the development of the Process Innovation Approach about 60% of the companies selected for the pilot studies operate on two types of business process which are:

- The core operating processes (which is profit centred)
- The support operating process (concerned with the maintenance of the organisations efficiency, integrity and credibility)

The support operating processes underpin the core processes, in some cases. However, the innovative stage of the re-engineering process was carried out by taking an overview of existing practices - the output is shown in Figure 10.4.

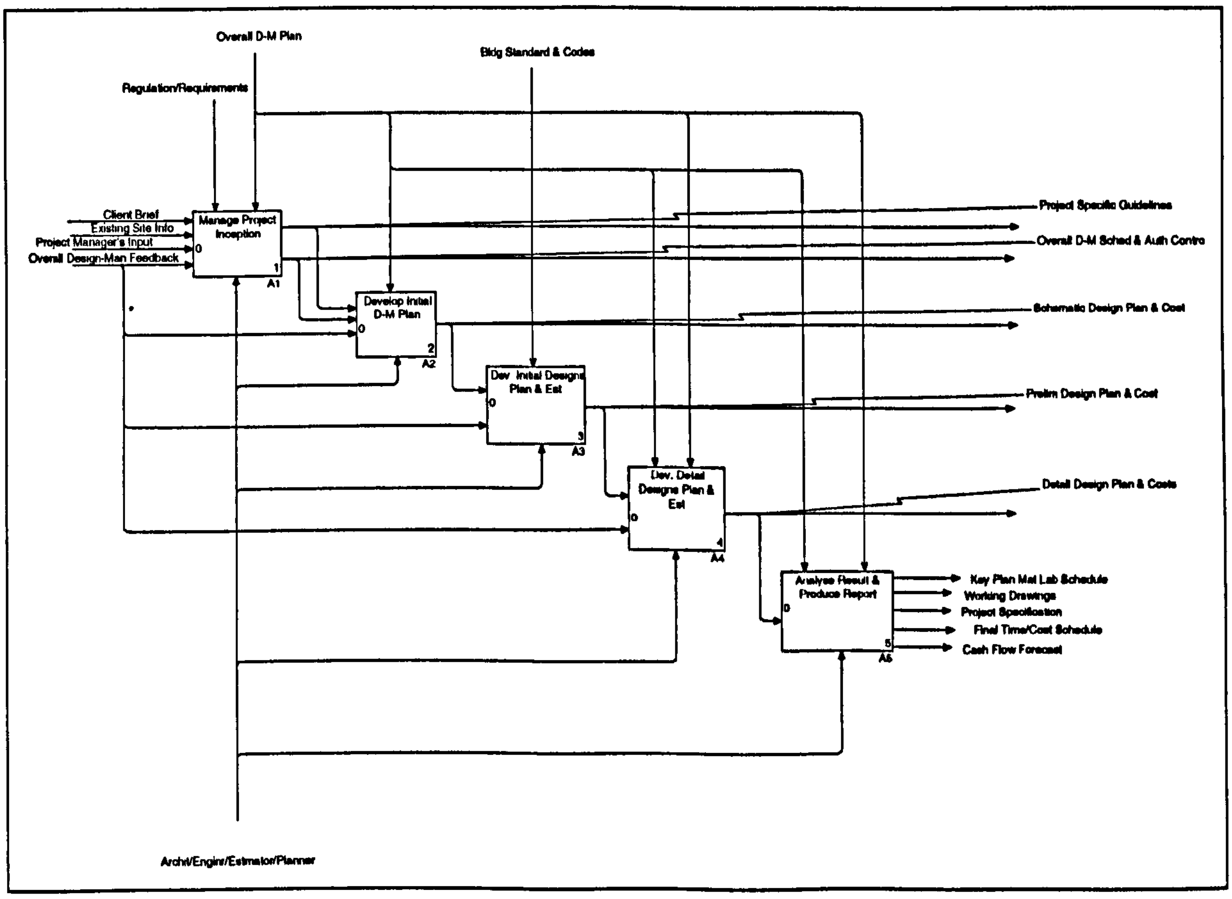

Figure 10.5: IDEF0 Model, Parent Diagram of the Innovative Design-Management Process (A-0).

Figure 10.5 shows the top - down logical functions in the Innovated Design-Management Process. The stage-by-stage discussion of these functions is carried out in the next section.

10.6 The Decomposition of the Proposed Innovative Process

The decomposition of the innovative process consists of the, top-to-bottom, logical breakdown of each of the functions constituting the innovated design-management process - as shown in the parent diagram, figure 10.5. This model shows the information decomposition from the main processes to the sub-processes within the framework of the Innovative Approach. The first parent functional activity of the improved process is the 'Manage Project Inception' stage and the details are discussed below.

10.7 Manage Project Inception

The Manage Project Inception stage is the first parent functional activity of the innovated process in design-management. The major sub-functions include the establishment of the project specific guidelines; establishment of the project control authority, and the overall design-management schedule/strategy. The sub-functional activities and the variables at this stage are shown in Figure 10.6.

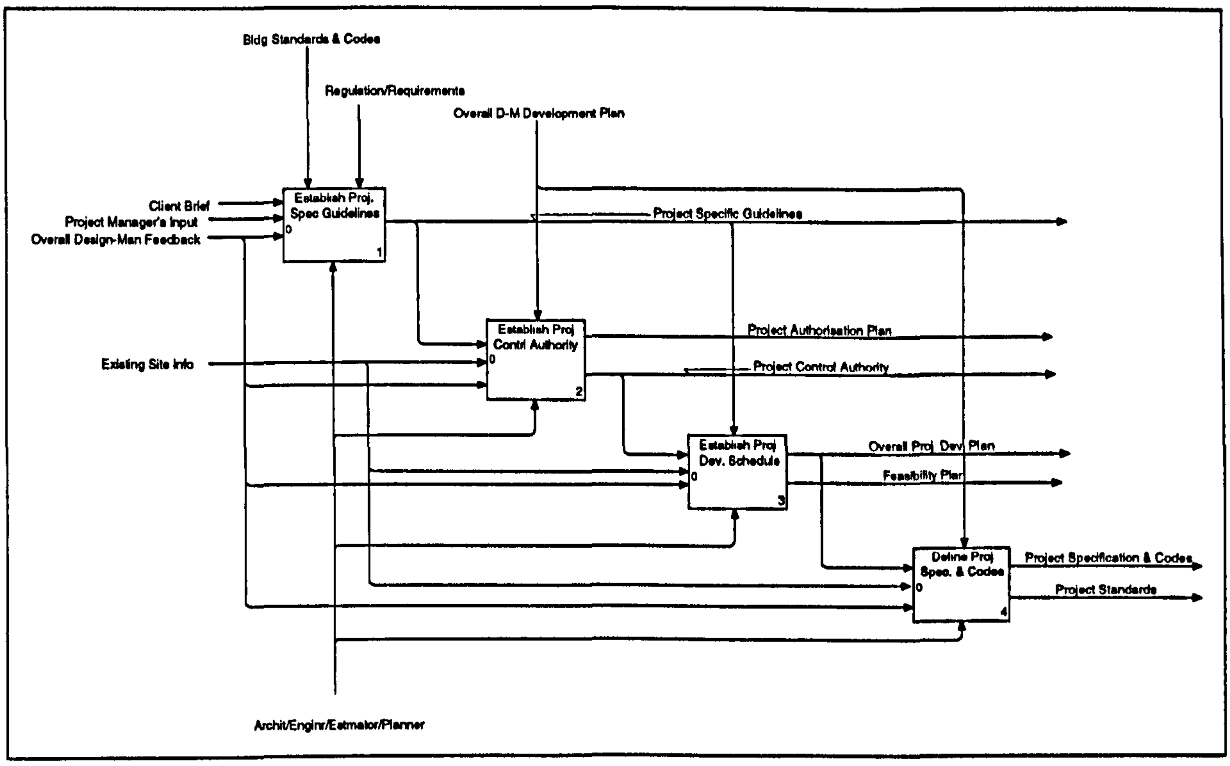

Figure 10.6: IDEF0 Model - The Manage Project Inception Stage (A1)

This process embodies the earlier section of the inception design phase i.e. the Establish Building Design Requirements. In the innovative process, this phase was carried out with integration perception, such that, it brings together the designer, planner and estimator to make consensus decisions in establishing both the client and project requirements in terms of quality, time as well as associated cost implications. The initial cost of this approach is comparatively higher, due to the earlier involvement of the planner and estimator. However, the problem of duplication of function and rediscovery of information is eliminated – hence cost and time saving. Furthermore, the consensus or joint decision making approach adopted in the innovative processes provides a better means to discuss problems and arrive at a cross-disciplinary decision/ solution, Fruchter (1996). Synergy will be achieved if the proposed integrated approach is adapted to the design-management and installation procedure. This, it is believed will result in well defined project intent/objectives, consistent and well defined processes, unambiguous standards, clear guidelines, feasibility plan, specifications and jointly acceptable codes that can be achieved as an output variable to the proposed approach. The output of the

Management Project Inception stage is used as the input for the subsequent primary function discussed below.

10.8 Develop Initial Project Plan

This is the second main functional activity in the proposed improved innovative processes with regard to design-management and planning. The Develop Initial Project Plan consists of feasibility and viability studies of the client's requirements, site visits, analysis of project finances, scheme design, scheme plan and outline project costs. With regard to the proposed process, the Develop Initial Project Plan is an amalgam of the Scheme Design stage and the first two sub-functions of the old Initial Plan and Initial Cost Appraisals, which are duplicated in the existing estimating and planning processes. The activities and variables that influence this functional process is shown in figure 10.7. Inferring form the model in figure 10.7, the Analyse Project Plan and Finances is an output of the first sub-function. This output is one of the main control variables for the 'Establish Project Design Basis' sub-function. This is a means to carry out the project within the project's budget ceiling and the planned requirements, which includes time and quality requirements. Furthermore, Construction Design Management (CDM) Regulations are applied in this approach where design risks and associated project hazards are analysed and addressed promptly. The output of this function includes Scheme Design, Scheme Plan and Cost; Site & Feasibility Report and Financial Plan. These are carried out so as to achieve synergy by using the co-ordinated decision making of the architect, engineer, estimator, and planner.

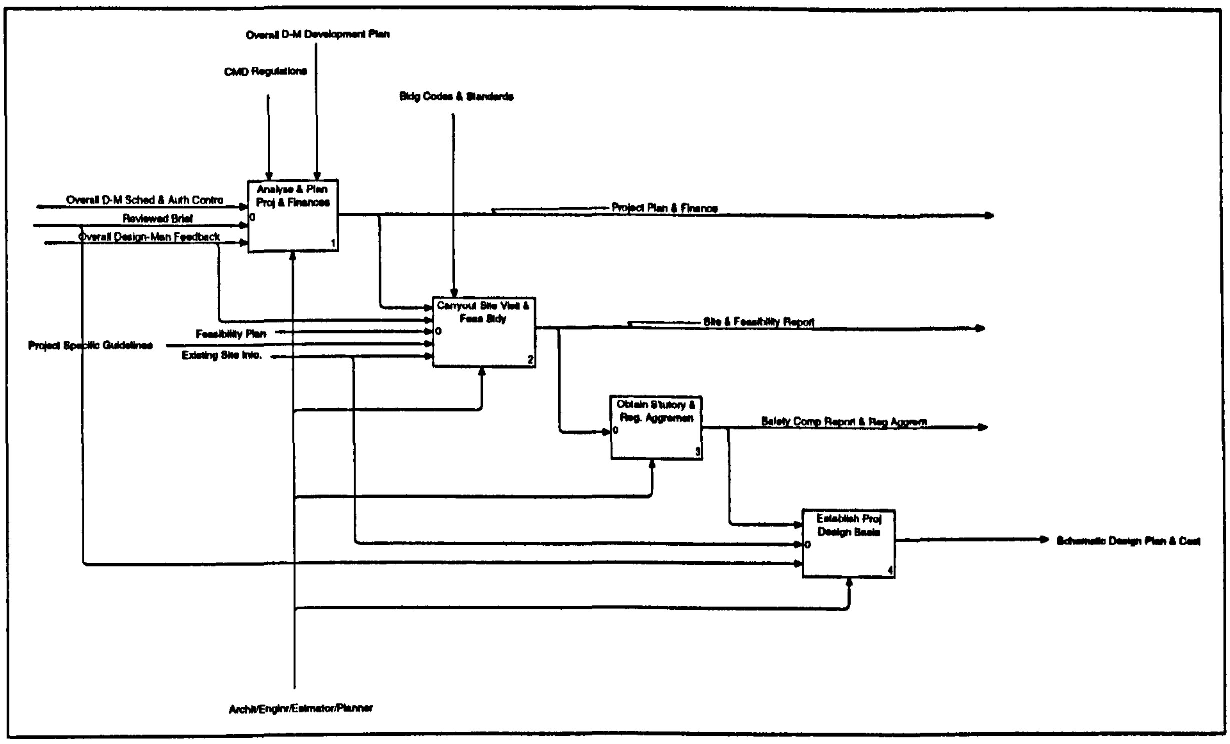

Figure 10.7: IDEF0 Model of the Develop Initial Plan Stage (A2)

The joint decision making approach in the innovative process virtually eliminates the problem of the "them-and-us" attitude/ syndrome introduced to the industry by increased fragmentation, compartmentalisation and competition in the industry. These adverse attitudes came about as a response to the stringent economic climate of the 1980's, Franks (1991), Anumba et al (1996). The Process synergy derived from multilateral decision making procedures adopted in this approach eliminates the "over-the-wall" sequence of activities characterised by rigid functional barriers found in existing processes. The proposed approach introduces the concept and practice of well defined functions and joint responsibility in executing the project in accordance to CDM regulations and requirement. This allows for a joint and thorough analysis of the client and project requirements. The output of this stage provides the input for the next function discussed in the next section.

10.9 Create and Approve Preliminary Designs, Estimates and Plan

The output of the 'Develop Initial Project Plan' formed the input and control variable for the Preliminary Design, Estimate, and Plan stage. The functional activities at this stage involved a synergetic approach where the preliminary activities in the design, planning and estimating stages are performed using the joint decision of the architect, engineer planner and estimator. In this process, the numerous phasing of existing design-management and planning processes with rigid functional barriers are eliminated. Furthermore, the duplication of functions in estimating and planning such as the Programme & Method Statement; and 'Create Initial Plan' are replaced with a common function, which is the 'Preliminary Estimate & Plan' stage shown in Figure 10.8. The activities in the proposed innovative processes are believed to be much better co-ordinated and as a result this facilitates the development of a standard format for the design-management and planning of BIPV cladding installation activities within a wider construction project setting. This will be analysed and discussed in case studies associated with BIPV cladding installations within the UK construction industry, in chapter 11.

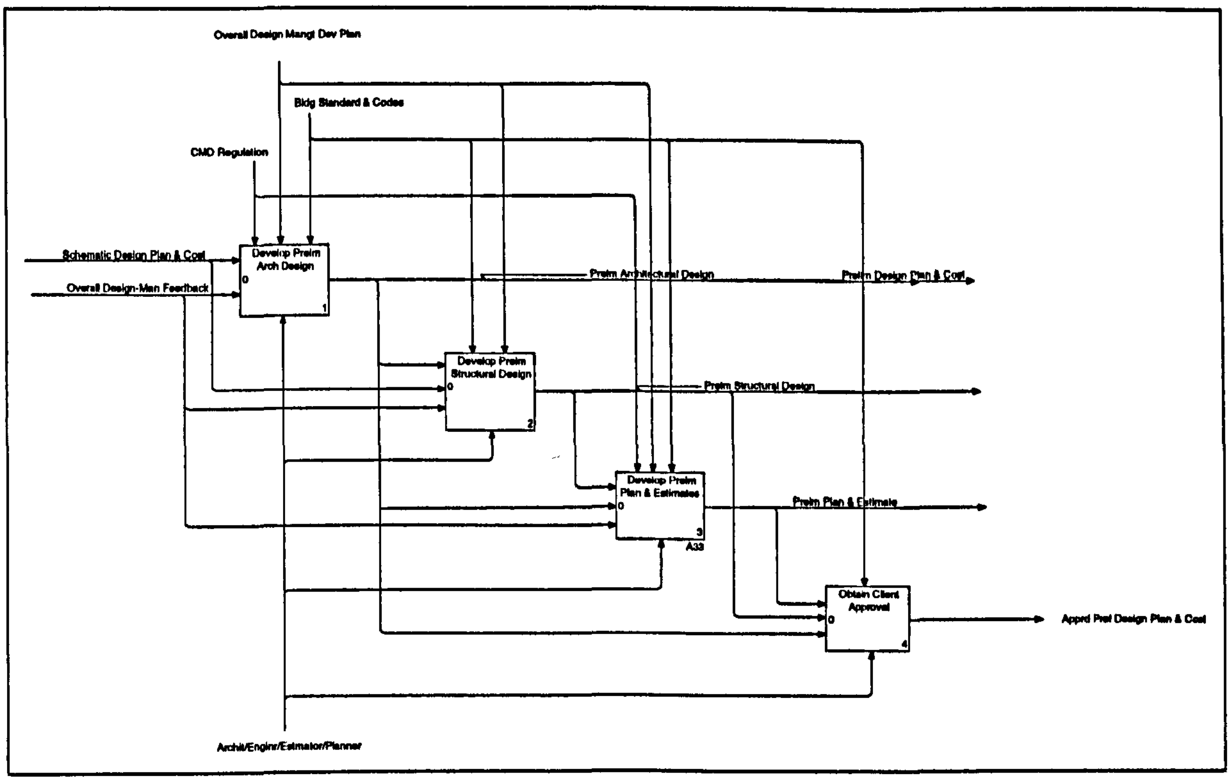

Figure 10.8: IDEF0 Model Parent Diagram the Create Preliminary Design Plan & Estimate Stage (A3).

Inferring from the model in Figure 10.8, the scheme designs, plans and cost estimates are achieved through a joint effort of the designers, engineers, planner and estimator. The scheme design is used as the input variable for the Preliminary Architectural and Structural Designs stages. The co-ordinated and consensus decision making approach in the proposed process also provides a framework for concurrent activities such as: Preliminary Structural and 'non-structural' (Architectural) design; Preliminary planning and Estimating to be carried out concurrently – hence fast tracking the procedures. This replaces the sequential functions in the existing Preliminary Architectural and Structural designs and also between the sequential functions in design and planning as well as the sequential functions between planning and estimating. In this approach, activities such as Select Cladding System, Generate Framing, Select Member sizes and Review Scheme are carried out independently but through the consensus review of the architects, engineers, cladding system designers, fabricators and other consultants. An IDEF3 model, in Figure

10.9, illustrates the concurrency in the functions, Details of the syntax and semantics of IDEF3 is discussed in chapter 8.

In the proposed process the joint decision making approach among the participants produce synergy in project co-ordination. The resultant functional activities are shown in Figure 10.9, eliminate the numerous phasing and sequence in design-management process with functional barriers, Thompson (1996).

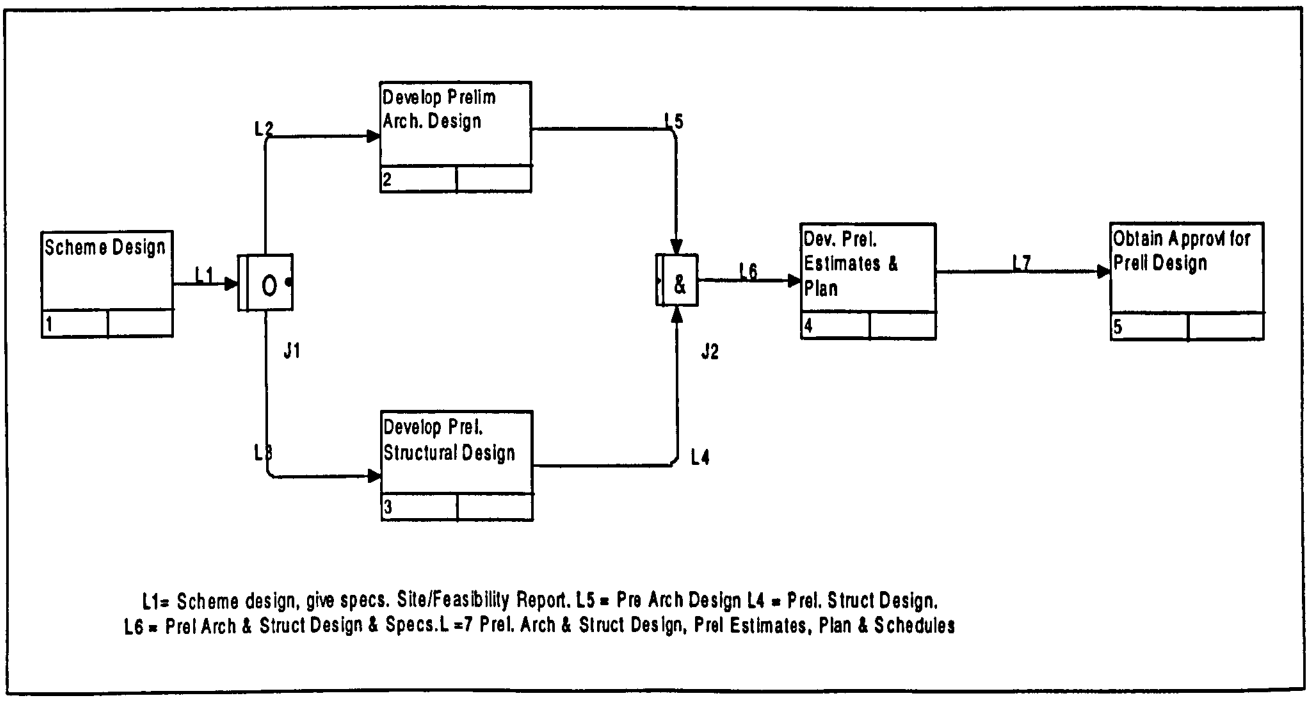

Figure 10.9: IDEF3 Process Model of the Concurrent Functions in Preliminary Design Plan & Estimating Stage.

Similarly, the joint decision making procedure and synergetic approach in the proposed innovative BIPV design-management, planning and installation process will provides less conflicting interpretation, a better understanding and a platform for integration. In this process, the Preliminary Architectural Design, Structural Designs, Work Break Down structure (WBS) and Initial Plan jointly produces by the participating team form the main input variables for the 'Preliminary Plan and Estimate phases - as illustrated in Figure 10.10.

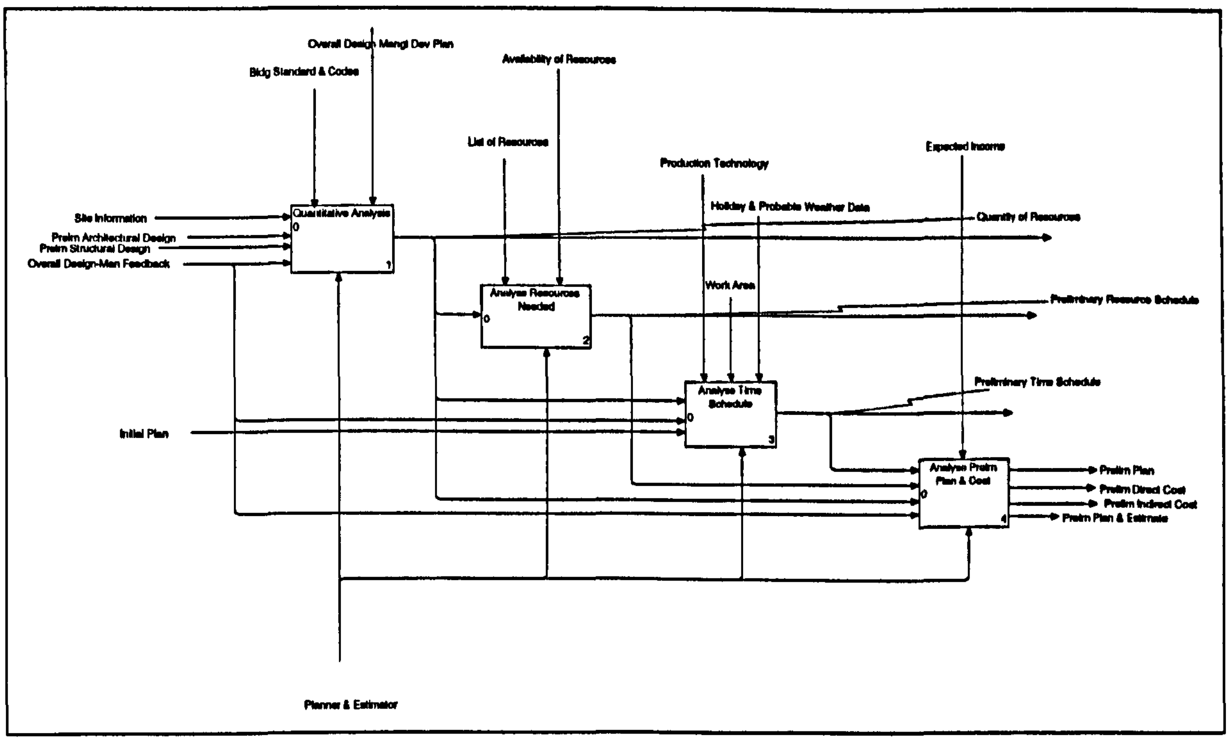

Figure 10.10: IDEF0 Model of the Develop Preliminary Plan & Estimate Stage (A33)

These sub-functions are performed through the synergetic procedure and by the joint decision making of the estimator and planner. In the innovative approach, the duplication of functions, the long and iterative processes and the rework found in the existing processes, as discussed in chapter 9, are eliminated. The output of the approved 'Preliminary Designs, Plan and Estimates forms the input variables for the Develop Detail Design, Plans and Estimates stage, which is discussed below.

10.10 Create & Approve Detail Designs, Estimates & Plan

The development of the 'Detail Design, Plan and Cost Estimates' in the innovative approach used the approved preliminary designs (Architectural and Structural) plans and estimates as the main input variables as shown in Figure 10.11.as L1 and L2

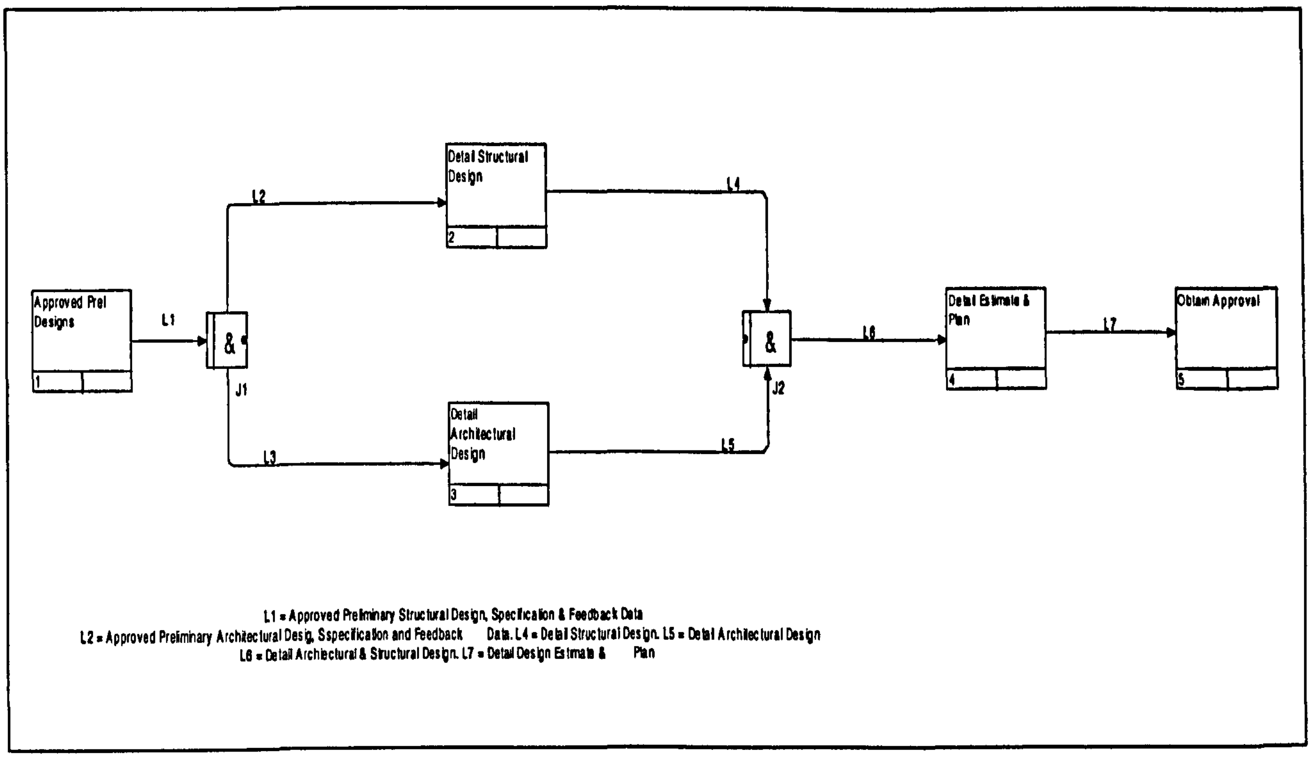

Figure 10.11: An IDEF3 Model of the Concurrent Process of the Create Detail Design, Plan & Estimate Stage.

The innovative approach addresses many of the problems identified in existing Design-management and planning processes, provides a formal platform for concurrent functions as shown in Figure 10.11. Inferring from Figure 10.11, the basic output of the approved preliminary design (Architectural & Structural) form the main input for Detail Architectural and Structural design. The detail structural design, the sub-functional and main variables required to carry out the Detail Structural Design are shown in Figure 10.12 inferring form Figure 10.12. The Approved Preliminary Structural Loading for the individual structural component generated in the previous stages. This includes the Structural Load Cases formed the basic inputs. Similarly, the Approved Preliminary Architectural Designs, which include the jointly approved layout and components, formed the input for the Detail Architectural Design.

The Detail Architectural and Structural Functions are carried out with clear functional responsibilities and effective cross-disciplinary communication. The output of these two functions, together with the Preliminary Estimates and Plan formed the basic input for the Detail Estimates and Plans shown in Figure 10.13.

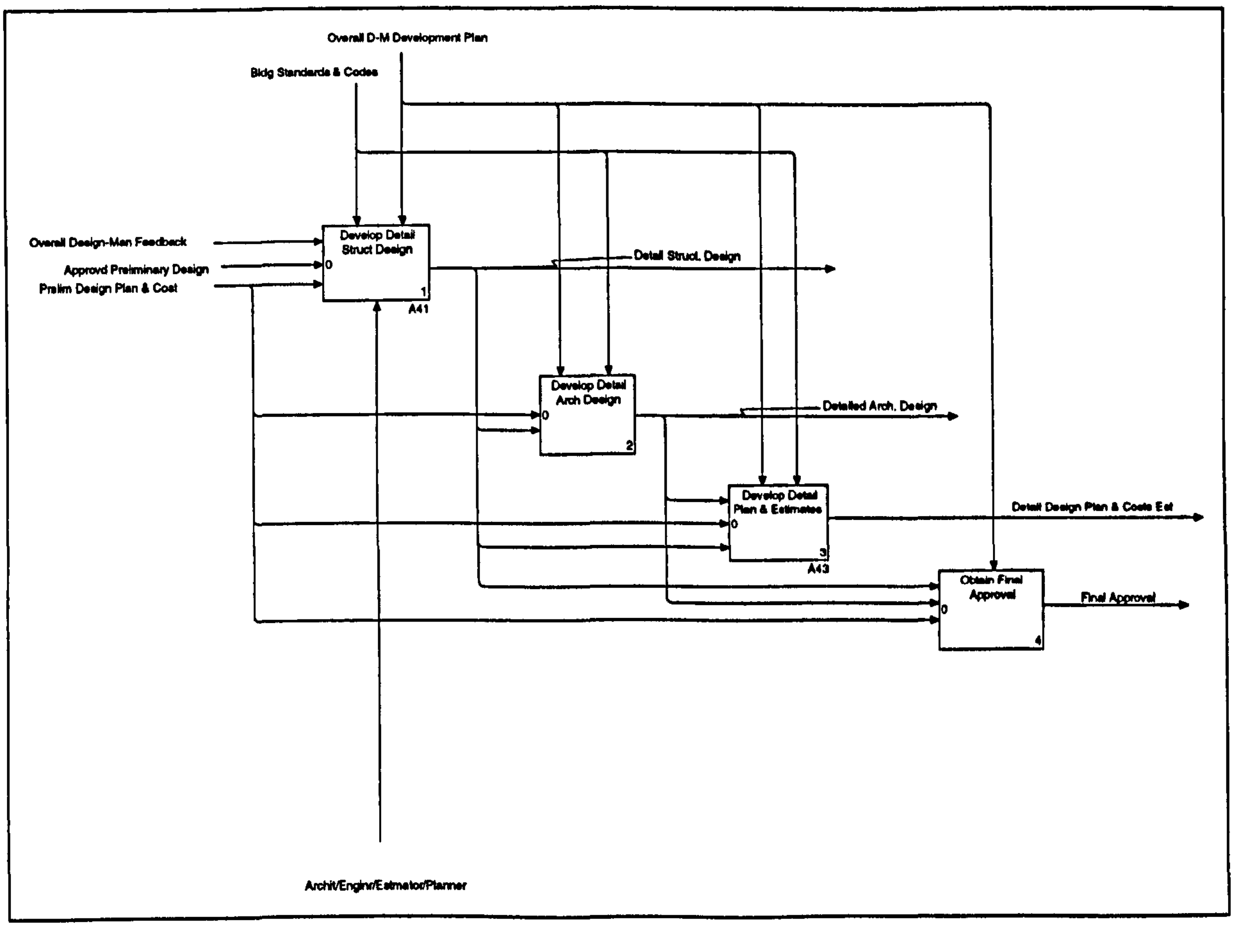

Figure 10.11a: IDEF0 Model Detail Design, Plan & Estimates Stage (A4)

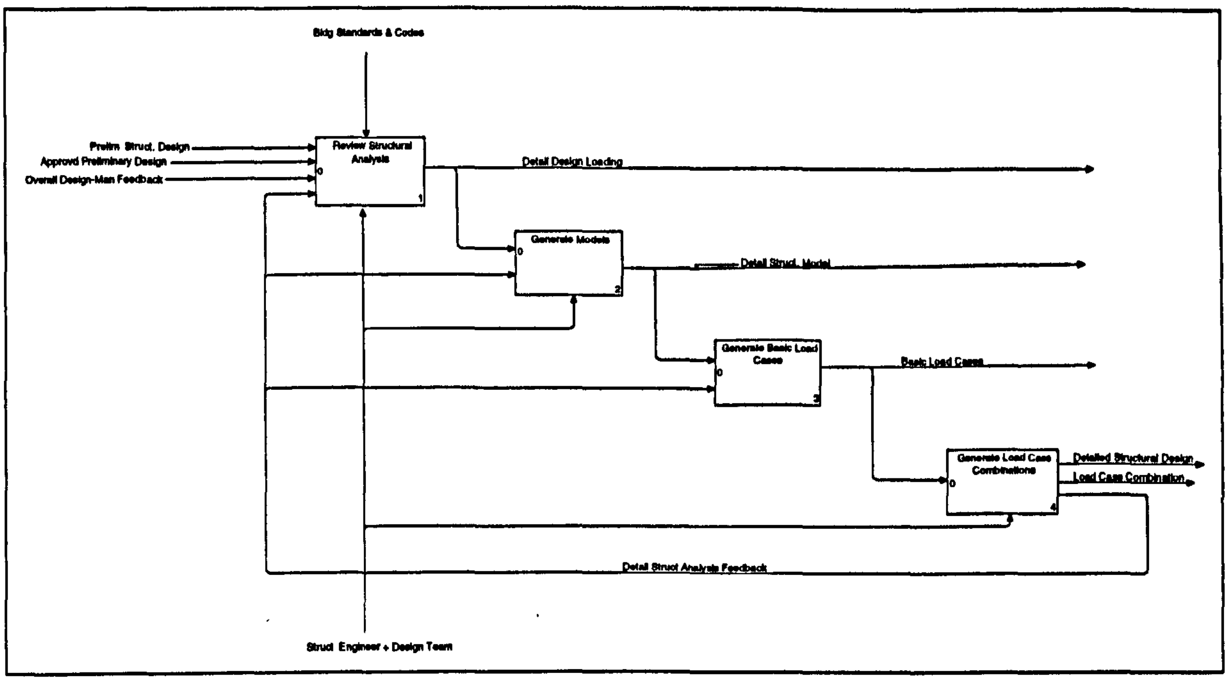

Figure 10.12: IDEF0 Model Develop Detail Structural Design stage (A41)

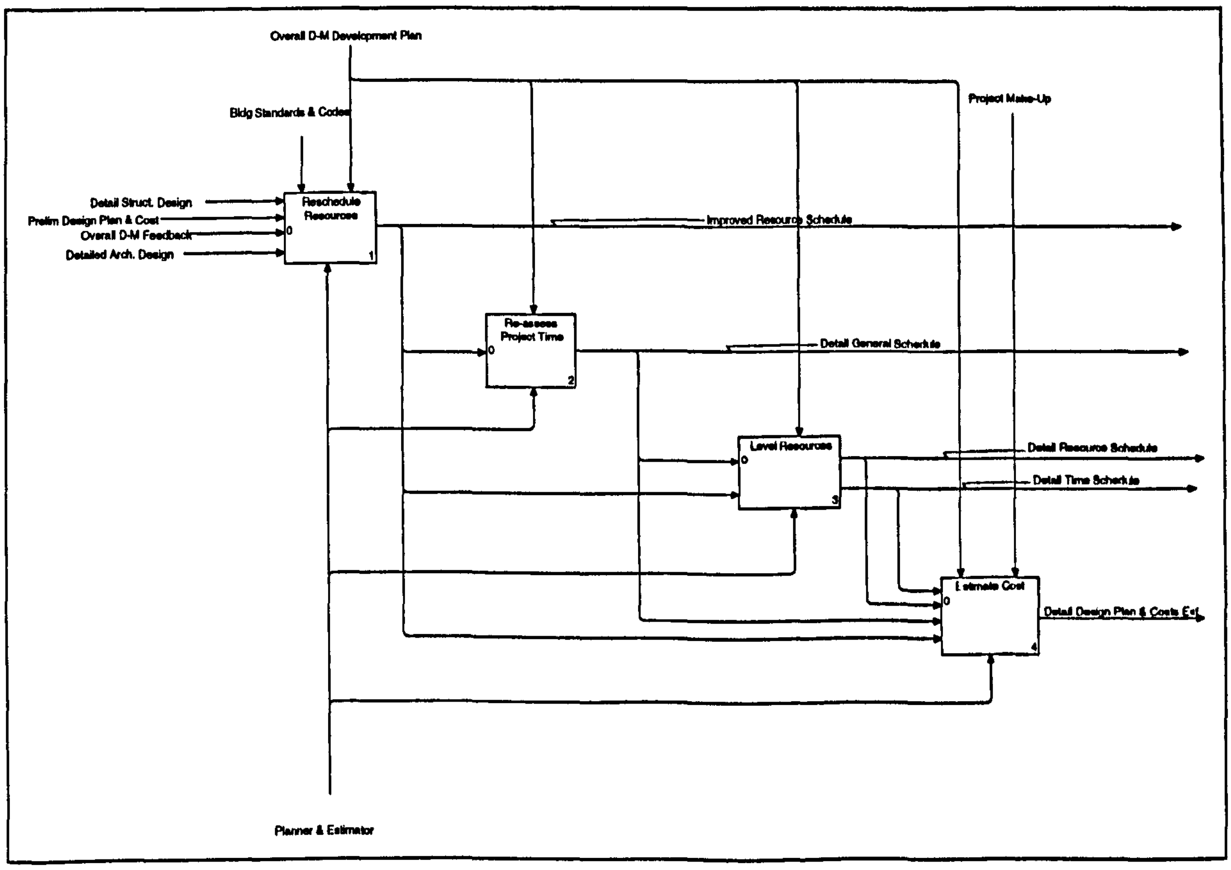

Figure 10.13: IDEF0 Model Develop Detail Plan & Estimates Stage (A43)

Inferring from Figure 10.13, the sub-functional activities at the Detail Estimates & Plan stage include Scheduling of Resources, Re-assessment of Project Time and Levelling of Resources. The output of these sub-functions formed the basic input for the next parent functional activity, which is the Final Analysis and Production Information stage discussed in the next section.

10.11 Final Analysis & Production Information Stage

The Final Analysis and Production Information Stage in the innovative approach, is distinct form existing processes where the separation of functions, compartmentalisation and fragmentation have been contributing to late detection of errors, and the lack of effective final analysis. In this approach, a dual functional activity, which involves the synergetic, collaborative and co-ordinated effort of all the team members (Designers, Engineer, Estimator, and Planner), is adopted. Figure 10.14 provides an illustration of this approach, where the various sub-functions including the analysis of the detail designs are carried out against the client's requirements and specification. Similarly, the analysis of the final project time/cost was carried out in a more speedy and time-cost effective way and ensured that the project is completed reasonably earlier than the initial project plan time. In practice, speeding up the project has serious repercussions on the project resources, the project cost and the cash flow, Kahkonen (1991). In the innovative process, the time schedule was assessed against other options such as maintaining increased resources or run extra shifts when the workers on the previous shift will prove ineffective after the normal working hours. Whatever option used the collaborative effort of the design-management team brought about the achievement of suitable alternatives for the project acceleration. These were evaluated against the final project schedule, the final cost estimate, and finally, the effect of the accelerated time was going to have on the cash flow.

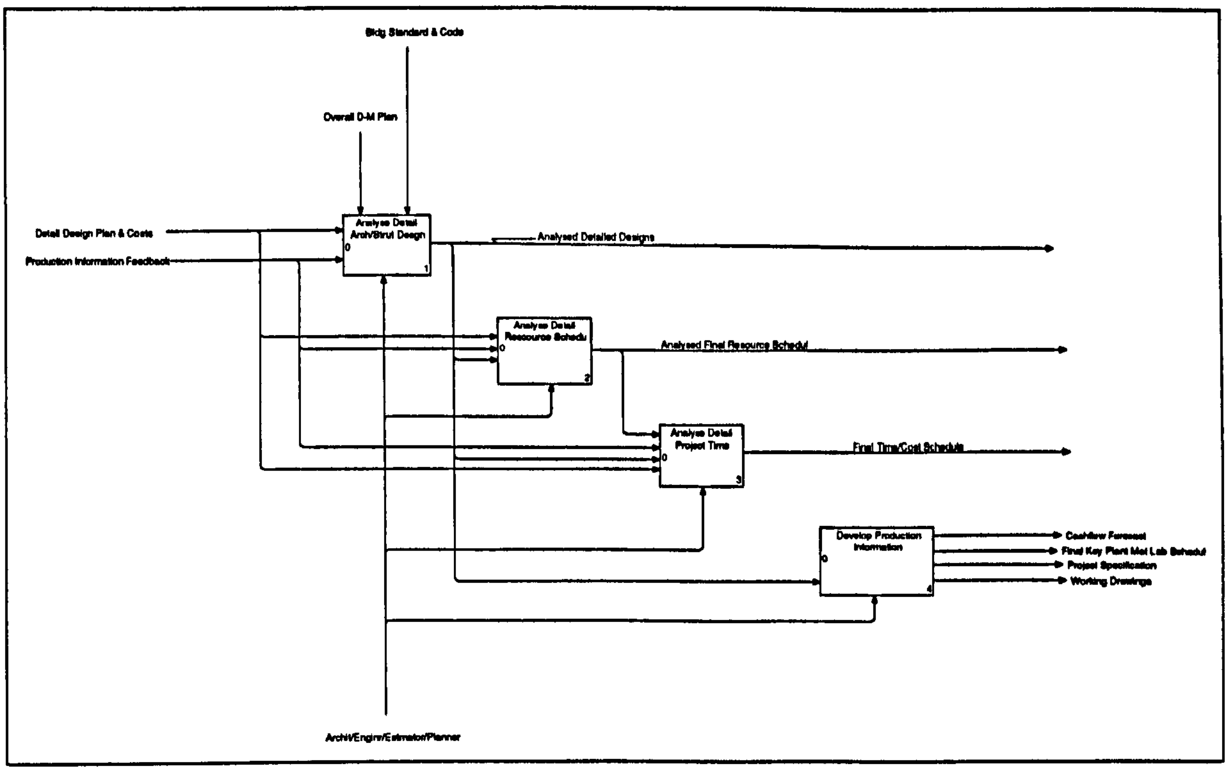

Figure 10.14: IDEF0 Model of the Analyse Result & Develop Production Information (A5).

The last function after a satisfactory analysis is the development of production information. The output of this function includes the Working drawings, Project specifications and other supporting documents such as Detail plans and Detail estimates.

In this research the means of assessing the level of improvement of the re-engineering approach is through the experimental costing of the overall performance of the innovative processes against the existing design-management process. The details of this approach are discussed below.

10.12 Assessment of the Level of Improvement of the Innovative Process

The shortcomings in traditional costing systems used in assessing the level of improvement in the industry have been discussed in chapters 6 and 7, with the solutions to the shortcomings given in the earlier sections of this chapter. Traditional Costing Systems used in the construction industry convey relatively little information about resources in areas such as design, engineering and other planning tasks, Amsler et. al.

(1993). In this section, Process Based Costing, which is quite distinct from previous methods that used value adding and non-value adding variables as the cost basis, is developed as a means of bench marking (measuring) the improvement performance. In this approach, the cost driver is duration based, as compared to previous methods where the cost driver had been only activity based, leaving previous processes inconclusive, Amlser et. al. (1993). The detail of this approach is described in the next section.

10.13 Process Base Costing

The work discussed in this section is a description of the framework developed in this research. This is aimed at measuring the performance of the improved design-management and planning of construction projects. This encompasses a range of construction activities, involving the installation of advanced cladding system with particular reference to BIPV cladding processes.

This approach is known as " Process Based Costing" and may be simulated in the SA-BPR CASE tool environment (Systems Architect - Business Process Re-engineering Computer Aided Software Engineering Tool) where an Activity Based Costing software applications is used.

BIPV cladding design-management, planning and installation processes were mapped in parallel, starting from the most abstract phase to the most robust level of decomposition, illustrating the logical relationship between the activities in each of the processes. This was carried out as prerequisite steps to the application the SA - BPR CASE tool – in a two stage process ("As Is"- existing and the "To Be" – improved processes). The alternative models of the existing and improved design-management and planning processes are then converted into two separate 'Node Trees' which illustrate the hierarchical activities of these two processes. Inferring from figure 10.15 there is earlier involvement of estimating and planning activities at the inception of the synergistic process. This process mechanism is the joint decision making of the architect, engineer, estimator and planner.

The output of the alternative processes (existing & improved) formed the basic input for the analysis of the "Cost Objects" for the costing activities in the measure of performance discussed in the next paragraph. In the use of Activity Based Costing for measuring of performance of activities, the resources associated with the performance of the various activities consume cost objects. However, cost objects in design-management and planning processes vary in relation to level of integration Amsler et. al (1993). In order to achieve a comparable and realistic cost for each of the varying group of activities, such as those in design, estimating and planning, cost objects are grouped in categories such that they reflect the duration of the activities and the intensity of resources consumed. In the construction industry, there are several factors, which affect the duration of activities. The important ones, which have a significant effect on the duration of activities in design-management, include procurement methods, the project size, the project characteristics, as well as the experience of the company executing the project, Griffith A (1989), Rugvie A (1990) and Franks (1991). In the quest to achieve a "duration based" cost driver, which reflects the influence of the above-mentioned factors, several costs from different projects with variable characteristics, were analysed. Based on continuity of activities, as well as effective co-ordination in information collection, data from projects delivered through one particular procurement method (i.e. Design &Build) was used for the analysis of the cost drivers. However, this was compared with the various costs accumulatively collected from other projects delivered by other methods such as the Traditional, Construction Management, and Contract Management. The details and conditions for the selection of cost data is discussed in the appendix. The costs from projects delivered through Design & Build projects were then divided by the number of projects to achieve the average cost driver groupings. With the classified cost drivers, and the varying duration, a cost model framework was developed. Figure 10.16 illustrates the classified cost drivers, the varying duration's in relation to the various activities, which followed the hierarchical processes shown in the developed cost model framework in figure 10.16. In current Activity Based Costing Processes Brimson (1988); Marrow et. al., (1991); Amsler et. al (1993) much attention has been focused on activities and labour-hours, making the implementation of the system focus on targeting static data rather than continuous data. In this Process Based Costing approach, the duration of activities shown in the models in Figure 10.16, and the resources (plant, labour and material) used to execute these activities form the basic variables for the calculation of the cost drivers where consideration is also given to overlap of activities. In order to achieve such continuous data gathering for effective implementation, a "Transitory" factor is added to the Duration Class to effect such implementation.

Using the innovative framework describe in Figure 10.16 as an add-on model the SA-BPR CASE tool was used to calculate the cost of the alternative processes. In this research, the duration for executing building design-management and planning activities using BIPV live projects and existing process was cost against the execution of the same project using the innovative process. The detail of this approaches it implementation and results are discussed in chapter 11.

10.14 Summary of Findings and Discussion

This chapter has presented the use of the Business Process Re-engineering approach to reveal the arbitrariness in the existing design-management and planning processes. These included significant amount of rework and duplication. Other flaws identified in the process were the 'over-the-wall' sequence of activities with rigid functional barriers. These factors are inherent in the existing design-management and planning processes brought about by the segregation and isolation of consultants, contributing to the 'them-and-us' attitude, which ferment barriers in communication, Anumba et al (1996). The fragmented and diversified functions of the different participants in design-management, planning and construction also brought about wider commitment gap among the members, lack of co-ordination and collaboration in the definition of the design intent and rationale. This led to loss of information, unwarranted design changes (variations), and unnecessary liability claims which are some of the characteristics of existing processes Frank (1991), Jebb et al. (1992). In this research, the use of the innovative framework, together with the Business Process Re-engineering approach demonstrate the means to make significant and innovative changes in the existing design-management and planning processes. The 'over-the-wall' sequence of activities with rigid functional barriers were virtually removed and replaced with concurrent functions with an emphasis on the collaborative and synergetic decision making of the architect, engineer, estimator and the planner. This approach provided the vital platform for integrated design-management planning and construction processes. The collaborative, consensus and joint decision making of the design-management team members improved communication links, strengthened the technical capability of the project team and provided better information design-management and processes. This narrows the gap between design knowledge cost commitment, constructability and supply chain management at the early stages of the project. The narrower commitment gap achieved through the synergetic approach of the team members further provides a means for unanimous review, risk analysis, supply chain analysis and prompt responses to changes which enhance buildability, Griffith (1989), Franks (1991). Other achievements of the re-engineering approach were discussed in chapter 8 and 9. The matrices of the developed re-engineering framework provided a better understanding and problem representation, Wirba (1996), Thompson (1998).

The innovative process matrix coupled with the better understanding of the problem representation in the design-management and planning domain would provide a framework for the development of specifications of a best practice guide as well as case based multiple decision support systems that would feed into a central repository. Details of these process and recommendations are discussed in chapter 11.

Conclusion

11.1 Summary

A summary of the rationale and major findings of this research is presented in the first part of this chapter. The main contributions of this research in the areas of:

- Design-management and planning of BIPV
- Integrated frame work
- Specification for a multiple decision support system
- Best Practice Guide for BIPV power systems
- Proposed BIPV models

are highlighted in the second part of this chapter. Further discussions, recommendations and areas for further research are discussed in the final part of this chapter - the concluding chapter of this thesis.

Interest in renewable energy has surged worldwide in the 1990's, despite continuing low international energy prices. The primary reason for this enhancement of interest include impressive technical advancement; environmental pressures, particularly climate change and broader sustainability concerns; loss of faith in nuclear power; and the possible benefits to other sectors, Boyle (1996). Many varied national, regional and global projections now indicate that renewable energy could make a substantial contribution to the world's energy supplies. However, many renewable energy sources still require further technical and / or industrial development and are not yet economically competitive in the current bulk energy market, (ESTU 1994(1), ETSU 1994 (2)). Many of the significant benefits are not reflected in current market structures and it may take decades to realise big contributions to the energy balance.

The integration of photovoltaic technology into the fabric of a building is seen as the most promising application of PV in many industrialised countries because of the design possibilities and the potential benefits of embedded electricity generation, (ETSU (1998(2)). The market for building integrated PV (BIPV) products is therefore one of the fastest growing sector of the overall PV market, increasing form 5% in the early 1990's to between 20 – 25% in 1998 Buston et al (1998). It is expected to rise to as much as 40% of the total PV market by the year 2010, ETSU 1998(1)).

Building integrated technology is the most cost-effective ways to reduce the cost of solar electricity. However, besides it high costs, there are other important factors to be considered such as architectural integration and aesthetic appearance of the building itself. To encourage the use of photovoltaic power generation, the power generation cost must be reduced to the same level as those of power purchased from electricity utilities, Uehara (1998). This can be done by significantly reducing the initial cost of PV system. Installation accounts for the majority of the costs of BIPV - besides the cost of the support structure and the PV modules, (Buston (1998), Pitts & Gyoh (1997)).

This thesis describes the work carried out to investigate and develop a technique for the optimisation of an integrated design-management and planning of building integrated photovoltaic system (BIPV). The most important or distinguishing character of this study is that it addresses issues set out by the challenge for Task VII of the (International Energy Agency) IEA photovoltaic power system Programme. This research addresses subtask 3 (Non-technical Barriers), focusing on the following subsections:

- Subtask 3.1- assessment of barriers to usage of BIPV by target groups
- Subtask 3.2- evaluation of the technical potential
- Subtask 3.3- analysis of the economics of PV in buildings
- Subtask 3.4- how can BIPV successfully be marketed to targeted audiences

This is intended to at making BIPV more competitive by achieving cost reduction through the optimisation of design-management and planning procedures. This is hoped, would lead to reduction in installation time, eliminating of non-valued added activities, improve the quality and confidence in the product and process, thereby, ensuring client satisfaction.

The quest to achieve the aims of this research necessitated setting some objectives and establishing a detailed methodology. This is intended to address the shortcomings of earlier approaches and also to satisfy the objectives of the research. The objectives of this research are:

- To carryout process re-engineering for integration of design-management activities, which incorporate design, planning and cost estimating functions.
- To develop integrated information models to support the re-engineering process.
- Determine optimal functions and processes thereby reducing overall installation cost and time. This would encourage lean construction/installation by eliminating non-value-added activities.
- Tailor clients' requirement to project objectives thereby ensuring client satisfaction and confidence in BIPV projects.
- Identify problems, constraints and limitation - Minimising duplication of functions and rediscovery of information.

In an effort to satisfy the first objective, a review of literature which led to an overview of the design-management domain in relation to the entire construction project structure was undertaken, this included BIPV installation project (in the case study). This was a means to achieve a better understanding of the various functions, the participants involved, as well as the information requirement of the various functional sections and sub-sections in construction. A design-management overview was also undertaken on this account. This encompassed the function of designs (architectural and structural), construction planning and cost estimating.

The critical analysis of the processes in design-management and planning was undertaken with the view to gain a thorough understanding of the functions, information flow and to precisely identify the problems associated with these processes. An analysis of the existing processes was undertaken in order to identify the flaws mentioned in the literature review. The following steps were taken to aid the interpretation of the analysis:

- Analysis of the strategy use in handling problems in design-management and planning was undertaken in chapter 8 and 9.

- A pilot survey which took the form of interviews, formal discussion and case studies on existing project was conducted so as to fairly unveil the flaws and arbitrariness in the processes in design-management and planning form a wide range of projects. It is also a means of eliciting knowledge from professionals in the various companies involved in the study and to assist in effective changes to flaws in existing processes. It was finally carried out in order to assess the effect the improved and redefined process will have on the overall processes and the operations of the various organisations involved in the study.

The major factors that have limited the integration of design, planning and estimating data were identified as follows:

- The uncoordinated processes and sub-process in the design-management, which operate with rigid functional barriers.
- The diversified, complex, wasteful and overlapping activities, which result to rework, duplication and errors.
- The implicit functions in estimating and planning were also found to be some of the factors affecting integration in design-management as well as the sharing of common data/information.

In order to satisfy the second objective, substantial changes were proposed as a means to virtually remove the flaw, which include duplication of function from existing practices that have been seen as militating against effective integration in design-management and planning. However, some of this arbitrariness was viewed to be very important and eliminating them will have adverse effect on the entire process. In order to make rational changes to the existing processes; a critical analysis of the methods that would provide radical and innovative changes was undertaken. The proposed methodology should be able to identify non-value-added function.

The use of SA/BPR CASE tool was viewed as the means to carryout analytical and innovative changes to design-management and planning processes. However, some of the limitations found with the use of SA/BPR CASE tool were as follows:

- The use of mathematical representations in SA/BPR and other CASE tools take a lot of time and effort to convert such mathematical representation into linguistic language.
- Effective decision cannot be reached with poor or missed data, when SA-BPR CASE tool was used.
- The use of this approach provided quantification problems and technological uncertainties, when more than one output is being processes at a time.

In order to over come SA-BPR CASE tool limitations, a strategy divergent from existing approach was proposed. The following steps were adopted as a solution to the shortcoming:

- The development of a framework for the innovative process which encompassed the use of Process Planning Matrix (PPM); Innovative Process Matrix (IPM); Innovative Activities Statement; and the Enhanced Process Matrix to enable the SA/BPR CASE tool to be utilised to its maximum potential.
- The use of linguistic variables in the matrices of the innovative framework in order to provide a better problem representation, which is more understandable, was carried out.
- Site-based studies to enable construction related companies, construction professionals and experts in process re-engineering to contribute in development of the proposed rational integrated process.

11.2 Findings

The finding of this study can be summarised as follows:

- Lack of a defined and consistent method of design-management and planning of BIPV project within the UK construction industry.

- Poor integration between the multi-disciplinary team, leading to duplication of function rework and rediscovery of information.
- Late involvement of specialist consultant and suppliers.
- Little or no effort made to clearly establish the clients requirement at the on set of BIPV project
- Miss match between client's requirement and project objective resulting to client dissatisfaction, rework and redesign.
- Value management not carried out at the design stage thereby value not optimised.
- Task and responsibility not clearly defined at the design, planning or estimating stages thereby leading to duplication of function, errors, rework and rediscovery of information. The line of communication was not clearly defined in case studies one and three, leading to errors, rework and redesign.
- Careful consideration not given to choice of procurement system that could cope with the complex nature of the supply chain of BIPV cladding system. In all three case studies lead to delays in delivery of PV modules and an ultimate delay in the overall building program plan.
- Key function tasks and responsibilities were not clearly defined at the on set of all three projects. A lack of definition of a clear communication line resulted in confusion, error and failure to carryout fundamental function in the installation process.

The integration of PV modules into facades of offices or industrial building is very promising. BIPV is an increasingly growing application of an environmentally friendly way of generating electrical energy, Gyoh (1996).

From the findings of this research, there is strong evidence to suggest that BIPV installation design-management and planning can be more complex than conventional cladding installation or indeed small roof-top mount or ground mount PVPS installations. The precise planning of design-management and planning activities will activate all the advantages of BIPV systems. This will also give BIPV a good reputation amongst the construction client forum i.e. the construction round table (CRT) thereby increasing significantly the number of future corporate and institutional building projects that specify BIPV installations.

The finding from case studies and surveys carried out as part of this research suggest that BIPV designers, project co-ordinators and planners need to take into consideration that PV modules have a complex supply chain. For instance, the PV cells used for the Doxford BIPV project was purchased in Japan and exported to Germany for wiring, stringing and laminating. The modules were then imported to the UK and delivered to site for incorporation into the SK60V standard SHUCO cladding sections. The BIPV modules used in Case Study 3 was manufactured and engineered in Spain. The modules were delivered to site for incorporation into a specially engineered BI-Spoke cladding section.

Designers also have to take into account the effects of different orientation, elevations, shading by neighbouring buildings or parts of the façade itself. The high operating temperature of PV modules and the associated effect on the performance efficiency needs to be allowed for by the designers of BIPV installations. It is also crucial to ensure the compatibility of warrantees of the various components of a BIPV facade.

The installation and operation of a BIPV system requires knowledge from the fields of PV specialist, Architects/Designers, Cladding Consultants and Engineers. The proper integration of the interface between the multi disciplinary team is crucial to the success of a BIPV project. This requires the optimisation of an integrated design-management and planning of the activities of the project partners by:

- A clear definition of the range of tasks and responsibilities involved.
- Identification of range of information required to carryout the main functions
- Provision of a matrix of those responsible to provide these informations and the associated time scale requirement.
- Establishing good communication networks between members of the construction team, breaking down traditional barriers and altering professional mindset.
- Achieving an agreed competitive overall construction time by negotiating better ways of construction with the contractor, who is selected on the basis of recognised past performance and financial stability.

- Using of Partnering in the procurement of BIPV work packages
- Matching of BPIV component/system choices with the client requirement/ project objectives at the initial design stage.

11.3 Contribution in Optimisation of Design-Management and Planning Processes

The main achievements in this section are the development of a framework to provide a systematic and effective process in design-management and planning. The innovative approach adopted in this research is different from 'Traditional' approaches, which duplicate rather than virtually eliminate wastefulness in design-management processes. Firstly, the uniqueness of this approach is in the analysis of the functions, variables and mechanisms/ participants involved in existing design-management, planning and estimating processes. SA /BPR computer simulation of the proposed models indicate that this approach would considerably reduce the over-run-time and over-run-cost in its operations and also achieve a consensus decision making that is likely to lead to high levels performance.

11.4 Contribution to Integrated System Framework Design.

The main achievement in this section is the development of a rational integrated design-management framework, which considers the views, perception and the requirements of the participants. The functions integrated include design, construction planning and cost estimating of building projects. The system framework provided extensive facilities to support these functions. The major component of this development is the Shared Project Model approach, which provided the vital platform for co-ordinating the integrated process between the various design-management and planning applications.

11.5 Contribution in Specification for a Multiple Decision Support Systems

The specification of the proposed decision support tool is intended to support design-management and planning of a BIPV façade and also system design choices and component selection. The proposed system is primarily intended to match project objective with the proposed PV façade.

The Decision Support System would fit the usual working environment of the designers and planners. The system would be integrated with Microsoft Project or Primavera P3, leading estimating, project management and planning tools. Another important demand on the BIPV Design-management Decision Support Tool (BIPV – DDST) is that it is compatible with AutoCAD R14 system integrated component database. The BIPV-DDST would give support to the user right from the start, with the graphic input of the building into AutoCAD system. Autodesk has provided AutoCAD R14 and AutoCAD 2000 with micros that would enable users to select standard PV modules from an external database and place them into a three-dimensional drawing. Using these macros the solar façade can be designed with the CAD program the planner is accustomed to. AutoCAD R14 and AutoCAD 2000 are fully compatible with Microsoft Project and Primavera P3 project management, estimating and planning environments.

The multiple function of the BIPV façade forms an important part of every BIPV building and represents the main design element for the architect. Evidence from the findings of this research suggests that the design of a façade form part of the procurement planning of the complete building. The scheme design options and detail drawings are usually carried out on computer aided design (CAD) environment. Therefore, it is essential that the design and decision making of BIPV systems should fit in as seamlessly as possible into conventional planning procedures.

The BIPV-DDST system is intended to support the functional determination process. This would also encourage and promote integration of a BIPV design-management process into an overall building project plan. The system can be further developed to include an optimised graphic user interface for easy and intuitive handling of BOS component data. Modules and inverters can be searched for with geometric or electrical properties as parameters. In addition to the basic information needed for the yield calculation. Details of these components are provided by complementary systems being currently developed. The PV-CAD is currently being developed in Kasei Germany, the ASHLING 7.0 energy simulation software is being developed at the National Microelectronic Research Centre, Ireland whilst the PVSYST 3.0 software is being developed in Geneva Switzerland.

The fundamental difference between proposed BIPV-DDST and above mentioned systems is that the above systems are, basically, standalone energy simulation software facilitated with climatic data as well as photovoltaic power systems component database. These systems lack the decision support knowledge base component and most importantly are not compatible (do not integrate) with CAD or project management, estimating and planning systems.

11.6 Contribution to Best Practice Guide for BIPV Power Systems

The Best Practice proposal put forward by this study for the Design-management and planning of BIPV system are as follows:

1. Ensure that project objective matches client requirement at all phases of the design, estimating and planning stages. The clients' requirement should be clearly established at the project inception stage.
2. Ensure early involvement of system designers, engineers, cladding consultant, PV specialist and suppliers.
3. Identify clearly major tasks and limits of responsibility of project partners. Define major activities to be carried out with associated time scale.

4. Value management technique should be used to optimise system component choices and procurement pathway for individual BIPV projects.
5. The choice of procurement method should be appropriate to the complex, BIPV façade, supply chain and the general project make-up.
6. Long lead times and method statements should be built into an integrated estimating and planning process.
7. Cost reduction can also be achieved through optimisation of degree of cantilever (in cantilever devices), project budget, PV tilt angle and visual aesthetics of façade.
8. Cladding system components and the photovoltaic power system component warrantee should be compatible; otherwise, suitable warrantee negotiations should be made.
9. Ensure the installed systems are properly tested and commissioned leading to reliable performance of PV system in service and good reputation for the technology.
10. An important aim of testing and commissioning is to ensure that the lifetime of the system as a whole is not shortened by poor quality component of installation method and that component, which intrinsically have shorter lifetime are incorporate in a manner allowing for easy replacement and buildability.
11. The designer should be aware of the requirements for the testing, commissioning and monitoring of the PV system during the design stage in order to ensure that appropriate provision is made for the access to test points.
12. Sufficient time should be allowed in the construction schedule for the testing and commissioning to be adequately carried out.
13. The designer and the client have a responsibility to observe the CDM regulations. The need for a planning supervisor who has overall responsibility for co-ordination of the health and safety aspects of design, planning, statutory obligation and associated liabilities.
14. The G59 agreement should be set –up with the REC for the purchase of electricity and inspection of plant.
15. Partnering should be used in BIPV projects – as a way forward.

The development of these guidelines have been drawn from the UK building and PV industry. The Latham and Egan recommendation as well as the findings of this research have been used as a framework these guideline.

The proposed Design Decision Support Tool (DDST) is intended to define a consistent method of design-management and planning of BIPV projects within the UK construction industry. It is hoped, the system would provide potential BIPV owners and operators with a methodology for procuring and maintenance of a BIPV system. This methodology may also ensure that clients and potential clients get the systems they require. The research specified that the proposed DDST system is designed using an open-ended architecture, which would allow the inclusion of extra modules, quality assurance, design and planning needs in terms of:

- Aesthetics
- Energy yield
- Optimal layout of PV in design evolution
- Output affected by
- Module tilt
- Orientation
- Output
- Shading
- Operating temperature
- Electrical system layout

Building regulation – mechanical suitability – thermal insulation – water tightness – noise protection and protection against fire and other design, estimating and planning variables are key factors that are central to the design-management process of a BIPV project.

The findings of this research reveal that several routes for the design, supply, installation and commissioning of BIPV systems are currently in operation within the UK. Some of these routes however, are not compatible with the supply chain and generic procurement practices within the UK construction industry. Against this background, a generic procurement process model has been developed as part of this research, see figure 11.0.

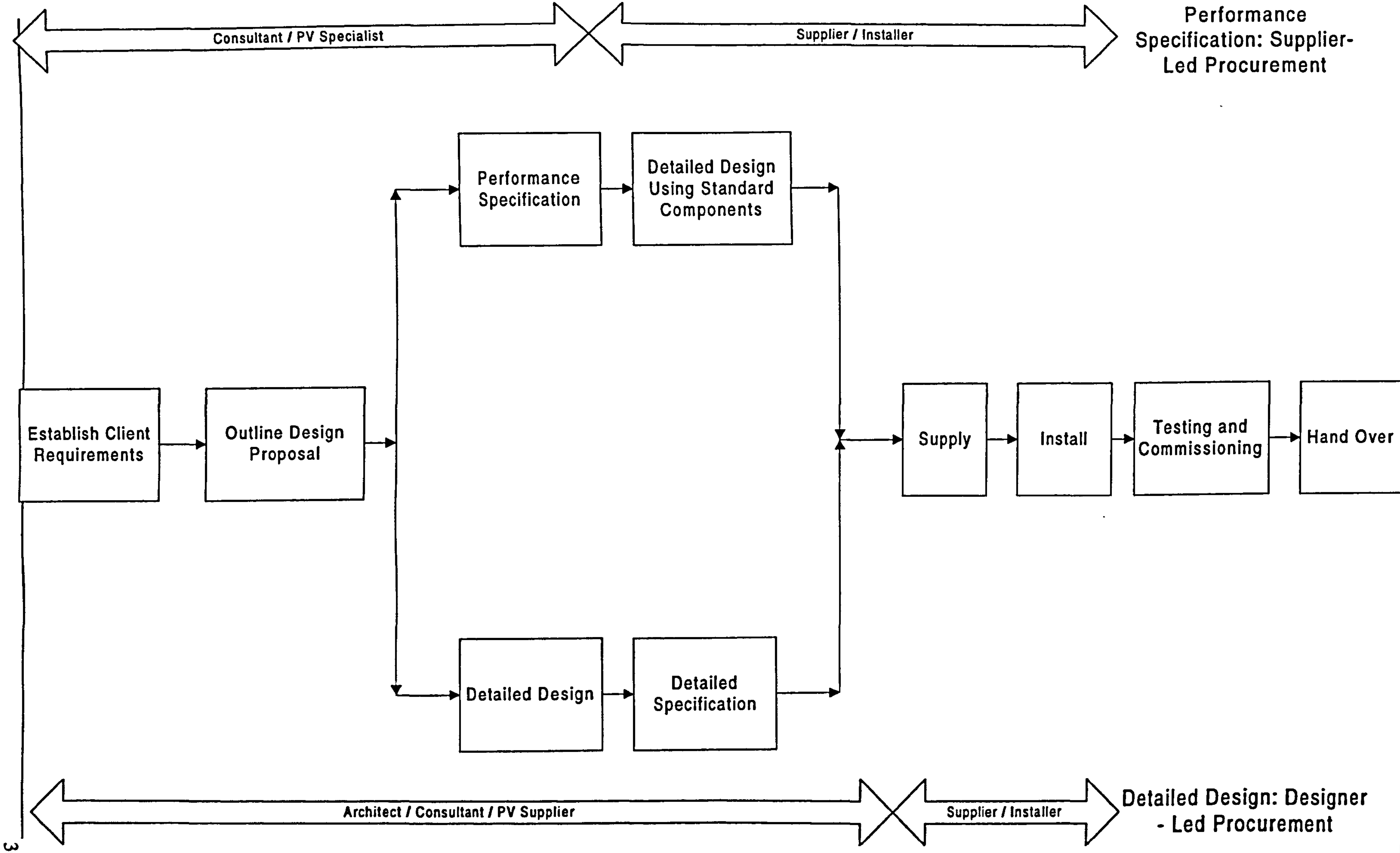

Figure 11.0: Proposed Generic BIPV Procurement Process Model

Two categories of procurement routes have been identified in existing procurement practices, namely:

- The Performance Specification Route
- The Detailed Designed Route

Inferring from the proposed generic procurement model in figure 11.0, if the performance specification route is followed, a consultant / PV specialist would prepare a performance specification and the cladding systems supplier would prepare the detailed design. The performance of the system may be specified in terms of power and energy output. Testing and commissioning requirements may be given within the performance specification. The performance specification may also specify that the appropriate standards are followed and that suppliers and installer demonstrate that the system is correctly installed and tested. This procurement pathway may be best suited to standardised cladding system and is supplier led as illustrated in figure 11.0.

Inferring form figure 11.0, if the Detailed design route is followed, a detailed design and specification may be prepared by a consultant / architect / PV specialist. The design should provide all the necessary information for the design, installation, testing and commissioning. The test points, expected values of test data and acceptable tolerances should all be specified. It is also recommended, by this research, that the client's requirements and supplier's proposals be clearly stated and agreed in the contract documentation.

11.7 Contribution to BIPV Design Management and Planning Processes.

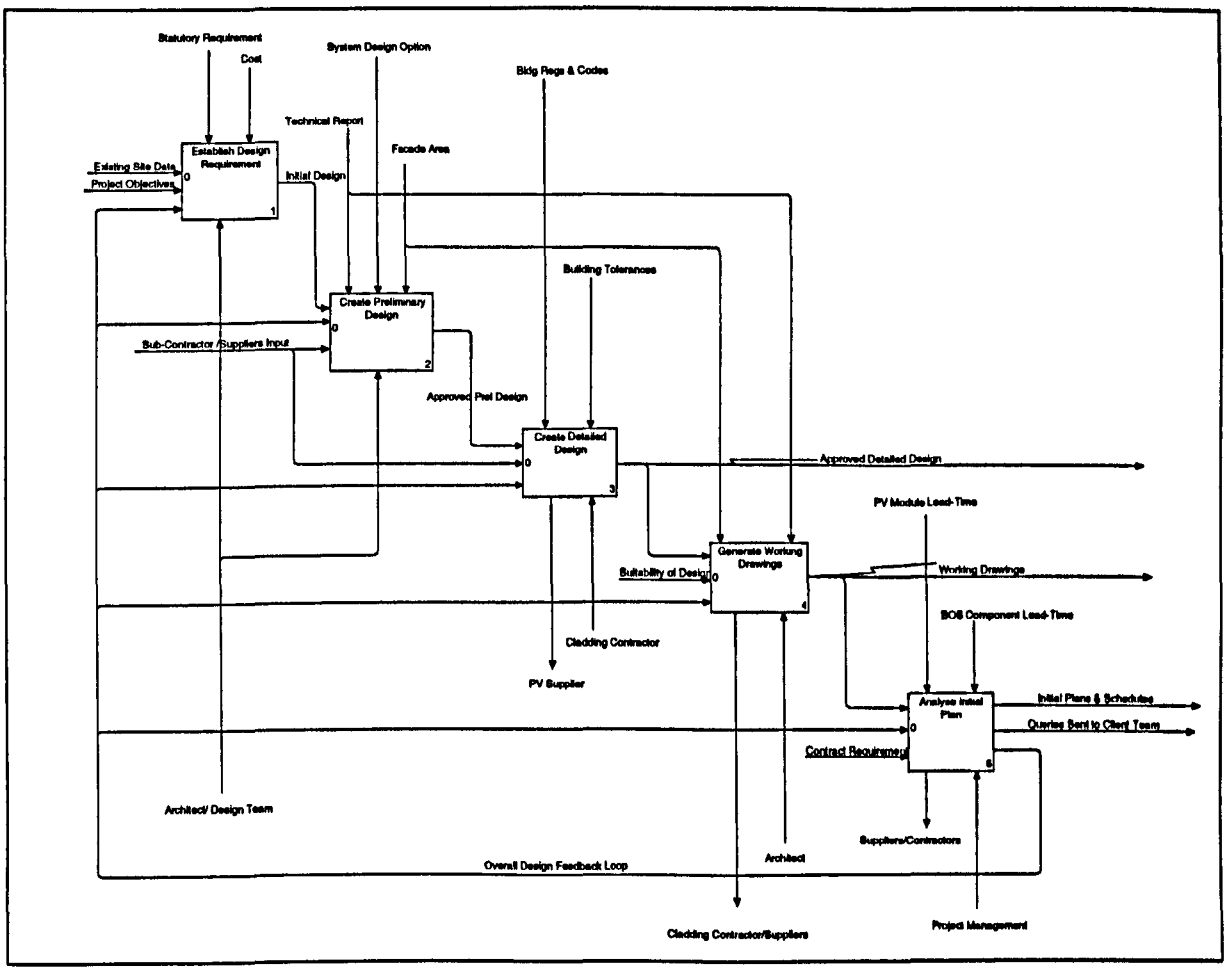

Figure 11.1: Proposed Design Management Model for BIPV Work Package.

The model in figure 11.1 is the proposed integrated design management model developed as part of this research study. The proposed rational and integrated model is designed to encourage early involvement of suppliers and specialist contractors. The model would also promote an early client and functional requirement determination at the project inception stages. The model is also intended to encourage consistency in design-management process of BIPV projects. This has been achieved through the effective integration of the task and responsibilities of the multi-disciplinary team. The model is characterised by feedback loops such that the suitability of the design is constantly under review. This approach might ensure that value management and is optimised, whilst client satisfaction is maximised.

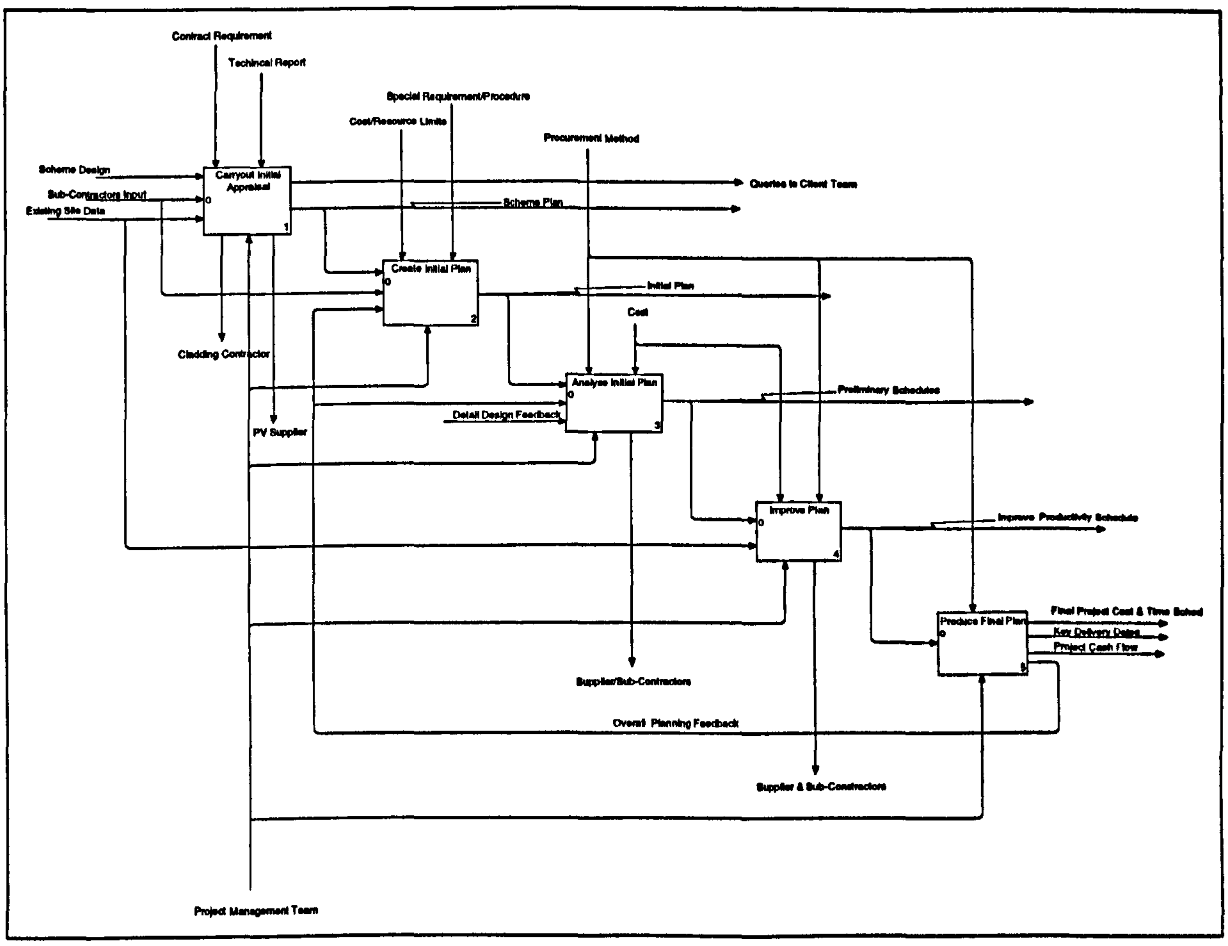

Figure 11.2: Proposed Planning Model for BIPV Work Package

Figure 11.2 is the proposed integrated planning model developed as part of this research work. The integrated planning sub-model is an integral part of the over all design-management and planning model. In this sub-model the key tasks and responsibilities are clearly defined. The inputs, output, mechanisms and control variables are identified and clearly defined. These variables are effectively integrated with those of the estimating sub-model. The suppliers and works contractors are involved earlier on in the project and at all levels of the planning and estimating functions. The development process of the proposed planning model took into consideration the controls that might be imposed by the complexities of the choice of procurement system and (or) indeed the supply chain. The model provides for effective resource management and levelling. The benefits of good planning as proposed by the above model would promote buildability during the installation process and also throughout the lifecycle of the BIPV façade. SA/BPR computer simulation suggest that the proposed model would provide a vehicle for all the project collaborators to view and agree on a multi-lateral strategy in line with the project object, scope of task and responsibility, cost and standard of workmanship as well as health and safety standards.

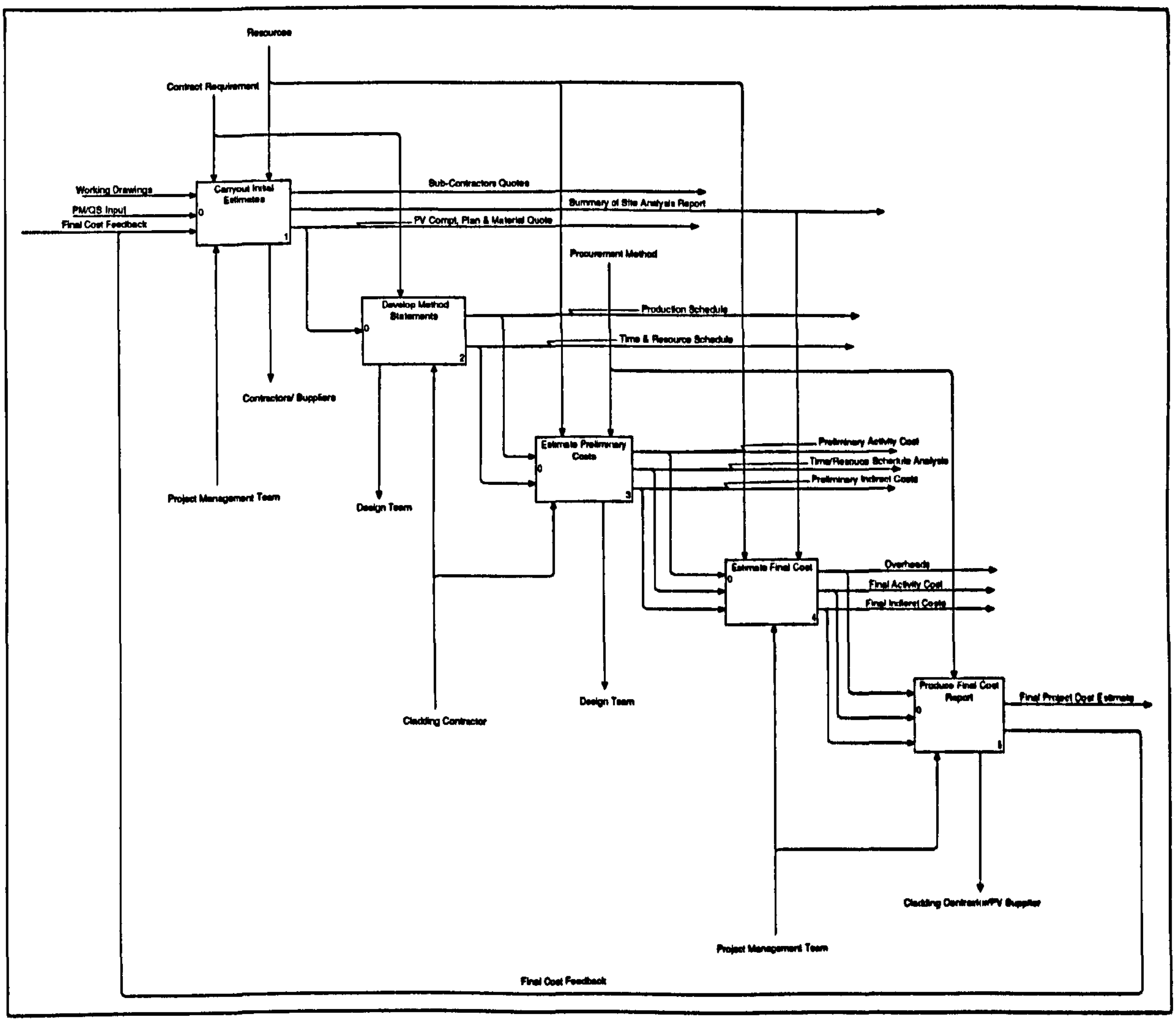

Figure11.3: Proposed Estimating Model for BIPV Work Package.

Figure 11.3 is the proposed integrated estimating process model. The planning and estimating functions are fully integrated such that estimating tasks and responsibilities are clearly defined. All three sub-models integrated to form a parent design-management and planning model that support BIPV projects. This approach is intended to significantly reduce the chances of duplication of function, omission of functions, errors, rework and (or) rediscovery of information. The line of communication between and within the sub-models is clearly defined. The model in figure 11.3 is the product of an iterative re-engineering process that encourages flexibility. The model is intended to function effectively under the complex supply chain and "one-stop-shop" procurement methods that characterise the UK BIPV sector.

11.8 Discussions

Photovoltaic solar energy is broadly recognised as one of the most important sources of renewable energy in Europe and it promised to be one of the key fuels of the future, ETSU (1998 (2)). The prospects of developing a PV industry depend on the ability to overcome institutional and technical barriers, (IEA (1997), ETSU (1998 (1)) ETSU (1998 (2)), Pitts & Gyoh (1997). Some of the institutional barriers identified during the course of this research include:

- Government expenditure and legal framework
- Lack of awareness of the potential and possibilities PV
- Level of PV industry investment
- Private investment in the PV sector
- Utility support programs
- Poor training

The cost breakdown of conventional cladding systems and BIPV installations are summarised as follows (1999 figures) (Ibid):

Conventional Walling Systems

- Cost of stone cladding £300/m2
- Double Glazing Cladding System £350/m2
- Granite faced precast concrete cladding £650/m2
- Polished stone cladding £850 - £1500/m2

Conventional Roofing System (Ibid)

- Roofing tiles (concrete or clay) £32/m2

- Aluminium pitched roof £44/m2

Photovoltaic cladding systems **(installed)** ETSU (1998(1)).

- Rain screen cladding system £600/m2
- Curtain walling using glass/glass modules 780/m2

Photovoltaic roofing systems

- Photovoltaic roof tiles £500/m2
- Photovoltaic modules on a pitched roof £650

The break down of the costs of a typical BIPV installation is as follows, Downie (1998):

For large installation > 40kWp

Array	45 – 60%
BOS & Power Conditioner	10 – 20%
Installation	30 – 50%

For small installation < 5kWp

Array	60%
BOS & Power Conditioner	25%
Installation	15%

The client requirements and project objectives should be clearly stated in the brief, when it has been determined that photovoltaics are required and applicable to a particular project. From the findings of this research some of the reasons for applying BIPV facades as indicated by clients and potential clients that took part in a survey conducted as part of this study is as follows:

- Supplying on site all or part of the electrical energy requirement
- Supplying the maximum power demand or some fraction of it
- Making a contribution to the environment
- Making an environmental statement
- Making a statement about innovative architecture and engineering design.

- Using PV as a demonstration or educational project.

Photovoltaic are worth considering at the design stage if the follow factors apply to a particular project:

1. **Location:** the site/building needs to have good access to south facing solar radiation.
2. **Usage:** The building type has an electrical requirement i.e. the output of the photovoltaic power system can be utilised on site and even exported to the national utilities.
3. **Design:** Photovoltaic facades are instrumental to the aesthetics and the clients and or users are in support of its application.

Design-management, estimating and planning processes of a building project should be able to take into consideration the following points in the decision-making processes.

- The cost of PVs can be offset against the cost of the building material/elements they replace. However, PV cost is relatively high. It is also interesting to know that the opportunity cost of a façade installation is fall less than the opportunity cost of a roof installation.
- Sizing a PV installation tends to be an iterative process in which energy requirement, area available and cost need to be optimised.
- PV electricity replaces conventionally generated power and so provides an environmental benefit of reduced CO2 emission. At the moment it is difficult to evaluation the cost in accounting terms.
- Hand-over documents should include I) project record summary ii) an operational and maintenance manual for the BIPV installation. Details of these documents can be found in Photovoltaic in Buildings testing, commissioning and monitoring Guide ESTU for the DTI (1998) produced by Halcrow Gilbert Associates.

11.9 Recommendation

The integration of PV modules into facades of offices or industrial building is very promising. BIPV is an increasingly growing application of this environmental way of generating electrical energy.

Based on the findings of this research it is recommendation that – a separate check lists should be developed for the design, planning, estimating and installation phases of a BIPV project. The checklist for installation should cover:

- Standard of PV array and module mounting support structure.
- PV system wiring
- Corrosion protection measures
- Position of Junction Boxes
- Main dc cables
- D/C circuit breakers
- Inverter(s)
- Earthing
- Lighting protection devices
- By-pass and blocking diode if used
- A/C switch gear.

The checklist should be completed in conjunction with a visual inspection and covers the following. Checklists of potential module fault are as follows:

- Damage to frame
- Cracked or broken glass
- Signs of delimitation or water infiltration
- Broken, damaged or discolored cells
- Broken damaged or discolored contact and grid.
- Damage/loose electrical connections to the junction box and leads.

From the findings of this research, there is strong evidence to suggest that BIPV installation design-management and planning can be more complex than conventional cladding installation or indeed small roof-top mount or ground mount PVPS installations. The precise planning of design-management and planning activities will activate all the advantages of BIPV systems. This will also give BIPV a good reputation amongst the construction client forum i.e. the construction round table (CRT) thereby increasing significantly the number of future corporate and institutional building projects that specify BIPV installations.

11.10 Further Research

The vast amount of work coupled with time constraints in this Ph.D. research project perpetually touches on some issues that need to be research further to advance the subject area. This work is disconcertingly not different and as a result, the following areas are recommended for further studies:

- The development and use of unified classification scheme for building integrated photovoltaic components and materials to classify design elements and provide clarity, consistency and compatibility with current constructional practice, building standard and codes.
- The measurement of performance on real construction project is sometime invidious since they show the multifarious nature of construction. However, the development and use of process-based cost engineering for bench-marking the performance of the entire project will provide more close to practical measurement of performance in projects. In this aspect, two possible strategies have been identified for future development:
  - I) Combining the BIPV process-based model with a commercial process re-engineering software package or;
  - II) Combining the BIPV process-based model with computer aided design system used by construction professional and companies

By combining the resulting tool would not only incorporate the use of duration-based cost driver in its cost analysis, but also provide an effective means of bench marking performance in design, engineering and other construction management activities.

In the second proposed strategy, a computer application of the process-based model combined with CAD system is advocated. This approach can provide a comparable cost data for alternative BIPV design and management processes at the inception stages rather than the later stages, which bring about late detection of cost as in existing practice.

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Glossary

Air Mass Number	A measure of the path length of sunlight through the atmosphere; expressed in comparison with unit path length where the sun is directly overhead; used to define the intensity and spectral distribution of sunlight.
Air Mass 1.5 (AM1.5)	The air mass number when the direction of the sun is 48 degree form the overhead position.
Alternating Current (AC)	Electric current in which the direction of flow is reserved at frequent intervals. The conventional grid supply is AC with an alternating frequency of 50Hz.
Amorphous	The condition of solid in which the atoms are not arranged in an orderly pattern; not crystalline.
Balance of System (BOS)	The parts of a PV system other than the PV array itself; e.g. support structures, wiring power conditioning units etc.
Blocking Diode*	A diode connected in series to a PV string; it protects its modules from a reverse power flow and thus against the risk of thermal destruction of solar cells.
Bypass Diode*	A diode fitted in parallel with each cell string of a module to prevent overheating (hot spot) of a cell due to localised shading.
Conversion Efficiency	The ration of the electrical energy produced by a PV cell (or module) to the energy from sunlight incident on the cell (or module). This is usually quoted for standard test conditions (STCs).
Crystalline	The condition of a solid where the atoms are arranged in an ordered pattern.
Consortia	A consortium is the grouping together of three or more organisations, generally or differing skills, with the objective of carrying out a specific project.
Continuity tender	A continuity tender is similar to the serial tender. Contractors competitively tendering for a project are informed that given satisfactory performance, they will be awarded a similar project to follow on form the completion of the first and that the price for this will be negotiated, possibly using the prices of the original bill.

Construction management (CM)	construction management or CM is the term used in the USA to describe management contracting.
Daylight Factor*	The illuminance received at a point indoors, from a sky of known or assumed luminance distribution, expressed as a percentage of the horizontal illuminance outdoors from an unobstructed hemisphere of the same sky.
Diffuse Radiation	Solar radiation scattered by the atmosphere.
Direct Current (DC)	Electric current, which flows in one direction.
Direct Radiation	Solar radiation transmitted directly through the atmosphere.
Design-build	Design-build or design-construct is where the contractor provides the design and construction under one contract.
Electron	Negatively charged atomic particle; an electric current is the movement of electrons through a material.
Fast tracking	Fast tracking is a means of reducing project time by the overlapping of design and construction. Each trade's work commences as its plans and specifications are substantially completed.
Fixed fee/prime cost Contract	Under this arrangement the contractor carries out the work for the payment of a prime cost (defined) and a fixed fee calculated in relation to the estimated amount of the prime cost.
Fixed price contract	A fixed price contract may be a lump sum contract or a measurement contract based on fixed prices for units of specific work.
Global Irradiance	The total irradiance (sunlight intensity) falling on a surface; the sum of the direct and diffuse irradiance.
Grid	1. The patterned metal contact on the top of the PV cell. 2. Common name for the electrical distribution system.
Irradiance	The intensity of solar radiation on a surface (w/m2).
Irradiation	The amount of solar energy received on a surface (kWh/m2).
Joint venture	A joint venture is the pooling of the assets and liabilities of two or more firms for the purpose of accomplishing a specific goal and on the basis of sharing profits/losses.

Kilowatt (kW)	Unit of power equal to 1000W.
Kilowatt-hour (kWh)	Unit of energy equal to 1000Wh.
Load	Any device or appliance (or set of devices or appliances) which is using electrical power.
Low-emissivity Glass*	Glass with a low-emissivity coating on one surface; this allows short wavelength energy from the sun to pass through but reflects long wavelength energy back in, e.g. from a room.
Lump sum contract	With a lump sum contract, the contractor agrees to perform the work for one fixed price, regardless of the ultimate cost.
Megawatt (MWh)	Unit of energy equal to 1,000,000W.
Megawatt-hour (MWh)	Unit of energy equal to 1,000,000Wh.
Micron	Unit of thickness equal to 10square 6m.
Multi-junction Cells*	Two (or more) different cells with more than one p-n junction; such an arrangement allows a greater portion of the sun's spectrum to be converted to electricity.
Management contracting	With management contracting the contractor works alongside the design and cost consultants, providing a construction management service on a number of professional bases. The management contractor does not undertake either design or direct construction work. The design requirements are met by letting each element of the construction to specialist sub-contractors.
Nominal Array Power	The power rating of an array in Wp, as measured under standard test conditions (STCs).
Negotiated contract	In a negotiated contract the client selects, at the outset, one main contractor with whom to negotiate. In essence the arrangement is the same as that for a two-stage tender.
Performance Ration	Ration of the system yield to the incident solar irradiation in the array plane.
Photon	A quantity of light having a fixed energy dependent on the wavelength of the light.
Photovoltaics (PV) Cell	Semiconductor device that converts light to electricity using the photovoltaic effect.

P-N junction	A junction formed between two semiconductors of different doping types; the usual configuration for a PV cell.
Package deal	A package deal follows the same lines as design-build, with the contractor providing the design and construction under one contract, but there is the implication that the building provided will be of a standardised or semi-standardised type.
Procurement	Procurement is the amalgam of activities undertaken by the client to obtain a building.
Professional construction management	PCM is a term used in the USA to describe an arrangement whereby the tasks of planning, design and construction are integrated by a project team comprising the owner, construction manager and the design organisation.
Professional construction manager (PCM) or construction manager	The PCM acts as a management contractor (UK) specialising in construction management within the professional construction management concept.
Project management	Project management is concerned with the planning and co-ordination of a project from inception to completion aimed at meeting the client's requirement and ensuring completion on time, within cost and to required quality standards.
Standard Test Condition (STCs)	Standard test conditions are defined as an irradiance of 1000W/msquare at normal incidence, a spectral distribution of that irradiance equivalent to AM1.5 and a cell temperature of 25*C.
System Yield	Useful energy supplied to the load by the PV system expressed as a function of the nominal array power (kWh/day per kWp).
Separate contracts	With separate contracts the client's professional adviser let contracts for the work with a number of separate contractors. This arrangement was commonplace prior to the emergence of the general contractor.
Serial tender	A serial tender is where a number of similar projects are awarded t a contractor, following a competitive tender on a master bill of quantities. This master bill forms a standing offer open for the client to accept for a number of contracts. Each contract is separate and the price for each calculated separately.

Target cost contract	This form of cost reimbursable contract involves the fixing of a cost either for the complete project or in respect of certain elements only, e.g. labour, or materials, or plant. If the final cost deviates from the target, the saving or excess is divided between client and contractor in pre-determined proportion.
Tradition contracting	The traditional form of contracting is where the client appoints an architect or other professional to produce the design, select the contractor and to supervise the work through to completion. The contractor is selected on some basis of competition.
Turnkey	A turnkey contract is one where the client has an agreement with one single administrative entity, which provides the design and construction under one contract, and frequently effects land acquisition, financing, leasing, etc.
Two-stage tender	With a two-stage tender three or four contractors with appropriate experience are separately involved in details discussion with the client's professional advisers regarding all aspects of the project. Price competition is introduced through an approximate or notional bill or schedule of rates. Further selection criteria are then used to determine which contractor carries out the job.
Uniformity Ration*	The ration of the illuminance to the average illuminance.
Watt (W)	Unit of power.
Watt-hour (Wh)	Unity of energy; one Wh is consumed when one W of power is used for a period of one hour.
Watt peak (Wp)	Power output of a PV module under standard test conditions (STCs).

ABBREVIATION

ACA	Association of consultant Architects
ASC	Amorphous Silicon Cladding
BBA	British Board of Agreement
BEC	Building Employers Confederation
BIPV	Building Integrate Photovoltaic
BPP	Best Practice Programme
BPF	British Property Federation
BPF	British Property Federation
BRE	British Research Establishment
BSI	British Standards Institute
BS	British Standards
BSI	British Standards Institute
CAD	Computer Aided Design
CASE	Computer Aided Software engineering
CD81	JCT Standard from of building contract with contractor's design, 1981 edition
CD	Contractors Design
CE	Concurrent Engineering
CEN	European Committee for Standards
CIRIA	Construction Industry Research and Information Association

CII	Construction Industry Institute
CIOB	Chartered Institute of Building
CPM	Critical Path Method
CRT	Construction Round Table
CR	Clients Representative
CWCT	Centre for Window and Cladding Technology
DETR	Department of Environment Transport and Region
DGU	Double Glazing Units
DL	Design Leader
DM	Design Management
DOE	Department of Energy
DOM	Domestic
DSS	Decision Support System
DTI	Department of Trade and Industry
EMI	Electromagnetic Interference
EMF	Electromotive Force
EPSRC	Energy and Physical Science Research Council
EVA	Ethylene Viulyn
FIPS	Federal Information Processing Standards
HMSO	Her Majesty Stationary Office
I	Current
ICAM	Integrated Computer Aided Manufacture
IDE 0	Integrated Definition for Functional Made
IDEP3	Integrated Definition for Process Model
IEA	International Energy Agency

IFC84	JCT Intermediate from of building contract, 1984 edition
IPCC	International Panel of Climate Changes
Isc	Short Circuit Current
ISO	International Standardisation Organisation
ISPRA	European Union Joint Research Centre Italy
I - V	Current - Voltage
JCT	Joint Contract Tribunal
JCT	Joint Contracts Tribunal
JCT 80	JCT Standard from of building contract, 1980 edition
JPL	Jet Propulsion Laboratory
KWp	Kilowatt Peak
KWh	Kilowatt Hour
LDC	Less Developed Countries
MBE	Management by Expectation
MC 87	JCT Standard from of management contract
MC	Management Contract
MIB	Movement for Innovation Board
MPP	Maximum Power Point
NCR	Non Conference Report
NCR	Non Conformance Report
NEDO	National Economic Development Office
NHBC	National House Building Council
NIST	National Institute of Standards Technology
NOCT	Nominal Operating Cell Temperature
NPAC	Newcastle Photovoltaics Application Centre

OBS	Organisation Breakdown Structure
OSTN	Object State Transition Network
PAS	Product Approval Scheme
PCU	Power Conditioning Unit
PM	Project Manager
PRPS	Photovoltaics Power Systems
PSA	Property Services Agency
PV	Photovoltaic
QA	Quality Assurance
R & D	Research and Development
R & D	research and development
RFI	Radio – Frequency Interference
RIBA	Royal Institute of British Architects
RICS	Royal Institute of British Surveyors
RICS JO (QS)	RICS Junior Organisation (Quantity Surveyors' Division)
SADT	Structural Analysis and Design Technique
SA/BPR	Systems Architect / Business Process Re-engineering
STC	Standard Test Condition
SOC	Standard Operating Condition
TA	Till Angle
TEL	Taylor Wood Row
TQM	Total Quality Management
TT	Total Tilted Insulation
UEALC	Union Europeene Pour L'agrement Technique Dans La Construction

UL	Underwriters Laboratories
UN	United Nation
UNGED	United Nation Conference on Environment and Development
UOB	Units of Behaviour
UV	Ultra Violet
V	Voltage
VE	Value Engineering
VM	Value Management
VO	Variation Order
Voc	Open Circuit Voltage
WBS	Work Breakdown Structure
WC	Work Contracts
ZSW	Zentrum fur Sonneneygie Und Wasserstoff

ANALYSIS OF THE PROCESSES IN THE PROCUREMENT METHODS WHICH SUPPORT INTEGRATION

This appendix presents the analysis of the processes in procurement methods commonly used in the UK construction industry and the level to which these methods support integration. The analysis also presents the various characteristics of the methods, which include the level of diversion of the functions of the participants. The first and oldest method analysed is the Traditional Procurements Approach and details are discussed in the ensuing section. Analysis of the Process in the Traditional Method. The analysis of the processes in the Traditional Methods of Procurement is illustrated in an IDEF0 in Figure A 1

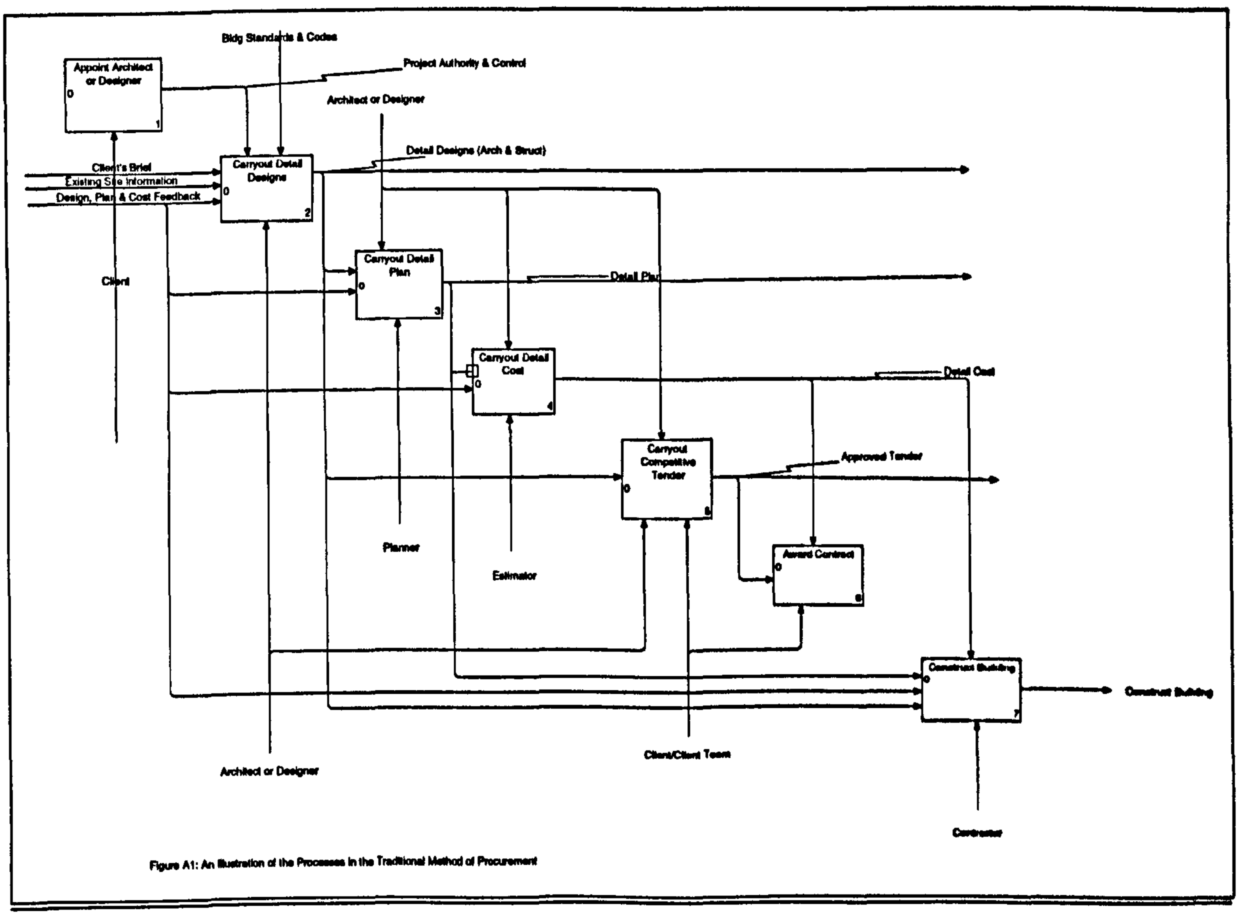


Figure A1. An Illustration of the processes in The Traditional Method Of Procurement

The analysis of the processes in the Traditional Methods of procurement is presented in Figure A1, and the characteristics identified in this approach are as follows:

- The design processes were found to be following a strict "over-the-wall" sequence with rigid functional barriers. The designs (Architectural, Structural and Services) are fully developed before bill of quantities are prepared. The tender preparation and, subsequently, the contract award before the commencement of the actual construction work follow this process.

- Inferring from Figure A1, the architect being the sole contact point and also controls the other phases of the Design-Management activities fosters greater client involvement, which brings fewer variations and eventually less disruption of work.
- Variations, which may occur, are easily incorporated in both the design-management and construction-management stages where the client is allowed to make changes.
- The separation of designs and construction activities including the rigid functional barriers bring about the "me-and-them" attitudes between the participants of the design-management team resulting also from the low level of flexibility in relationships. Similar attitudes also exist between the design-management and the construction-management team as a result of the separation of functions in these areas.
- The end-on design, planning and cost estimating processes with disparate sub-processes before building arrangements are finally made bring about rigid sequential functions which create a longer design-management duration and eventually the overall project duration.
- Lines of communication between the participants tend to be tenuous and interest of all parties suffers as a consequence.

Although this approach provides the client with the complete design, total cost and the overall duration of the project, it is provides to be unsatisfactory for large and complex projects and do not pave the way for integration of construction information (Franks, 1991). The quest for more advance, better-structured and skilful approach towards integration brought about the development of the "Management" System discussed in the ensuing section.

Analysis of the Processes in the Management System of Procurement

The analysis of the processes in the Management System of procurement is illustrated with an IDEF0 model in Figure A2.

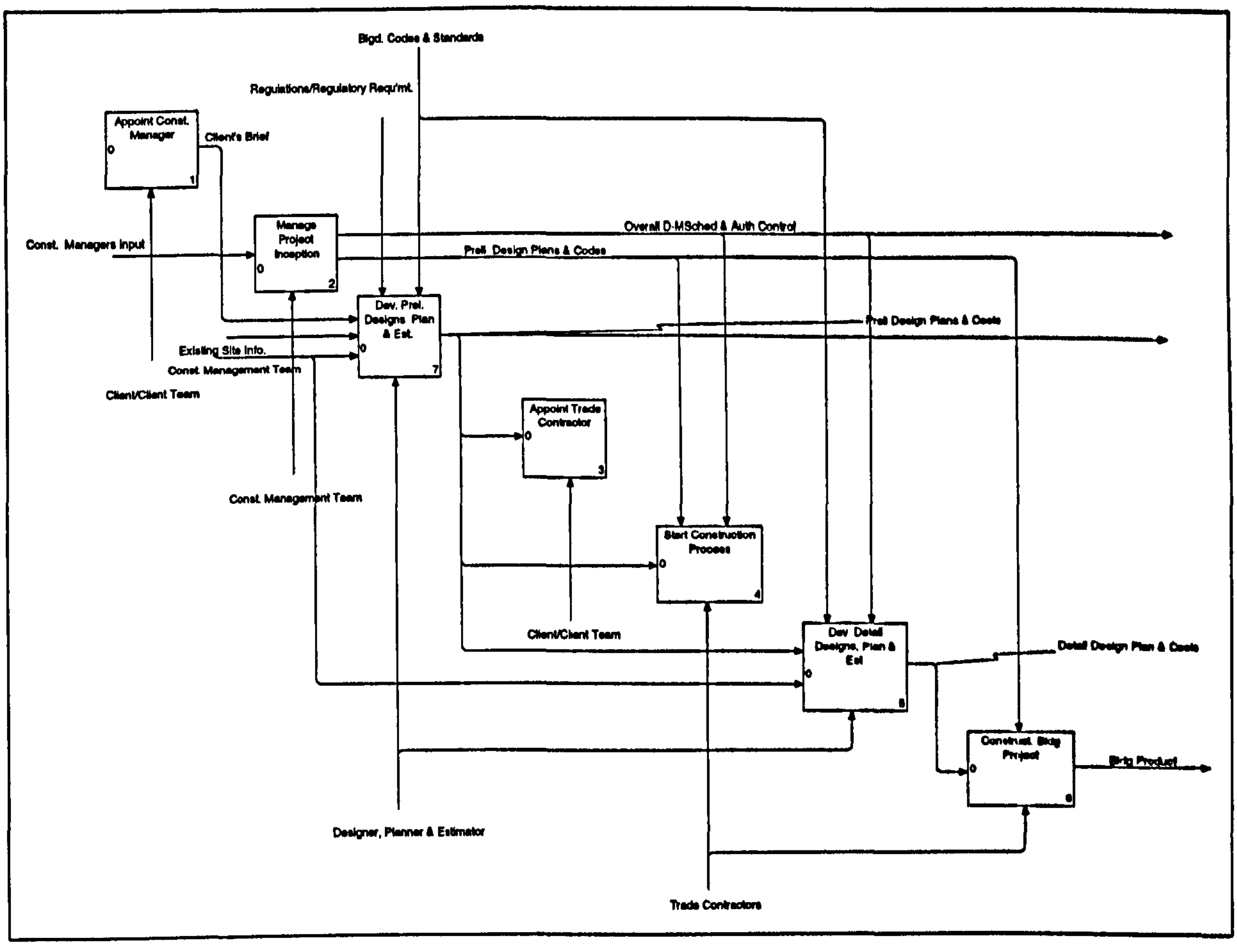


Figure A2: An Illustration of the Processes in Contract Management

Procurement Method

The analysis revealed the following characteristics:

- Work commences as soon as design proposals have been accepted by client and preliminary drawing approved by the local authority creating some sorts of overlap functions between the design-management and the construction-management activities.
- The "them and us" attitudes are reduced and lines of communications are improved, which makes it easier to integrate both the design-management, as well as construction-management team.
- However, some of the inherent limitations in the design-management functions in the traditional method, which includes the rigid lines of communication, and sequential functional are also found in this approach (Rougvie A, 1991).
- The total duration and cost of the project is not known until the last "package has been let. Also the release of the Trade Packages tend to be longer than expected.

Although the "Management System" brings about substantially shortened overall project duration resulting from the overlapping of design-management and construction management functions, this approach has inherent deficiencies, which require improvements. This includes the lack of opportunity by the design-management team to develop the "whole" design, plan/schedule and cost documents, as they are required to release the design "packages at intervals". Also the lack of co-ordination within the design-management team resulting from the separation of design and costing functions do not enhance functional co-ordination. This approach also does not provide the framework for integration. These shortfalls characterised with management system brought about the development of other advanced processes, and the major ones are discussed in the ensuing section.

Analysis of the Processes in "Fast Track" & Concurrent Engineering.

The downward cost pressures blurring with ever more specialised building trades and increasing technical complexity of projects are creating a demand for reduction in lead times, and costs through the integration of Design-Management and Construction-Management process. This has brought about the emergence of "Fast Track" and "Concurrent" engineering approaches in the industry as a means to provide shorter project duration. However, "Fast Track" is a practically oriented approach without a solid conceptual or theoretical basis. In this section analysis of "Fast Track" processes studied for the past 6 months in the case studies has been presented in an IDEF0 model in Figure A3

The Construction Management Company not getting involved in the inception plan and design stage bring about lack of definition of project authority and control which leads to poor definition and development of both the client and project requirements. The separation of the design processes (Architectural Structural and M & E Services) as illustrated in Figure A4 open the entire design to errors and numerous variations.

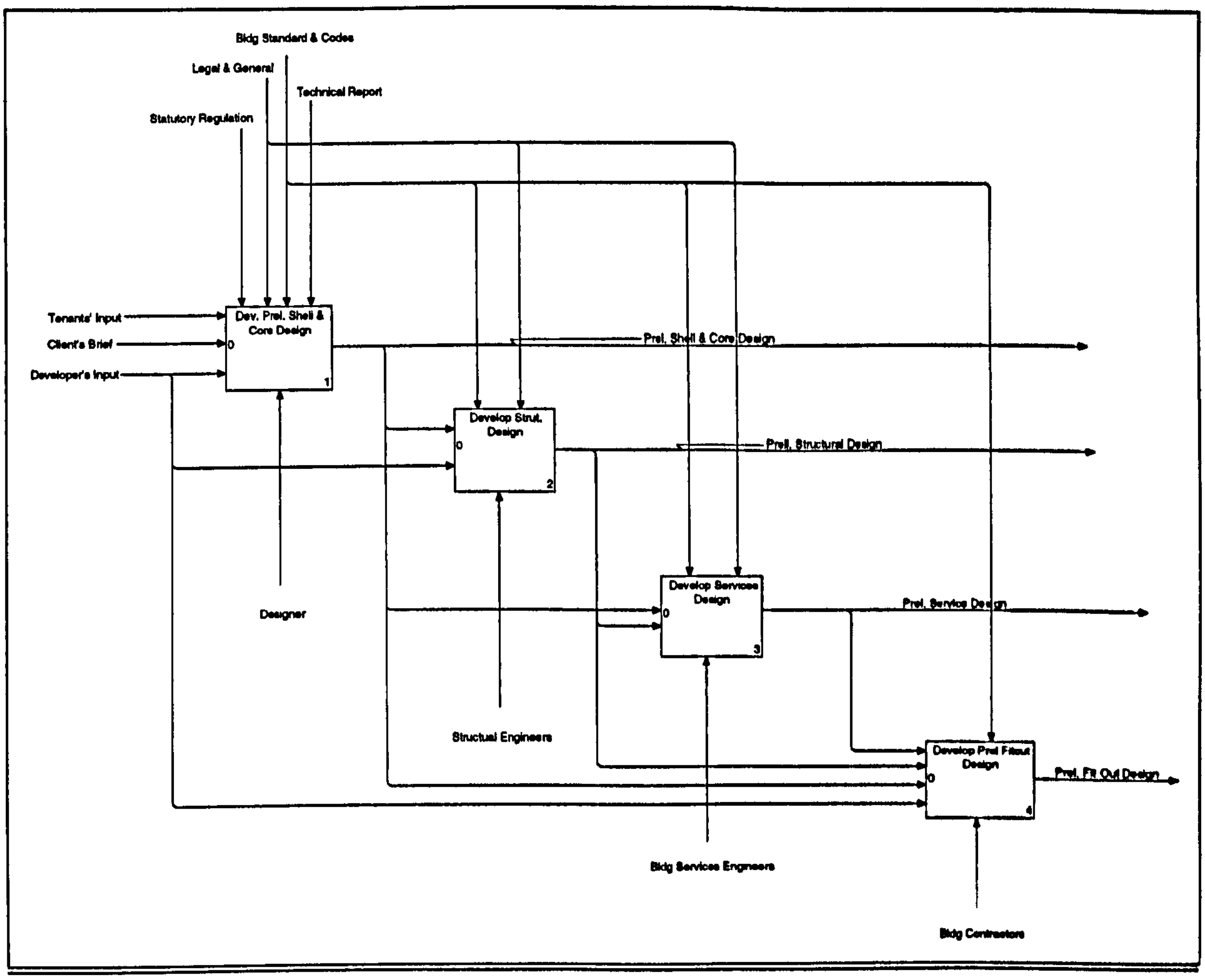


Figure A4: An Illustration of the Processes in the Design Stage of the "Fast Track" Method

The separation of Estimating and Planning functional activities as illustrated in Figure A3 open the entire process of functions, rediscovery of information already acquired by other participants.

Although the lines of communication between Construction Management Team and the Trade Contractors are comparatively shorter than the other previous methods, it takes longer time for Method Statement and Trade Designs by Trade Contractors to be approved and included in the detail designs.

Design Variations in this process were analysed to be high and the cost implications are not promptly assessed. Although the Fast Track Method brings about a reduced project completion period with corresponding reduction in financial on the sums invested, this approach is not fully tested and also has inherent deficiencies in its process, which require radical and innovative changes.

Concurrent engineering on the other hand has stood the test of time and similarly aims at reducing the duration of engineering time, increasing the value of the product, while at the same time reducing the cost. However, the analysis further indicated that overlapping of design and construction in both approaches, do not necessary lead to optimal performance (Crowley A., 1996). Other methods are discussed in the ensuing section.

Analysis of Processes in Design & Built Method

The analysis of the processes in the Design & Build System is illustrated with an IDEF0 model in Figure A5.

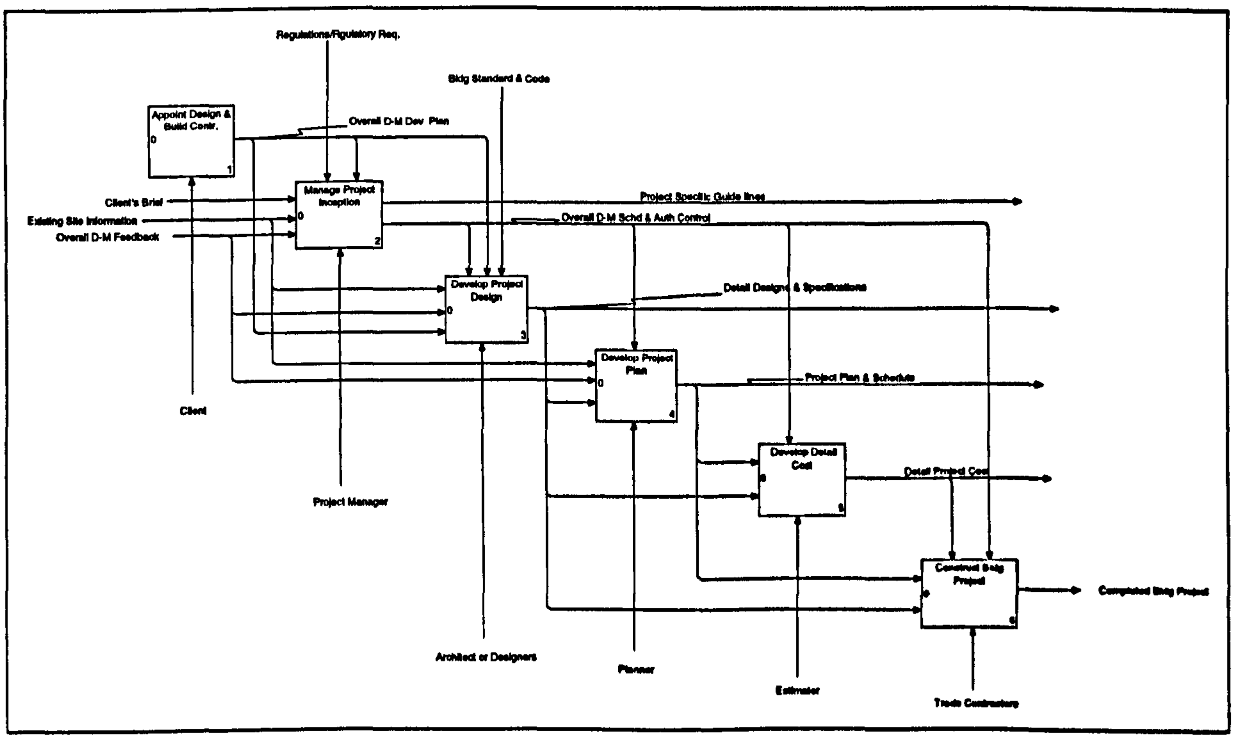


Figure A5: An illustration of the Process in Design & Built

Procurement Methods

The characteristics of the Design & Build Processes are as follows:

- Operating under the same umbrella, Design & Build Method provides a single point of responsibility, where the client has direct contact with the contractor.
- The lines of communication are improved with flexible relationship among the participants of both the design-management teams.

- The response rate to potential variations is high and the cost implication of such variations, if occurred, can be promptly assessed and the cost control for the client is thereby facilitated.
- There are less construction problems due to direct labour employment, trained staff, incentives and motivation to workers.
- Total project duration is substantially shorter than in both the traditional and management methods.
- It is the cost-effective way of procuring a building particularly, where speed of design, effective project control and construction is important.

Although the processes involved in this approach provide the very fabric for integration of construction information, bring about high productivity, and at the same time provide the chance for technological innovation, since all the team members operate under the same umbrella. However, the approach in general lacks the stimulus for design innovations, such as, those between the estimating and planning activities, which require radical changes.
IDEF0 model in Figure B2.

Inferring from the IDEF0 model in Figure B2, the processes in Ericsson's Turnkey projects are complex with numerous participants with varied responsibilities, which makes the monitoring and co-ordination of information within the organisation difficult. In an effort to effectively co-ordinate and communicate information across the various disciplines, the developed Unified Classification Scheme was used to demonstrate the flow of information in these processes. It also demonstrates how effectively classified data can be easily filtered for the generation of various reports. The output of these processes is illustrated in B3, as well as in the attached Progress and Post Construction reports.

Conventional cladding project: a multi-story building within the UK construction industry.

The project is a detail description of one of the interested case study projects looked during the course of this research. A detail description of the analysis and finding of the entire survey is discussed in chapter 9.

The architect of the ' multi-story building – conventional cladding project' developed the concept design in terms of use of space and aesthetics in order to fulfil the client's brief. A consulting engineer designed the superstructure and client's requirements, such as areas clear of columns and the planning grids were taken into account. This research case study analysis (chapter 9) suggests that during this period, the parallel design development process does not give due regard to the requirement for the structure to support and restrain the cladding. The engineer quite rightly made assumptions about how the frame will be loaded, and laid down rules about where loads from the cladding can be imposed on the structure – a typical restriction is that loads from the cladding must not be imposed outside750mm from the Centre line of the stanchion. The architect, however, had his own criteria and this where the technical gymnastics started for the cladding specialist, because by this time the designs were frozen and could not be revisited. Inevitably this meant more cost to the client because the estimators had to price what they saw on the drawings. 'Repetition' and, so far as possible 'standardisation' should be the key words when designing for cost effectiveness and buildability.

This case study is a classic example where good intention introduced vast cost. The engineer had looked at each span and load condition and designed a beam section to suit, which in his mind would produce the most economical structure. The real effect was to create 40 different edge conditions around the perimeter of the structure. Cladding panels which were identical externally had to have different support and restraint details to cope with the varying edges. The job with 650 panels and apparently 80 different panel types suddenly jumped to 260 panel types at additional cost of £250, 000. When this was pointed out, it was considered too late to change. The client paid without knowing. The are countless examples of this sort of waste.

Another typical result of lack of knowledge by design team is being over-cautious in determining the cladding zone. The case studies analysis undertaken as part of this research often saw drawing, where too great a space had been allocated for the cladding between the building line and the face of the structure- in some instances up to 500mm. While it is better that the space is too wide rather than too thin, the cladding contractor is faced with the problem of transferring the cladding loads back to the Centre line of the edge structure over what is a considerable distance. This creates real engineering difficulties because the task of containing load transfer corbels within the floor zone becomes very complex. This can be and is done, but it is very expensive.

Analysis and Discussion

Good communication at the design stage is vital to the success of a project. Early and continuing dialogue involving the professions, contractors and specialist contractors is one issue, which could dramatically improve construction efficiency. This means exchanging information at the design stage when all the key elements of the project can be addressed.

In recent years there has been significant re-appraisal of the role of both main contractors and specialist contractors with more than 90% of construction work being undertaken by the specialist, Downing (1999). Main contractors are no longer able or willing to manage the construction processes as they used to do. This is not necessarily the fault of the main contractors, as they are also frequently appointed too late themselves. Much of the time most members of the construction industry are performing management and technical gymnastics to overcome information-flow difficulties.

The point of all this is to find some answer to the problems. Sir Michael Latham and Sir John Egan have the answer. The cladding and construction industry must alter the supply chain mechanism. The industry must devise ways of bringing the interface contractors together, with the architect and engineer present as well. The industry needs a procurement method that enables the specialists to discuss the best ways of achieving the client's design intent. At the same time, the frame contractor and cladding contractor can detail for efficient fabrication, which culminates in good buildability and therefore efficient ways of working on site. The process the industry needs is partnering. This can be difficult to introduce into an industry that has been dominated by confrontation and conflict – partnering needs trust, honesty and willingness to share risks.

CASE STUDY ONE

Project: The Northumberland, Building Newcastle, UK (Northumbria Solar Project)

A 40kWp photovoltaic façade has been included in the refurbishment of a four-story University building, to provide the first large-scale demonstration of building integrated PV that is also connected to the UK main network. Old sapling concrete panels were replaced with rainscreen cladding that incorporated 465 high-efficiency PV laminates, rated at 85Wp each, bonded into pre-assembled frames mounted below window of the south facing wall. Array string was mathematically modelled to limit power losses due to inherent shadowing form neighbouring structure. A single 40kWp SMA inverter is connected to the University campus supply. The system has been in almost continuous operation since December 1994, producing an annual average yield of over 500kWh/kWp. The system has provided detailed information on PV façade and system design principles as well as appropriate methods to mitigate effects of shading and interaction with the network.

Instead of replacing the original crumbling façade with standard building components, units incorporating photovoltaic panels have been used. These panels generate electricity and also form part of the weathertight building envelope. They are architecturally integrated into the building façade.

The photovoltaic panels, which convert solar energy directly to electrical energy, are integrated into the inclined cladding units. Inclining the units not only increase the overall electrical output from the photovoltaic panels but also provides shading of the windows in the summer months thus increasing comfort levels for the occupants of the building. The façade can provide a maximum power output of 40kW, which fluctuates according to the local weather conditions.

Project Partners

- Newcastle Photovoltaic Application Centre
- Ove Arup & Partners
- BP Solar Ltd.
- IT Power Ltd
- Estate Services Department

In 1989 it was identified that there was a significant failure in the concrete cladding panels covering Northumberland Building. Tests were carried out on the panels and the results showed that the concrete was deteriorating through carbonisation. The only reasonable solution was to replace with a rainscreen system.Taking a general look at the building it was also identified that:

- The windows were at the end of their useful life
- The roof covering required replacement
- The electrical system needed upgrading
- Improvement were required to the heating system
- Improvement could be made to the arrangement and use of space in the building

Northumberland building is an intensively used building housing the Information Services Departments of Economics & Government. The problem of closing down these areas were immense as there was insufficient decant space within the university to house such activities during term time and it was therefore decided that the work had to be actioned during the vacation period. Given the extent of works the only way the project would succeed was by careful planning and co-operation with all the building users.

Various teams were set up to identify and solve the problems, which would be encountered on such a project. There was tremendous teamwork and the co-operation of the building users and the involvement of them contributed substantially to the success of this project.

Plans were laid for the works to be carried out during the summer of 1994, with the key dates as follows:

13 June 1994	**Commencement on site**
26 August 1994	**Completion of internal works**
18 November 1994	**Completion of external works**

There was slippage in respect of completion of the works and whilst the occupants had to endure a number of inconveniences the activities of the University were maintained including University's main computer housed in the Centre of the works. The general costs are as follows:

The overall contract sum	**£1.7m**

Indicative cost of the various elements

Roof covering	£ 45,000
Asbestos removal	£ 25,000
Window replacement	£210,000
Rainscreen system	£225,000
Rewiring	£311,000

Indicative costs of Photovoltaic Installation:

PV panels	£165,000
Frame and support systems	£159,000
Inverter	£ 37,000
PV wiring	£ 40,000

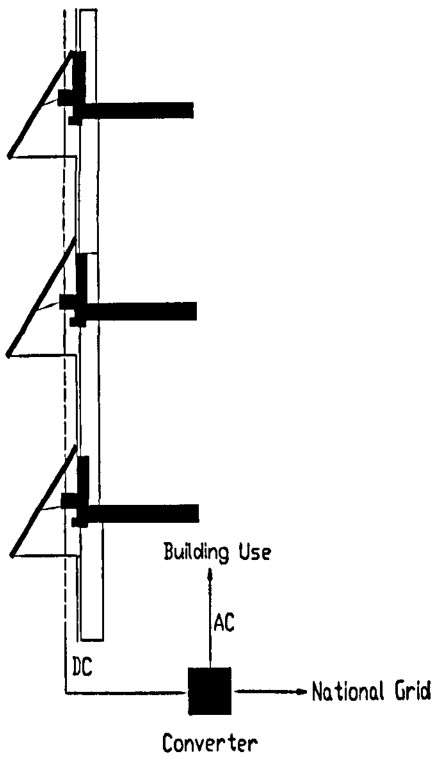


Figure C1: Schematic Cross sectional detail through the Northumberland Photovoltaic Façade.

Design and Installation

The Northumberland Building is a five-story block, which houses several academic departments, as well as the central computer unit for the University. It is situated on the main city campus in central Newcastle upon Tyne (latitude 55°N, longitude 1.6°W). The north and south façade were replaced during the summer and autumn of 1994, due to deterioration of the old cladding. PV modules are incorporated into the aluminum rainscreen overcladding system on the south façade, forming an integral part of the weather barrier for the building. The façade orientation is 16° off south towards the east.

The cladding panels are finished with light gray polyester powder coating which is visually complementary to the PV laminates. The front faces of the laminates and the frame are in the same plane to eliminate self-shading effects. The laminates are fixed in place using a structural silicone sealant. The PV cladding is inclined at 25° to the vertical to improve solar collection, provide some shading of the windows and give a pleasing appearance. There is a ventilated air gap behind the rainscreen planes and this assists in the control of the module temperature.

Due to the position of the façade in the centre of the University campus, the system experiences significant shading due to surrounding buildings, mainly in the morning and during the winter season. Whilst this is clearly not an ideal situation with regard to electrical output, it allows the characteristics of a shaded system to be investigated for a UK location. For city centre façade systems, it is unlikely that it will always be possible to select areas for PV cladding with are totally unshaded at all times. The understanding of the effects of shading, for UK climatic conditions, should allow assessment of the trade-off for installation of system of partially shaded facades during the design stage.

The main system components for the Northumberland BIPV installation are:

Solar Modules – manufactured from 36 high efficiency BP solar Saturn cells which generate a peak power of 85W from a laminate area of 0.63m^2. The solar modules are electrically connected in strings of fifteen, to generate the required operating voltage, and 31 string in parallel. Banks of five modules are sealed into overcladding elements and hooked onto the wall. The modules are then electrically connected into the wall mounted junction boxes in total 465 laminates cover an area of 293m^2, and produces a maximum rated power of 40kW DC, under standard test conditions.

Overcladding elements: the solar modules are sealed into the Rainscreen overcladding units. These are manufactured from powder coated aluminum and are designed to simply clip onto the wall mounted brackets to minimise the ingress of rain.

Junction Box – a weatherproof enclosure incorporating two bypass diodes for each solar module and the necessary terminals for connecting to the outside world.

DC Switch panel – Each of the 31 module strings are connected into the main dc switch panel. Provision is made to allow isolation of individual string and blocking diodes are incorporated to prevent interaction of module strings on localised shading. Sensors monitor the current and voltage of each string and feed these signals to remote monitoring station. The switch panel incorporates lighting protection and facilitates for connection to the station earth.

DC-AC Inverter – the 40kVA efficient converts the DC power, generated by the solar array into 415V 3 phase AC power suitable for connection to the building electricity supply. The inverter is line commutated and has been certified to meet the electricity council's requirements for connecting to the electricity grid by the Regional Electricity Company (REC).

The Design Process.

This case study captures the design-management and planning of the Northumberland Solar Building, using IDEF methodology. The design management function for the Northumberland solar façade project has been decomposed into five key sub-functional activities as follows:

- **Establish Design Requirement**
- **Create & Approve Preliminary Design**
- **Create & Approve Detail Design**
- **Generate Working Drawings**
- **Carryout / Appraise Initial Plan.**

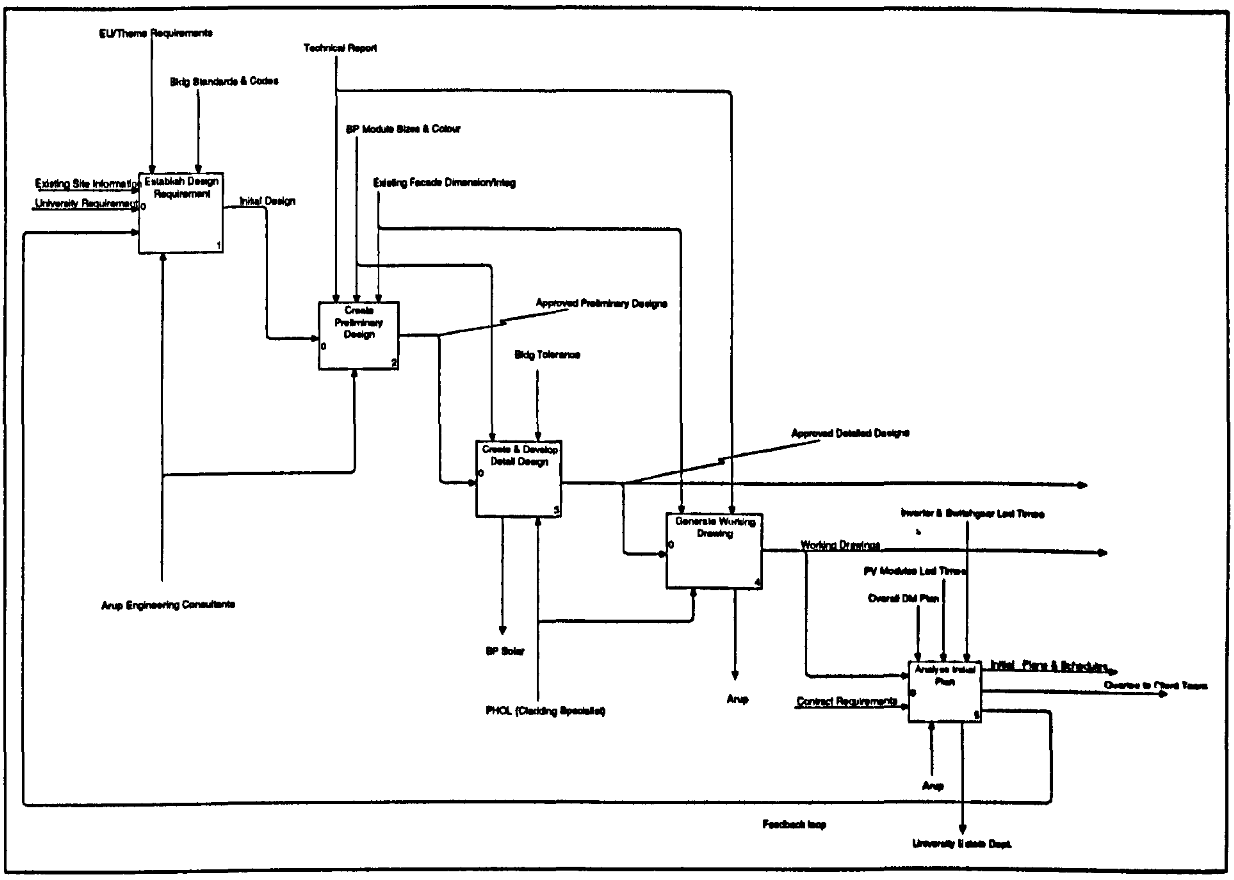


Figure B1: IDEF0 Model of the Design Process at Northumberland Building

Establish Design Requirement – at the initial stage of the project NPAC assembled a project team and assumed the position of the project manager/ coordinator. NPAC had no previous experience of construction project management or management expertise of handling design information. NPAC was unable to technically define to the consultants, what was required in terms of their individual tasks and responsibilities and exactly what needed to be done – when, how and why. This resulted into the following difficulties:

- Consultant not clear as to exactly what their role, task and boundaries of responsibility.
- Poor design information coordination
- QS/ Cost Engineer was not appointed
- Poor definition of the project objective
- Poor definition of the client requirement and expectations in the clients brief
- Not possible to adequately match clients requirement with project objectives.
- Unsuccessful design which led to redesign/rework, re-negotiation and re-tendering

The main constrains of the 'Establish Design Requirement' function are - European Union (EU) Theme requirement. The PV work package was EU funded, therefore the project had to conform with certain requirement such as I) project requirement specification ii) reporting method and periods iii) work progress iv) funding application timing – as this affects project cash flow.

The University's Estate Department requirements was a contract condition in terms of specification of suppliers, manufacturers, adaptation of the university's working practices with regard to working hours, working area, as well as health and safety. These requirements constrain almost all the functional activity in the BIPV design, planning and installation functional activities.

The problem was further exacerbated by, I) Ove Arup Engineers/Project Managers had not previous experience with PV's or indeed BIPV installation, ii) the other consultants with expertise in PV technology did not have any experience of building construction projects and did not know enough about building integrated photovoltaic systems.

The first iteration of the 'Establish Design Requirement' was unsuccessful. On the second iteration, it was decided that Arup Engineers, experience construction managers and engineers take over the function of project management and coordination. Thereafter the project ran fairly smoothly with fewer problems. The Output of this functional activity is the project design requirements as a whole.

Create Preliminary Design and obtain Approval – Ove Arup Engineers carried out this functional activity. The input for this functional activity is the design requirement in terms of photovoltaic façade specifications. This function was constrained by a number of factors:

- The existing (fixed area) dimensions of the building as well as the structural integrity of the existing building.
- Photovoltaic conversion efficiency variables also had to be taken into consideration in the development of the preliminary design I) orientation of the façade, ii) tilt angle of the façade in terms of optimum tilt angle relative to the local latitude.
- The design was also constrained by BP module dimensions, colour and general configuration.

The output of this functional activity was the approved preliminary design. The approval stage was fairly straightforward. The sub-function activity is discussed in next section.

Create Detail Design and obtain Approval – This functional activity went through a number of iterations. Ove Arup Facades initially carried out the PV cladding detail design. The initial detail design did not meet the client's requirement or indeed the project objectives.

The initial design led to unsuccessful tenders. The tender costs where much too high. This was due to a combination of factors:

- Ove Arup Engineers, the project managers, not fully understanding what was expected in terms of the project objects and client requirement did not provide Arup Façade with a clear and unambiguous brief and specification. This resulted into a detail design that did not meet the client's requirement or project objective. The first attempt led to unsuccessful tenders.
- The failure to appoint a cost engineering or quantity surveyor to monitor and cost control the detail design process was a key factor.

As a result the 'Detail Design' function was sub-contracted to PHOL (Façade Engineers). PHOL was better equipped and placed to carry out the detail design to meet the desired project object in terms of cost and performance.

The rework and redesign of the detail design functional activity resulted in a project delay of between 6 to 8 weeks and cost an additional 15% of the original cost of detail design functional activity. This delay had a snow ball effect on the rest of the project, which was not quantified in accounting terms.

Arup originally specified the junction boxes at the design stage. Arup had determined their positions in relation to the panels and other component. The boxes were centrally located in the original design. These drawings were passed on to the electrical contractors for action. The suppliers were unable to deliver the specified junction boxes within an acceptable time frame. The electrical contractor specified an alternative junction box. The new junction boxes did not fit. The cables from the end modules were not long enough to reach the boxes. The junction boxes had to be redesign and repositioned. This rework was due to duplication of function and lack of proper coordination and communication between Arup and the electrical contractor. This poor communication during the design stage led to these errors.

Generate Working Drawings – The Generate Working Drawing activity was carried out by PHOL. This function went through an iterative process. PHOL generate the working drawing just for the PV façade. The input of this functional activity is the detail working drawing for the entire refurbishment project as well as the working drawing for the existing structure.

This functional activity was constrained by I) poor workmanship of the original structure ii) the dimension on the existing drawing did not match the on-site measurement. This inconsistency resulted to rework in terms re generation of working drawing consistent with on-site measurements iii) the original tolerances allowed were inadequate and needed to be redesigned to interface properly with the new windows installed just about the PV panels. Additional consideration had to be given to the weight of the rainscreen cladding. Traditional rainscreen is clad is usually made of lightweight aluminum and is secured at opposite ends with hooks clipped/attached to pre-mounted wall brackets. In this case, the additional weight necessitated the engineers to provide additional support at the mid-point of each panel. This had a knock on effect on the installation procedure. Three persons were required to maneuver the panel into place as oppose to two persons, when conventional aluminum rainscreen cladding is installed.

PHOL (Façade Engineers) an integrated specialist cladding company. They manufactured and incorporated the BP solar laminates in the rainscreen cladding system at the Northumberland Building. The cladding was all of non-standard, bispoke, sections specially designed and carefully engineered by PHOL. PHOL, an integrated cladding company, carried out the necessary calculation and computer simulation. The sections were developed using Computer Aided Design and technology.

Carryout Initial Plan and obtain Approval: Ove Arup carried out this functional activity, in consultation with all the project players. Arup coordinated the activities of the design team and the works and specialist contractors. The main input for this functional activity is the project data and the working drawings. The mechanism by with this function was carried out called heavily on the planning and working detail of PHOL, the cladding specialist, and the overall project master plan as designed by Arup the project managers base on the contract requirement. This functional activity was constrained by project requirement in terms of working times and area. The entire project needed to be completed during the summer holidays. Extension of time, resulting from earlier mentioned redesign work, further exacerbated the time constraint issue. Project management was granted 8 weeks extension in which they planned to substantially overlapped work packages in an effort to fast-tack the project.

Estimating Process

As far as the PV cladding side of things was concern in this project, the estimating function was largely ignored. This led to the various design proposals not meeting the primary project objective – cost. The first round of tender was a disaster. The entire design and specification of the cladding had to be reworked. A quantity surveyor, Bucknell Austin, was appointed at this stage to monitor and control the cost of the cladding design proposal.

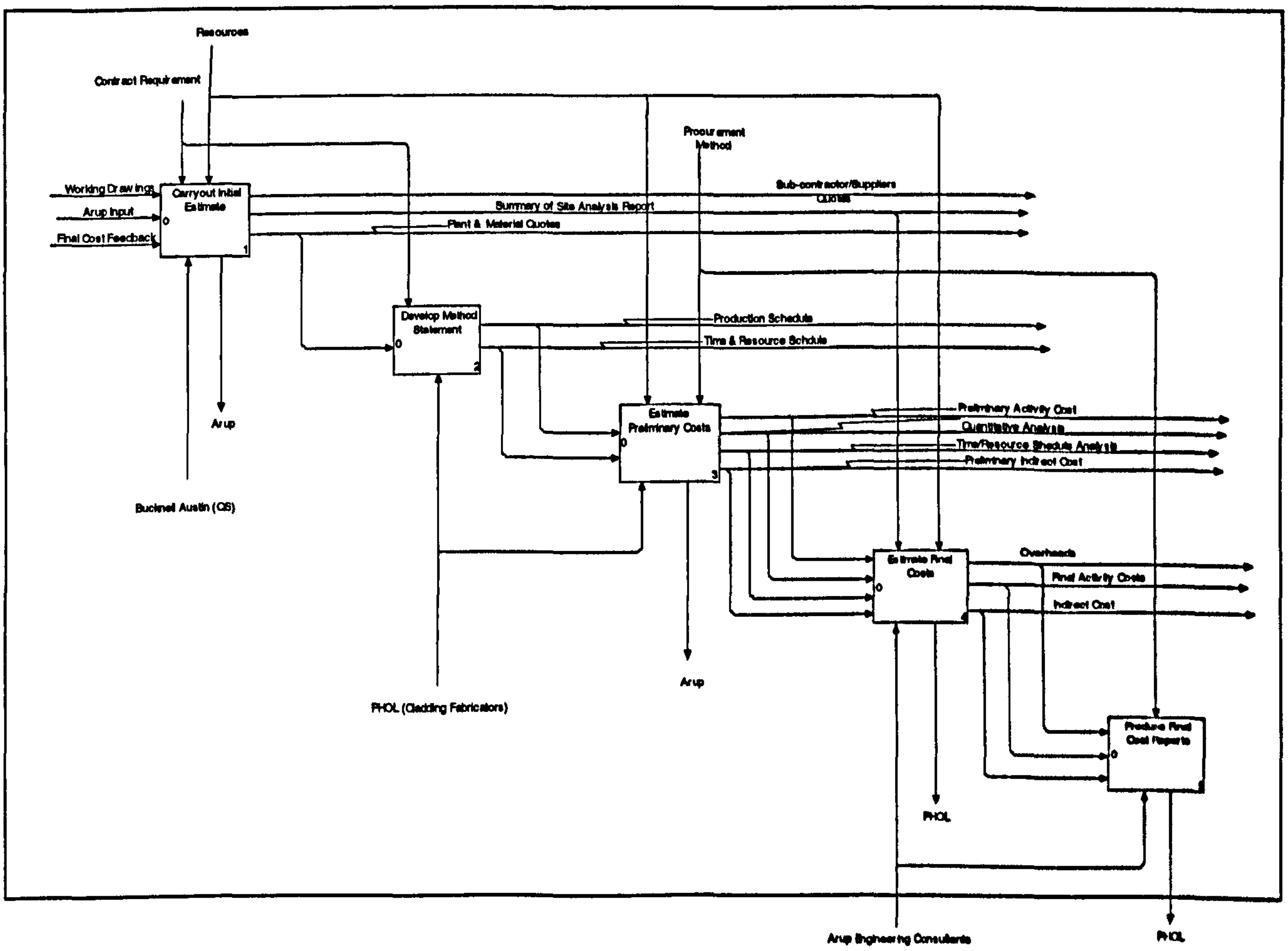


Figure B2: IDEF0 Model of the Estimating Process at Northumberland Building

Individual specialist or works contractors carried out the estimating function for their respective work packages. Ove Arup carried out the project planning and coordinating function. The estimating and planning functions were separated.

Carry out initial estimate function – Arup Engineers using past experience as the input variable loosely carried out this functional activity. The constraints were the contract requirement and building regulations.

Develop Method Statement – Arup developed a detailed method statement. The method statement cover matters relating to I) quality ii) fabrication in terms of control sample, tolerances, components and assembly iii) handling and storage iv) installation in terms of workmanship, inspection and testing, protection and cleaning v) maintenance.

Estimate Preliminary Cost – Bucknell Austin, the QS appointed by Ove Arup consultants, eventually carried out this function. In input variable for this functional activity was the quotes from PHOL the cladding specialist contractor, initial productivity, time and resource schedule. The output of this activity was the preliminary activity costs, analysed time and resource schedule and preliminary indirect costs. This functional activity was constrained by the contract requirements and regulation and the procurement method which was Design and Build.

Estimate Final Cost – Bucknell Austin (QS) carried out this functional activity. The input variable was the final cost feedback form all the work package contractors, quotes form suppliers and sub-contractors as well as all the out put variable from the 'estimate preliminary cost' stage.

Produce the Final Cost Report – Ove Arup consultant in association with Bucknell Austin (QS) carried out this functional activity. The input variable for this functional activity was the output variable of the 'estimate final cost stage' such as the overheads, activity costs and indirect costs. The output of this functional activity was the final project cost and time schedule, final cash flow schedule as well as other supporting documents.

Planning Process

Carryout initial appraisal – Ove Arup consultant, the project engineer and managers carried out this functional activity. The input variable was the scheme design, existing site information and the condition of contract in terms of working time, working area, project duration time limit, building occupancy period and health and safety requirements. The output of this functional requirement was scheme project Programme and queries that were sent off to the client's management for clarification.

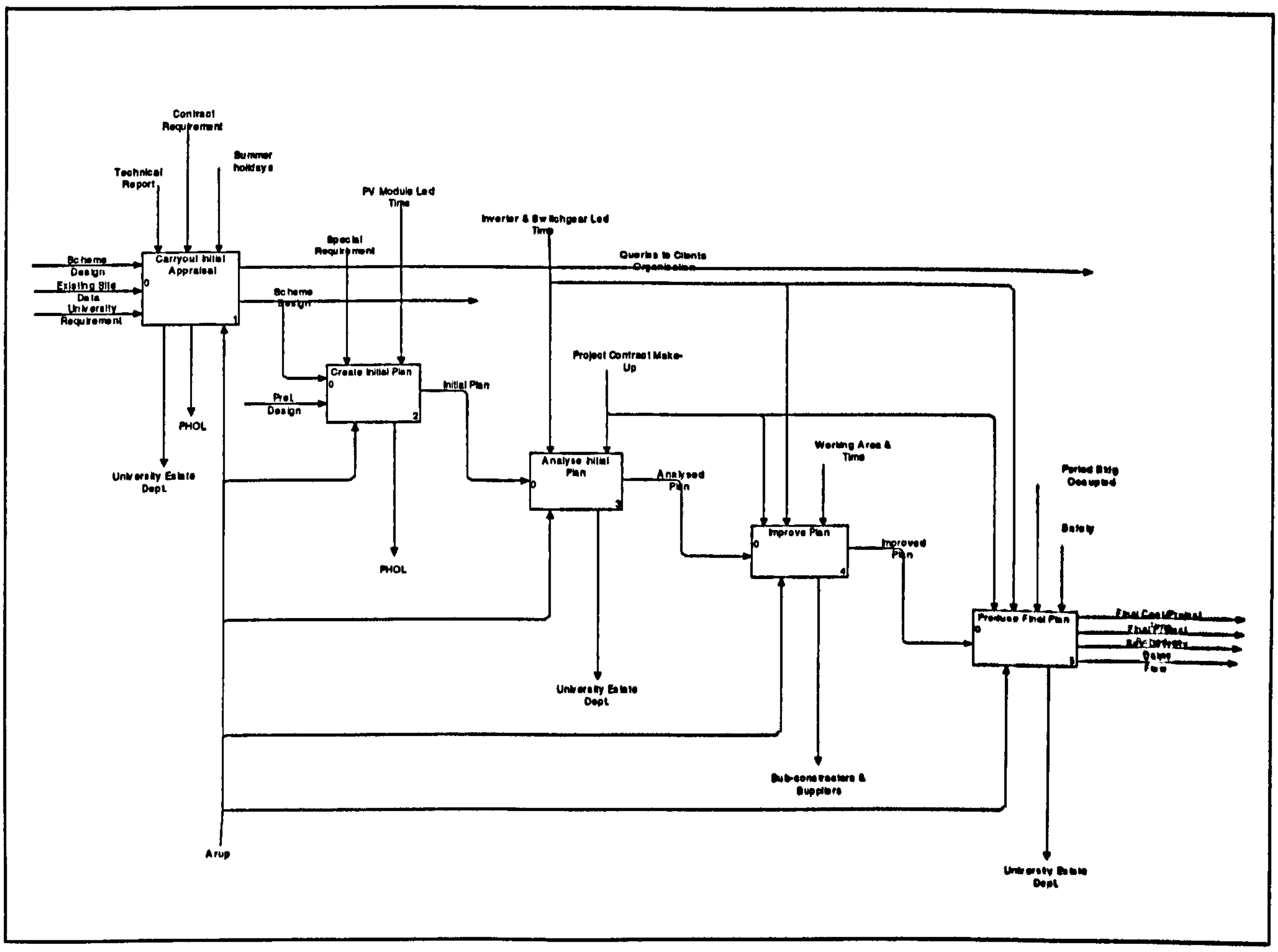


Figure B3: IDEF0 Model of the Planning Process at Northumberland Building.

Create Initial Plan - Ove Arup consultant carried out this functional activity. The constraint of this function was the condition of contract, working area and working time. Other constraints include project duration limitation, company list of resources, PV special requirement and procedure as well as building occupancy period. The long lead-time of the BP solar modules, inverter and switch-gear was built into the project plan. The output of this functional activity is the initial plant schedule.

Analyse Initial Plan – The design team carried out this functional activity, lead by Ove Arup consultants. The initial plan had to be completely re-engineer, due to the 6 – 8 weeks rework of the design phase. The input for this functional activity was the initial plan; overall planning feed back, detail design and the project management input. The specialist and trade contractors did a summary of specific work items, within individual work packages. However, Ove Arup consultants carried out the overall planning. The output of this functional activity was the resource limits, preliminary general schedule and the preliminary key plant labour and material schedule.

Improve Plan – the improved plan functional activity was carried out by Ove Arup in consultation with the design team, client organisation, specialist contractor and suppliers. The input for this functional activity was the resource limits, preliminary schedules, detail designs and existing site information. The output for this functional activity was the detail general schedule, improve productivity estimates and time schedules. Improved labour, plant and material schedule was carried out by the different sub-contractor for their work packages. The entire contract was let out on a design and build bases to Ove Arup Engineering Consultants. The inverter and switchgear did affect electrical work and this had to be built in at the 'Improve Plan' stage.

Produce Final Plan- this functional activity was carried out by the works contractors for their respective work packages. However, the overall final plan for the entire project was compiled by Ove Arup and passed on to the client's organisation for approval. The input for this functional activity is the detail general schedules, improved productivity estimate and time, as well as improved labour, plant and material schedules.

CASE STUDY TWO

Project: The Solar Office, Doxford International Business Park, Sunderland UK.

Background

The Solar Office at Doxford International Business Park is a new office building designed for Akeler Property Developers Limited and locate near Sunderland in the north east of England. The construction of the building was completed in March 1998 with the exception of the internal fit out which will be carried out to the requirement of the tenant. The glazed south façade has a fully integrated 73 kWp photovoltaic array.

The Solar Office is a commercial development and as such has to compete with conventional building in the UK property market. It is the first speculatively constructed building to incorporate building integrated photovoltaics and it is one of only a few to adopt a holistic energy strategy. Funding from the European Regional Development Fund (ERDF) supported the photovoltaic installation and low energy design. The Department of Trade and Industry (DTI) provided support for design development, testing and monitoring of the building performance.

The Design

The building was designed to minimise the use of energy whilst its external fabric was designed to replace a significant amount of the energy that it uses. This formula for energy self-sufficiency is one of the key building blocks for future global sustainability. The design addresses environmental and energy conservation issues, including an energy consumption target of 85kWh/m^2/year compared to that of a conventional air-conditioned office at 233-423kWh^2/year. A 73kWp photovoltaic array is integrated into the building envelope. This is expected to provide about 55,000 kWh of electrical energy per annum under UK conditions, representing between one third and one quarter of the expected total energy consumption.

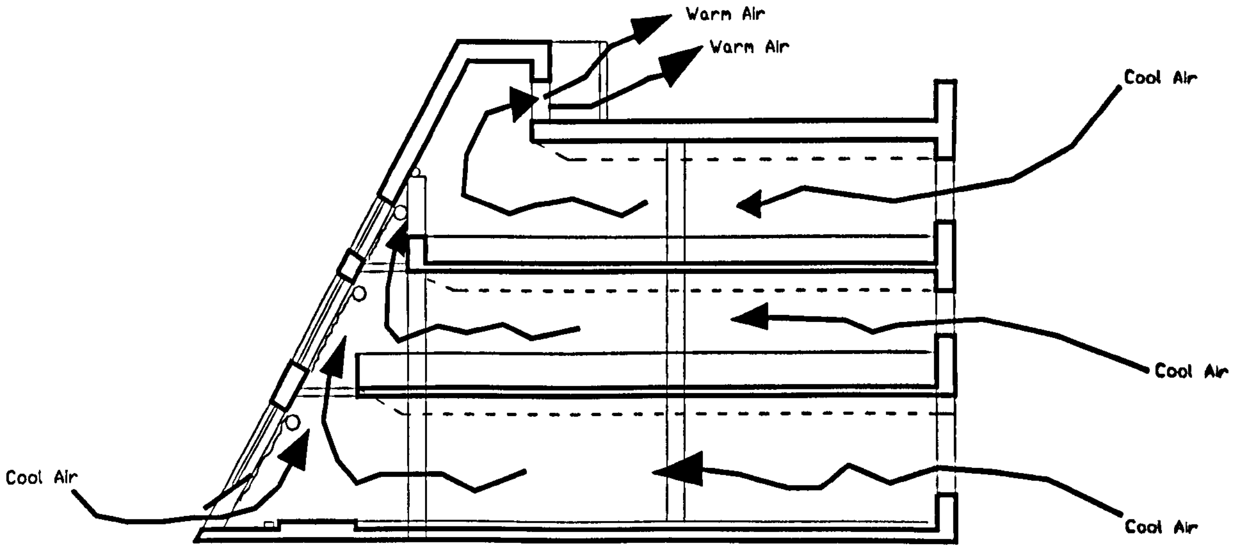


Figure C2: Schematic section through the Doxford solar office building.

The main objective of the environmental design was to find a symbiosis between the low energy measures and those needed for photovoltaic installation. In some key areas, the optimisation of the photovoltaic power generation runs counter to that for low energy design. For instance, the photovoltaic façade required as much sunshine as possible and therefore introduces the risk of interior spaces being overheated. Other issues include compensation for the lack of thermal capacity in the façade material and their relatively poor insulting properties. In addition, curtain wall inhibits the introduction of careful graded, glare free daylight into the building.

The PV system incorporates polycrystalline silicon solar cells in a glass/glass module construction. Bands of clear glazing have been introduced into the façade to allow views out and to ensure good internal light levels. The risk of glare is minimised by the introduction of modules with a reduced number of cells immediately above the glazed panel and by provision for the introduction of locally controlled roller blinds. The heat accumulation behind the array is used in a passive manner to assist with the natural ventilation of the building via the stack effect.

The reconciliation of energy generation and energy conservation has been paralleled by reconciling the building with the site, especially the key issues of layout, orientation and climate. The building had to be positioned such that it maximised solar radiation, whilst avoiding overshadowing from adjacent structures or from its own mass and detailing. It also needed to avoid any risk of the solar façade dazzling drivers travelling north on the nearby trunk road and to mitigate disturbance from the traffic noise. A south alignment of the façade and an inclination of 60° were used to maximise solar radiation, while the inclined and sealed facade overcame the potential problems of dazzle and traffic noise.

Office windows were placed on the north, north-east and north-west to avoid the need for control solar gains for low morning and evening sunshine. The placement of the car park at the front of the building ensured that the solar façade would not be overshadowed and that a sense of anticipation would not be felt by revealing the façade only after encircling the building. The building is located on an exposed site close to the North Sea and the wind has been used to assist the natural cooling of the building. A wind trough surmounted with baffles running the length of the façade ensures that negative pressure is introduced immediately outside the upper vent regardless of the wind direction and this reduced pressure encourages air flow out of the vents. This in turn encourages air to be drawn in through the windows on the opposite side of the building keeping the interior cool in the summer. This system complement the stack effect caused by the heating of air immediately abutting the inside face of the façade see figure C2.

The photovoltaic System

The PV system consists of polycrystalline silicon cells in a glass/glass encapsulation. The system was designed and supplied by Schuco International, who also provided the monitoring system. The modules are made up of the following:

- 5mm heat strengthened white glass
- 2mm cast resin with solar cells
- 4mm heat strengthened glass parsol
- 12mm krypton filled void
- 6mm laminated glass with low e coating –giving a U value of 1.2 W/m^2K

The incorporation of double-glazing is expected to increase the module operating temperature and hence decrease the system efficiency compared to an equivalent system with single glazing or a ventilated cavity system. It was felt to be more important to minimise the heat loss in winter, on the one hand and have the reassurance of a tried and tested proprietary cladding system on the other.

Nine different module designs, in terms of size, shape and cell density were used. The modules were designed to meet the needs of the physical integration and shading levels for different positions on the façade. All the modules are rectangular except for two, which are trapezium-shaped to fit around the entrance area.

The total array area is 646m2 with nominal rating of 73.1 kWp. It is split into four sub-arrays, two on each side of the entrance and with slightly different orientations. The two west sub-arrays are oriented 5 degrees off south toward the west, whilst the two east sub-arrays are the same angle off south towards the east. This enhances the visual aspect of the façade, but in practice, results in only a very little difference in output between the different sides of the array. There are two large sub-arrays each consisting of 17 series string and with an array rating of 35.6kWp. Each of string feeds into its own 35kWp inverter. The two small sub-arrays have a single series string and are rated at 0.94kWp. They feed into a 0.85kWp inverter and are located around the building entrance. In all cases, the modules are strung down the façade to a junction box in the supply trench at the bottom.

Installation

The outline design of the building was carried out in November 1996 with the detail design phase being commenced in January 1997. The PV system was included from the outset but the design could not be finalised until after the tendering process, which occurred in March/April 1997. However, due to the fast-track procurement timetable, work on site commenced at the end of April 1997 with the foundation and the installation of the steel framework.

The need to integrate the design and procurement of the PV system with a rapid construction schedule meant that several design aspect were finalised during the course of the construction period. For instance, the trench at the bottom of the façade had to incorporate all the junction boxes, the two small inverters, a heating coil and the vents. The trench, however, was an item of the ground works package – as a result the size of the trench had to be decided before the electrical wiring services and specification had been completed. This required both expertise on behalf of the design team and the incorporation of an allowance for later design changes. This type of situation is likely to occur wherever customised design of the PV system is coupled with a rapid design and building construction.

Matching warranties provided by the various manufacturers of the PV installation with those required by interests concerned with financing the project and establishing agreed quality and performance standards for the installation had to be resolved during the construction period – due to time constrained construction time table. A Bay of the façade was set up in advance of the building installation in order to set the standard for workmanship and appearance.

The Project Partners of case study three are as follows:

Akeler Developments	Clients
Studio E Architects	Architects
Aukett Associates	Co-ordinating architects
Rybka Battle	Building services engineers
Whitby Bird & Partners	Structural Engineers
Mott MacDonalds	Civil and traffic engineers
Bowmer & Kirkland	Main contractor
CMC	Project management
Bickerdike Allen & Partners	Acoustic engineers
BRE	Air tightness
NPAC	PV Monitoring
SCHUCO	Façade system suppliers
Dane Architectural Services	cladding contractor (fabricator & Installer)

This case study captures the Design-management and planning procedure in the Doxford Solar Office project, using the IDEF methodology. The design function of this project has been categories and decomposed into five main sub-functions:

- Establish Design Requirement
- Create & Approve Preliminary Design
- Create & Approve Detail Design
- Generate Working Drawings
- Carryout / Appraise Initial Plan.

The Design Process

Establish Design Requirement: Studio E Architects, Rybka Battle (Building Services and Environmental Engineers) carried out this functional activity. Akeler Developments (the client), Bowmer & Kirkland (the main contractor) and Schuco (façade supplier) all had substantial input into the Establish Design Requirement functional activity. The major constraint of this functional activity was that the system produces 73kWp after the inverter and that the system cost no more than £1m. Inputs for this activity included the existing site information, project management input and other client's requirements. One of the major client's requirements was to design energy efficient building, using passive means and an integrated solar façade to meet the energy requirement of the building. The main output was the initial design.

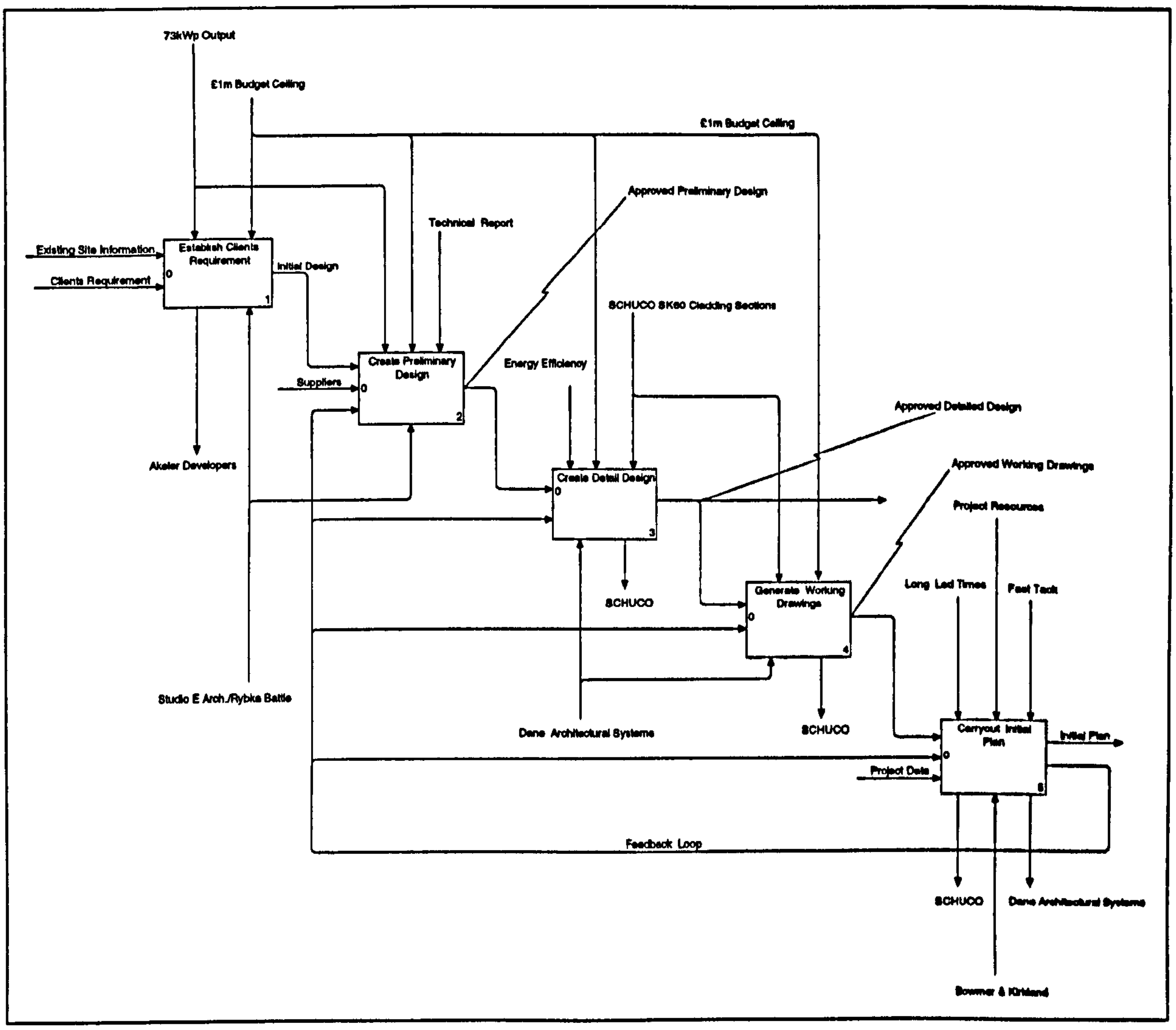


Figure B4: IDEF0 Model of the Design Process – Doxford Solar Office.

Create Preliminary Design and obtain Approval: Studio E Architects carried out this functional activity with substantial input form Dane Architectural services, Schuco systems suppliers and Ryka Battle services engineers. The input of the activity was the client's brief, the initial design and the overall design feedback. The technical report constrained this activity. The output of this activity was the preliminary design. The SCHUCO SK60V standard aluminum section was chosen for the cladding system profile. It was decided that the PV laminate would be incorporated into the standard SK60V SCHUCO cladding section on site.

Create Detail Design and obtain Approval: Dane architectural services in collaboration with their supplier/ partners (SCHUCO) carried out this functional activity. Bowmer & Kirkland, the main contractors, sub-contracted the entire cladding package to Dane Architectural Systems, a cladding fabricator and installer. Dane Architects partnered with SCHUCO, their system supplier, to carry out the detail design and specification. SCHUCO supplied the system whilst Dane Architects fabricate and install the entire system. Dane Architectural Systems carried out the detail design and structural calculations of the cladding grid system.

Generate Working Drawings: SCHUCO, the system suppliers, carried out the necessary analysis, on the architectural scheme design, and recommended the use of their standard SK60V cladding box sections. SCHUCO also generated the working drawings showing the standard electrical connections, whilst Dane Architectural Systems carried out the detailed working drawing for the cladding grid. Dane Architects prepared the method statement, structural design and checked the suitability of the design with Bowmer & Kirkland and SCHUCO. SCHUCO supplied the system to Dane Architects. SCHCO bought the PV cells from Kysera solar cell manufacturers. SCHUCO design the stringing configuration and connections specifying the cell spacing and configurations within the module. SCHUCO produced full working drawings of the wiring, wire sizes and configuration of the entire PV laminate. SCHUCO sub-contracted the actual cell stringing and module manufacture to a Germany based company. The PV laminates were encapsulated into double glazing unit and delivered to site for incorporation into the SK60V cladding section.

Carryout and Analyse Initial Plan: Bowmer & Kirkland carried out the initial plans and project master plan. The master plan and individual work package plans were included in all tender documents. The master plan timing considerations were part of the tender documents sent out to contractors tendering for the respective works packages. These dates had to be adhered to in the tender prices and initial work package plan.

Planning Process

Carryout Initial Plan: Bowmer & Kirkland carried out this functional activity. The project master plan was included in all tender documents. All tenders were built and developed around the master plan. The PV modules were ordered in advance as the have long led times. The sequence of activity was as follows: firstly, Dane Architects completely installed the SK60V SCHUCO grid sections. Secondly, the PV modules were installed in three stages. The modules were supplied in three stages; therefore, the installation had to be planned in three stages. The wiring activity overlapped with the module installation. Finally, Kiockner & Gummisch carried out the wiring of the PV system up to the inverter.

The project relatively smoothly, the planning was well co-ordinated by the Bowner & Kirkland (Management Contractor).

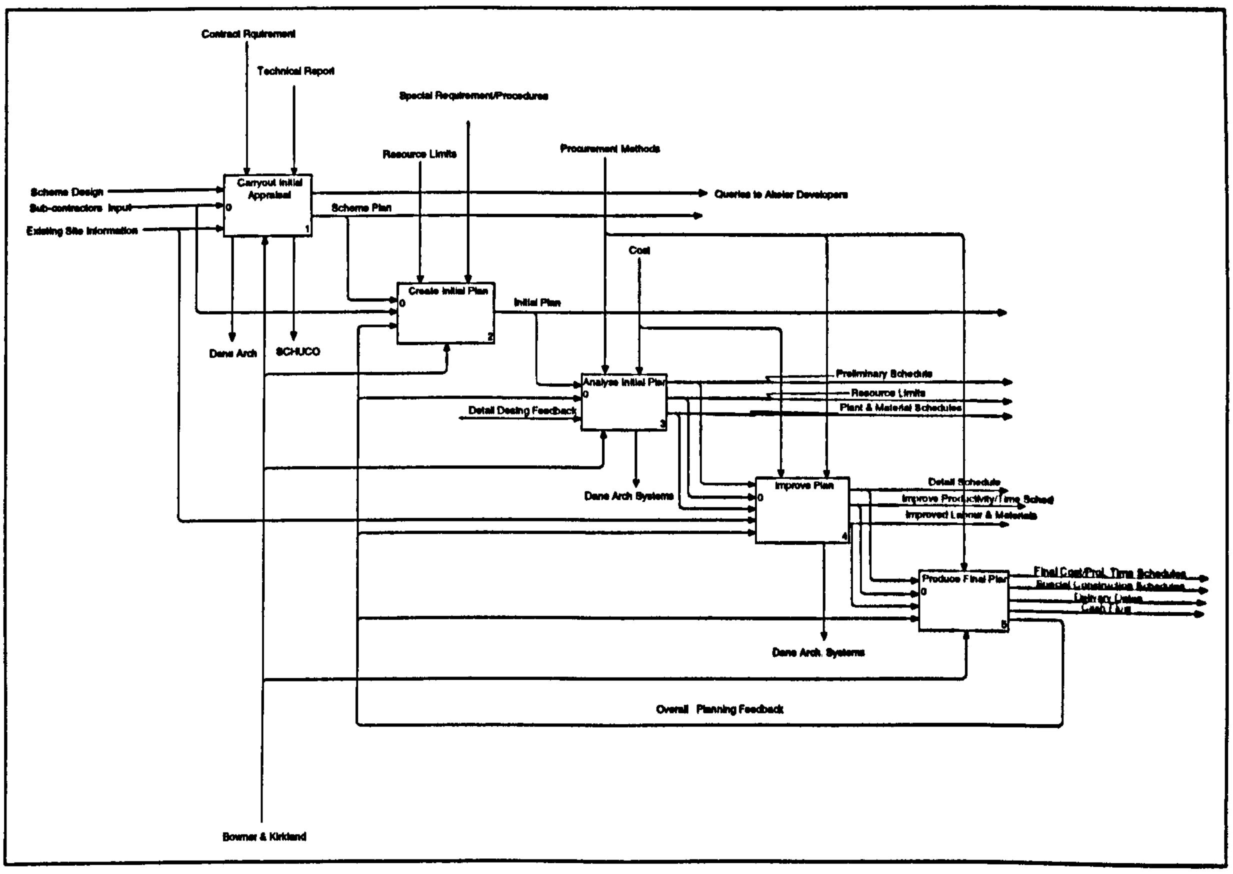


Figure B5: IDEF0 Model of Planning Process – Doxford Solar Office.

Analyse Initial Plan: Bowmer & Kirkland carried out this functional activity. The initial plans of the various work packages were analysed. In some cases negotiations were carried out - with minor compromises worked out around the master plan. The input of this functional activity is the detail designs, initial plans, and the overall planning feedback. The outputs of this activity are the preliminary general schedule, preliminary key plant, material and labour schedules. The constraint of this activity is the general contract make-up.

Improve Plan: Bowmer & Kirkland carried out this functional activity. The inputs of this functional activity were changes in key delivery dates, overall planning feedback, existing site information, and poor weather conditions.

Produce Final Report: Bowmer and Kirkland carried out this functional activity. The main inputs of this function are the individual work-package final report, tender prices and method statements. The major constrains is the project contract make-up. The main outputs are the final project cost and time, special construction schedule, key delivery dates, final project resource estimate and cash flow.

Installation: Dane Architects installed the grid system and incorporated the double glazed PV modules into the SK60V sections on site. Kiockner & Gummisch, a nominated sub-contractor, designs and carryout the wiring as well as soured and installed the inverter systems. The initial designs of the inverter wiring was carryout by SCHUCO however, Kiockner did the detailed design and specification. Kiockner also supplied the inverters.

Estimating Process

Carryout Initial Estimates: the individual work package contractors carried out the initial work package estimates. These costs were the major input for the competitive tender prices submitted to Bowmer and Kirkland the main contractor. These individual estimates formed the major input variable for the overall project initial estimate.

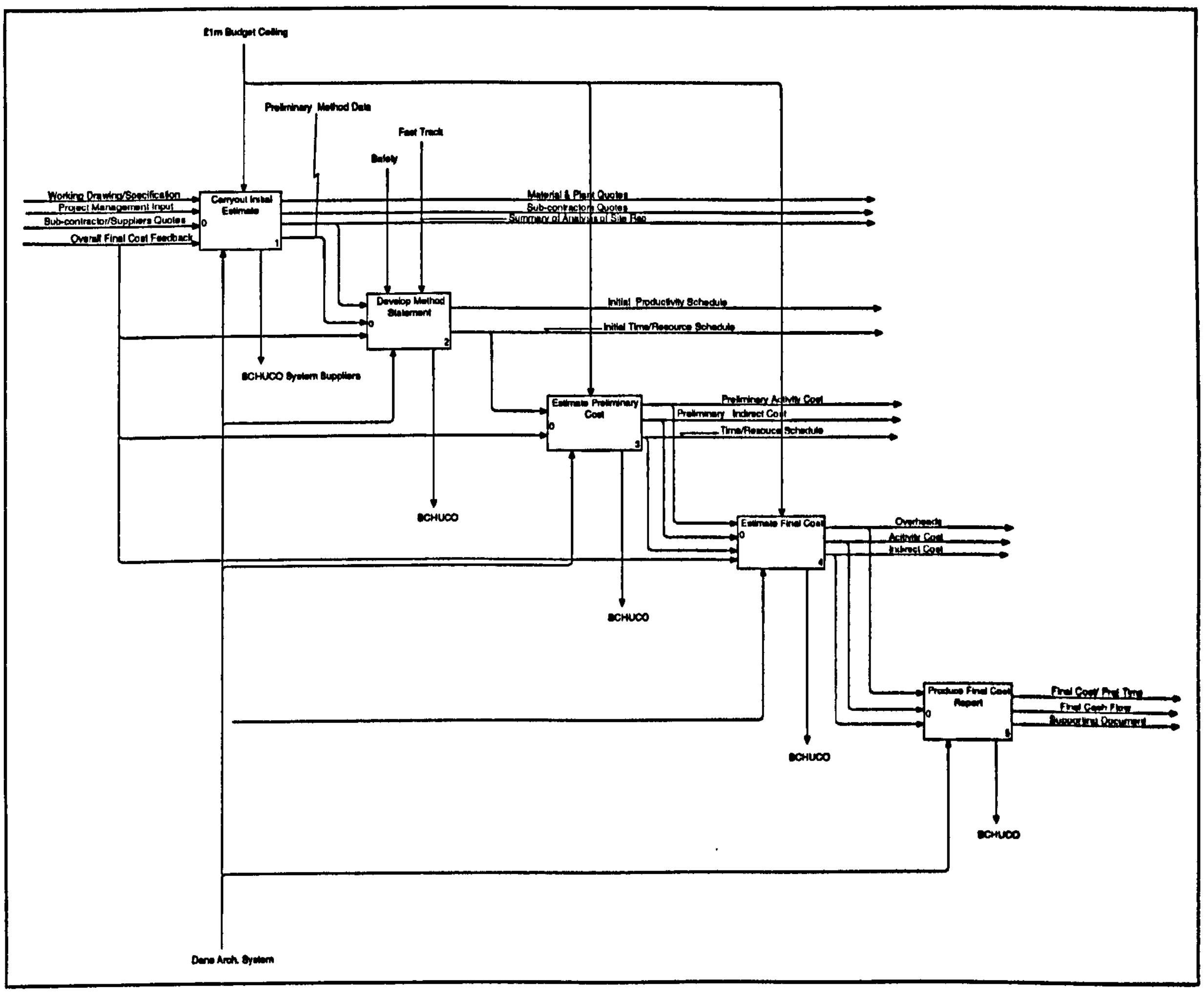


Figure 6B: IDEF0 Model of the Estimating Process – Doxford Solar Office Project

The main input variables for this functional activity are the working drawings, project management input, key labour, plant and material costs and the final cost feedback. The outputs were the data for preliminary methods, sub-contractors quotes, material and plant quotes. Constrains were contract requirement and availability of resources.

Develop Method Statement: The individual work package and specialist contractors developed method statement for their respective work packages and obtained approval from Bowmer and Kirkland the main contractor. The input for this function is the data for preliminary method, the summary of analysis/site report, final cost feedback, quotes form suppliers and sub-contractors. The constraints were the contact requirements, availability resources and the standard method of measurement. The output of this activity are the initial productivity schedule and the initial time and resources schedules.

Estimate Preliminary Costs: Bowner and Kirkland carried out this functional activity. The outputs of the initial cost estimates are the inputs of the Estimate preliminary cost. This includes sub-contractors quotes, plant, material, and labour quotes and preliminary method statement data.

Produce Final Cost Estimates: CMC, the project managers, and Bowner and Kirkland, the main contractor, carried out this functional activity. The outputs of this activity include the final cost feedback and all the output of the preliminary estimate cost function. Constrain of this function is the procurement method and the project contract make-up. The outputs are the project overheads, activity costs and indirect costs

Produce Final Cost Report: Bowner and Kirkland produced the final cost report. The key inputs of this functional activity include the overheads, activity cost and indirect cost. The main constrain is the procurement method. The major outputs are the final project cost and time, cash flow and supporting documents.

Discussion

The conflicts in optimisation of PV power generation and low energy design should be reconciled, where possible, by mutually reinforcing and striking a balance between the respective requirements. Careful design detail which address the areas of conflict to include ventilation of the façade to prevent overheating as well as the introduction of additional thermal mass to reduce heat losses through the façade.

CASE STUDY THREE

Project: UK Based Solar Mansard Installation (Non Grant Funded)

The identity of Case Study Three has been with held due to a special request from the client organisation.

A 7.7 kWp photovoltaic mansard façade was installed in the refurbishment of a three story institutional building. The PV system provides some of the buildings energy requirements. The system is also connected to the main UK grid network.

The entire old office block was due for refurbishment. The parent organisation has allocated budget and cost centre to all work packages involved in the proposed refurbishment project I) re-cladding ii) weather proofing iii) old water tanks decommissioning iv) asbestos decommissioning v) general making good.

The subsidiary department that occupied the building to be refurbished made the following request to the parent organisation - instead of replacing the original mansard cladding with standard conventional component units, the mansard is re-clad with building integrated photovoltaic panels. The parent organisation accepted the proposal on three conditions:

- That the proposal fall within the budget allocated to re-cladding.
- That the system is safe to the building and its users.
- The subsidiary department sorts a competitive package deal selective tendering for the PV façade.

The client was presented with two options. The first, involving the use of amorphous silicon and second, the use of crystalline cells. The client opted for the multi-crystalline panel, as the client objective was to maximise the efficiency of the installation.

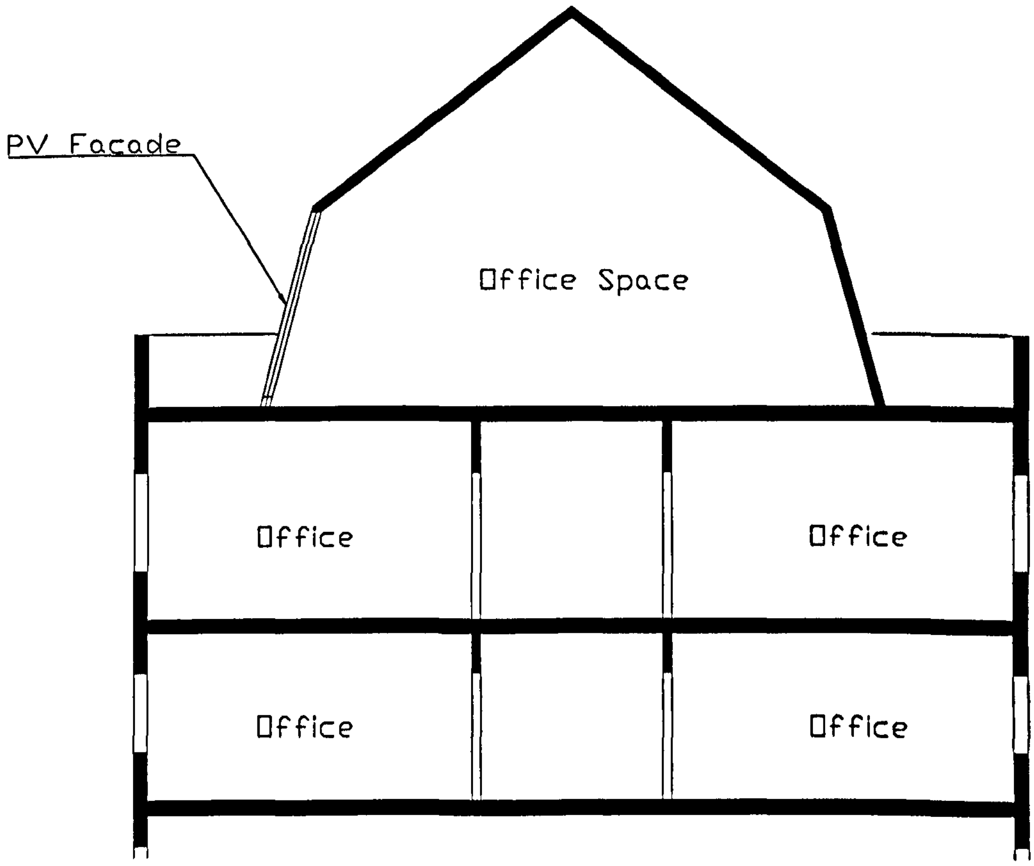


Figure C3: Schematic cross-section of solar mansard installation.

The subsidiary department had in-house PV engineering expertise, whilst the parent organisation had in-house construction expertise. The subsidiary set up the PV façade project team. The PV system project team consisted of the following:

- In-house photovoltaic expertise
- In-house construction expertise
- Engineering consultants
- Other work package contractors.

7.7kWp polycrystalline installation consisting of 102 modules......Standard junction boxes attached to individual modules. All strings feed into the DC switch panel, each module string are connected into the main DC switch panel. Provision is made to allow isolation of individual string and blocking diodes are incorporated to prevent interaction of module strings on localised shading. DC-AC inverter converts the DC power, generated by the solar arrays into AC power suitable for connection to the power building electricity supply.

This section of case study three captures the design, planning and estimating functional activities for a solar mansard installation for a UK based institutional building, using the IDEF methodology. The design function of this project has been categories and decomposed into five main sub-functions:

- **Establish Design Requirement**
- **Create & Approve Preliminary Design**
- **Create & Approve Detail Design**
- **Generate Working Drawings**
- **Carryout / Appraise Initial Plan.**

The Design Process

During the conceptual design stage, the client opted to consider the possibility of replacing the mansard cladding with solar photovoltaic panels. These proposals were accepted on condition that the cost of the PV installation does not significantly exceed budget allocated for re-cladding using conventional building materials.

Establish Design Requirement: The in-house PV expert of the client organisation set out outline design requirement at the project inception stage. There was a profound failure of the design consultant in translating the client's requirement into technical specification in line with the client's objective. The consequences became increasingly evident during the construction and installation stages of the project.

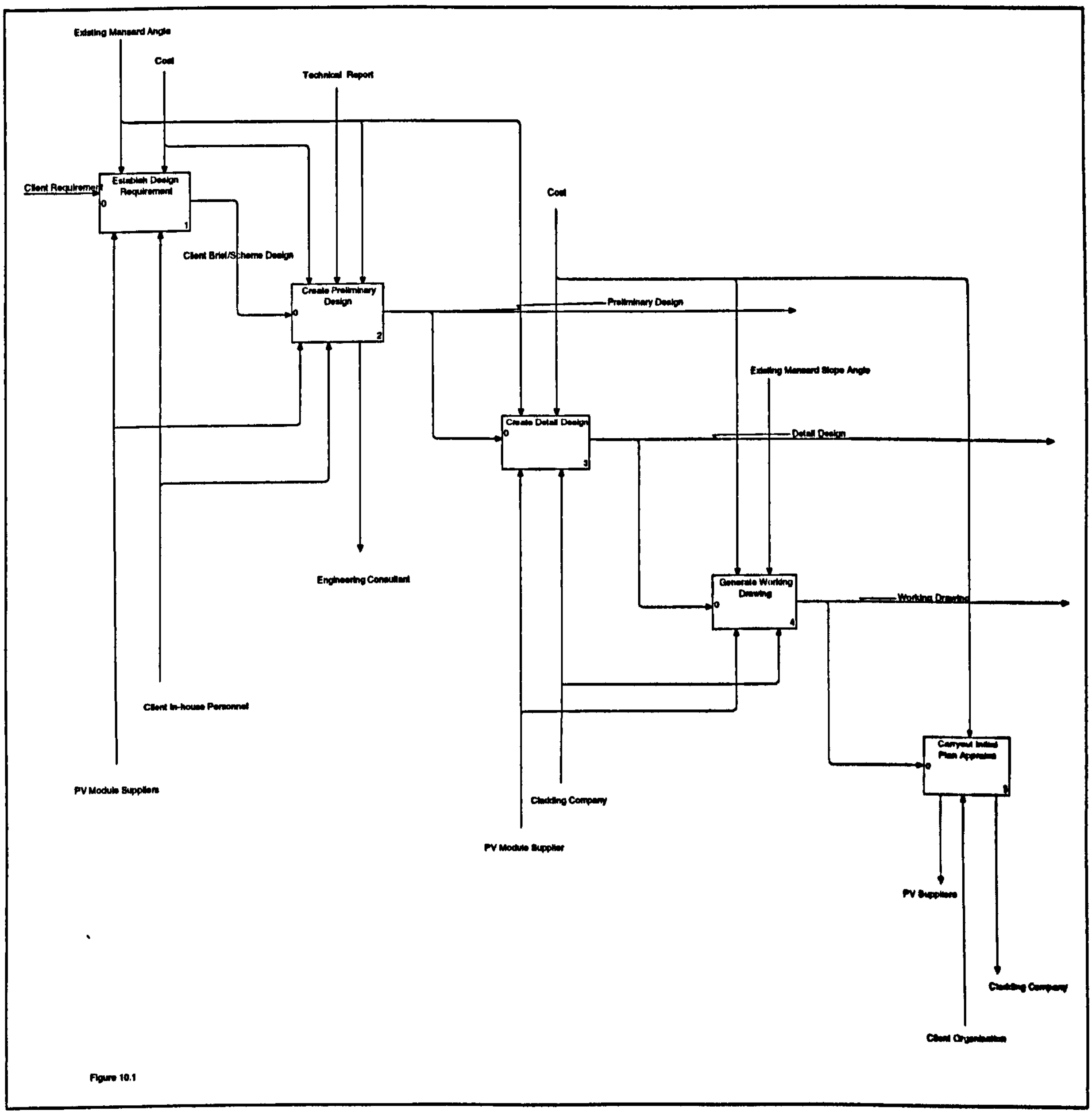


Figure B6: IDEF0 Model of the Design Process – Case Study 3.

The input for this activity was the client's requirements, existing building structure and existing site conditions. The constraints were costs, time, procurement method and safety considerations. The client is of the opinion that there was not enough discussion on the options at this stage. The stage was not entirely successful, as the client has expressed great dissatisfaction on the way the consultant handled it. The client was ultimately presented with just two options out of over half a dozen technical possibilities within the project constrains. The client would have preferred the tilt angle of the façade to be oriented towards the summer months.

Create Preliminary Design & Obtain Approve: The preliminary design (scheme design) was carried out by an engineering consultant and passed on to the cladding manufacturer, an integrated cladding company. The scheme design was constrained by the tilt angle of the existing façade. The PV module suppliers designed and specified the module configuration, string and switchgear and all other Balance Of System (BOS) components. Enough thought wasn't given to the possibilities at this stage. The input of the preliminary design stage was the output of the 'establish client requirement' which was ill defined. The preliminary design stage inherited inadequacies from preceding design activities, such as establishing the client's requirement.

The profound absence of an experient project manager/ co-ordinator further exacerbated the problems associated with lack of design integration and information co-ordination between members of the project team.

The PV module manufacturer was in the process of lunching a new product and saw this as an opportunity to further their course - commercially advertise and test the product in terms of performance and appearance. The PV suppliers objectives was profoundly different form the project objective. This led to re-work and re-design. The analysis of the client's brief was completely over looked – no value management/ engineering was carried out on how best to achieve the project objective.

Create Detail Design & obtain Approve: The PV module manufacturer carried out the detailed design of the module configuration, wiring and BOS design. The cladding manufacturer carried out the design of the cladding system and associated support structure. This phase was characterised by poor integration of design, planning and installation Programme.

The G59 procedures that govern the installation of small generators to the grid system were not consulted. The regional electric company (REC) was not notified of the project before and beyond this stage in the design development. No member of the project team was prepared to take responsibility for this function. The client organisation was left to their devices, by the consultant team, to sort out the problem with the REC. this resulted to a further delay to allow the normal procedure of checking and approving the suitability of the design to run its course. This time lag was not, anticipated and, builds into the project Programme. These failures resulted in further delays in installation and project delivery dates.

Generate Working Drawing: The cladding manufacturer generated the working drawing for the façade. Whilst the module manufacturer produced the working drawings for the PV module and BOS components. The client and the cladding consultant had made changes to the area of the façade. This was not communicated to the module suppliers. The modules and BOS specification delivered on site did not reflect the changes made to the approved detail design of the façade. The resulted to re-design, re-work and further delays. The first couple of re-design and re-work attempt failed to meet the client's requirement. The PV module suppliers overlooked the importance of checking the suitability of the design. The cover plates for the PV infill were found to be too large. This was discovered during installation. The stringing design specification was found to fall well short of expectation. The wiring design by the consultant completely ignored shading in its stringing configuration. This meant that every string would have been shaded in the mornings.

Carryout Initial Plan and obtain Approval: the in-house client representative apparently carried out this function. This function was poorly carried out. The functional activity was characterised by poor co-ordination. The preceding work to the re-cladding work was carried out to plan. However, the PV work package planning was not properly co-ordinated. Lag time where not built into the project. The old mansard roof cladding was removed and prepared for immediate action on PV installation. There was a four-week delay in the delivery of the modules to site. The meant the building occupants had to do without a roof for a month. The failure for the module suppliers to deliver on time was due to a combination of factors:

- The module manufacturer was updating and expanding its manufacturing facility form 4MW to a 10MW annual production capacity.
- The cladding company went into a stretch and was undergoing restructuring. This affected the progress of work on site.

Planning Process.

Carryout Initial Appraisal: The entire refurbishment project was not properly integrated with PV re-cladding of the mansard roof. It is not clear as to who had the overall responsibility of the project planning that covers the entire PV system installation. The initial appraisal of the PV work package was highly fragmented. The cladding consultant carried out this function in terms of their specific task and responsibilities. The PV module supplier duplicated this function in isolation of the cladding contractor's efforts. This duplication of function and lack of integration and co-ordination of information led to the following errors.

- The modules were delivered to site four week behind schedules
- The cladding contractor was not aware of the date of the arrival of the modules
- The cladding contractor was in position to commence work on site on the arrival of the modules
- The cladding contractor asked for a four weeks extension of time – to enable them build in the revised new dates into existing scheme of work. This resulted to an additional four-week delay.
- Client organisation had to put up with open roof for eight weeks.

Create Initial Plan: Each package contractor created an initial plan for their individual work package. These were not properly co-ordinated. Changes were not effectively communicated and lag time was certainly not built into the project Programme.

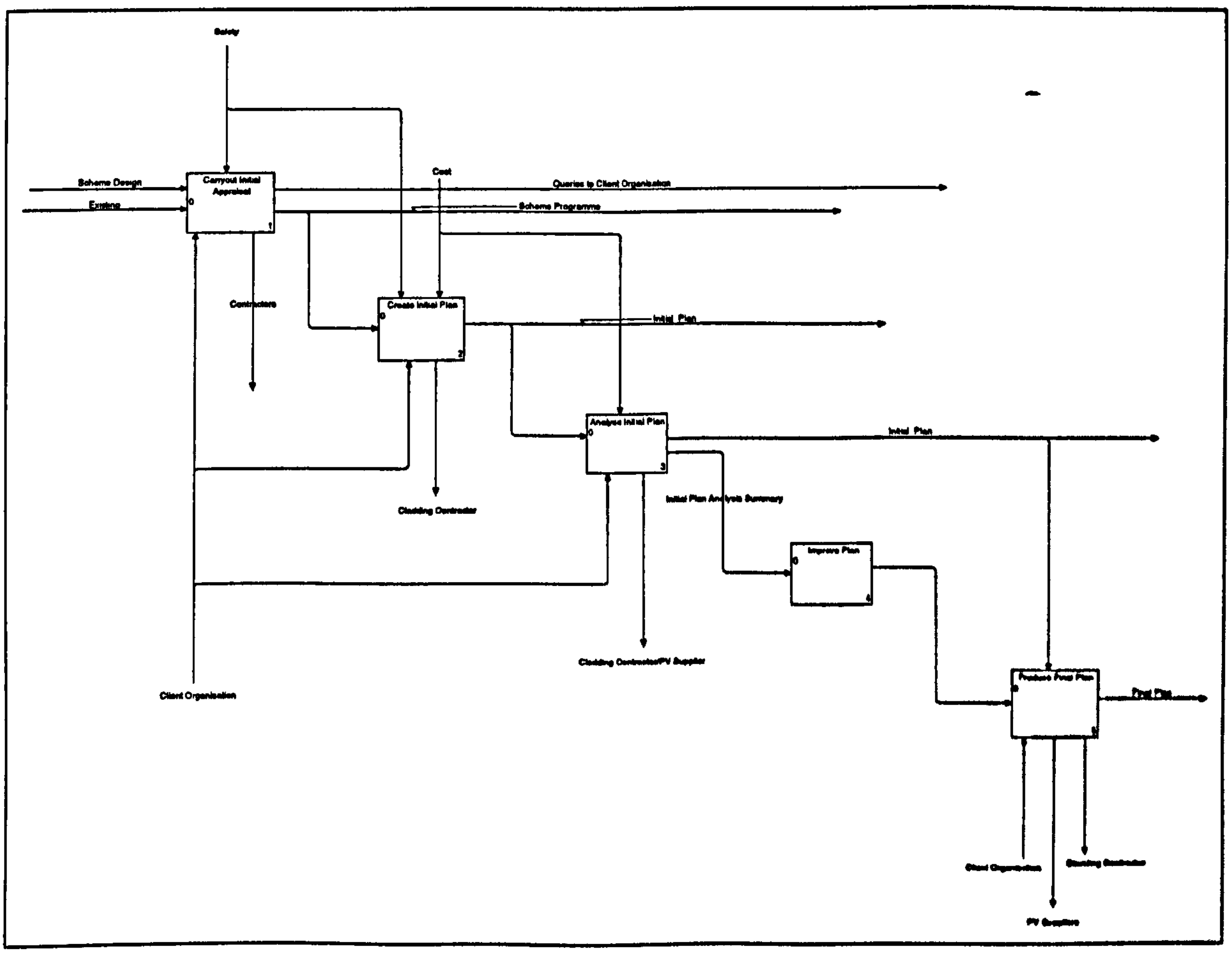


Figure B8: IDEF0 Model of the Planning Process – Case Study 3.

Analyse Initial Plan: The initial plan and the respective start days for the work packages was negotiated between the client organisation (works department) and the cladding contractor. The input for this functional activity was -the negotiated start dates for the individual work packages. The constraints were not properly identified or taken into consideration in the planning process.

Improve Plan: This functional activity was largely ignored until the programmed was completely de-railed. The initial pan was not improved at the appropriate time. The input of the functional activity was the results of the ad hock sequence of activities that led to disastrous results.

Produce Final Plan: The final plan was very much organic and was event led. A summary of the account of event is as follows:

- The removal of the asbestos cladding and the installation of the PV cladding was not properly co-ordinated
- The PV modules had long led times that was not built into the construction Programme
- The inverter also had long led time, which again was not effectively built into the Programme. This affected electrical work. The inverter was further delayed due to a change in specification designed to cope with a larger installation this was not built into the project Programme.
- The engineering consultant that developed the scheme design was marginalised and was eventually side lined.
- The solar panels that were scheduled to be installed in the October 1997 were delivered to site on the December or 1997. The installation actually commences in January 1998.
- The inverter that was scheduled to be installed in October 1997 was actually installed in June 1998. This eight months delay had a snow ball effect on electrical work and other related works.
- Poor weather conditions further delayed the electrical work by 2 weeks.
- The solar panels were schedule to be delivered just in time (JIT). The modules arrived for weeks late. There was an addition four-week delay in the installation exercise. This resulted in the client having to store over 100 module for eight weeks. Additional cost associated with this blunder has not been estimated in accounting terms.

The client was so dissatisfied that she pulled out of to deal. The client consulted with her solicitors seeking for redress in connection with the bridge of contract. The contract documentation did not have any clauses of penalties or liquidate damages arising from a breach of contract. There was a profound failure on the part of the client's in-house advisers to properly check the contract document for inclusion of relevant penalty clauses arising from breach of contract.

The Estimating Process

Carryout Initial Estimate function: during a refurbishment work carried out on an office building, it was decided to replace the re-clad the mansard roof with PV modules. The client's organisation carried out this functional activity. They obtained quotes form selected contractors. The main constraint of this functional activity is that the costs of the proposal fall within the allocated budget. Inputs for this activity were the working drawing, project team input, key plants resources available and the final cost feedback.

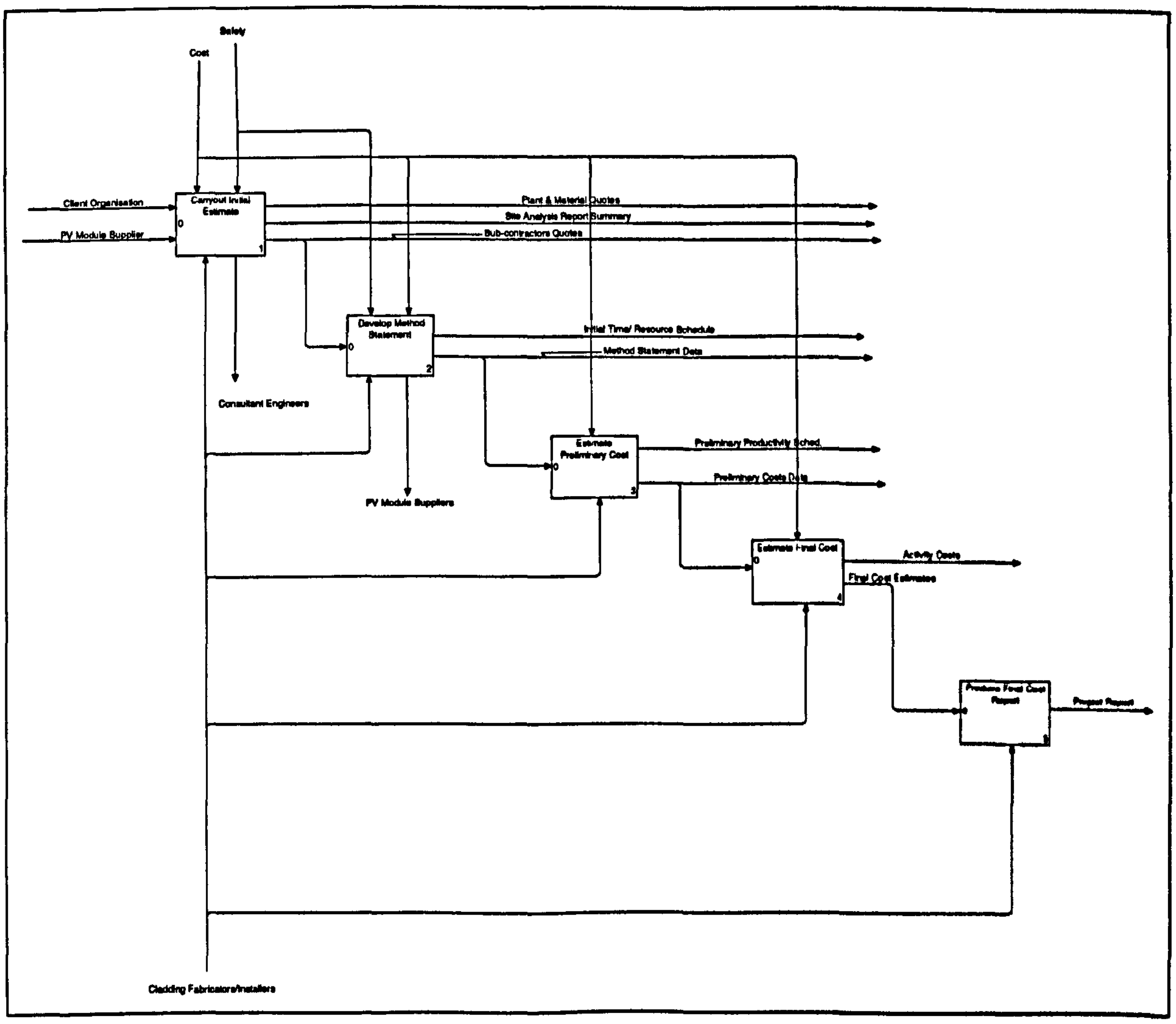


Figure B9: IDEF0 Model of the Estimating Process – Case Study 3.

Develop Method Statement: The cladding contractor and PV module suppliers performed this function within their respective domain of expertise. The method statement for the installation of the modules did not seriously take health and safety factors into consideration. The installation of the PV module commenced from the top level. An 'A' ladder was used in hoisting the panels whilst the module hung rather loosely during the installation exercise. The input of this activity was the final cost feedback, quotes from suppliers and sub-contractors, summary of analysis report and initial estimate appraisal data. The outputs of this activity are initial productivity schedule and time schedule.

Estimate Preliminary Cost: The cladding manufacturer carried out this functional activity. The input of this activity was the initial productivity schedule, the initial time and resources schedule, quotes form suppliers and sub-contractors and the final cost feed back. The constraints of this activity were the project contract make-up, the procurement method, and the contract requirement. The outputs of this stage are the preliminary activity cost, the analysed time and resource schedule and preliminary indirect costs. The mechanism by which this function is carried is by the in-house estimator of the cladding manufacturer.

Estimate Final Cost: The contract was let the cladding manufacturer and installer as a package deal contract. The cladding contractor carried out the final cost estimate. The main constrain of this functional activity are the procurement method and the project make-up. The input of this activity is preliminary activity cost, the time and resource schedule, preliminary indirect cost and quantitative analysis.

Produce the Final Cost Report: The cladding contractor carried out this functional activity. The main input are the project overheads, activity costs and indirect costs. The main constrain is the procurement method whilst the main output are the final cost and project time, final cash flow and supporting documents. The project final cost report estimated the project cost at about £800 m^2. This does not take into consideration the extra costs associated with re-work, re-design, error and excessive delays in project delivery.

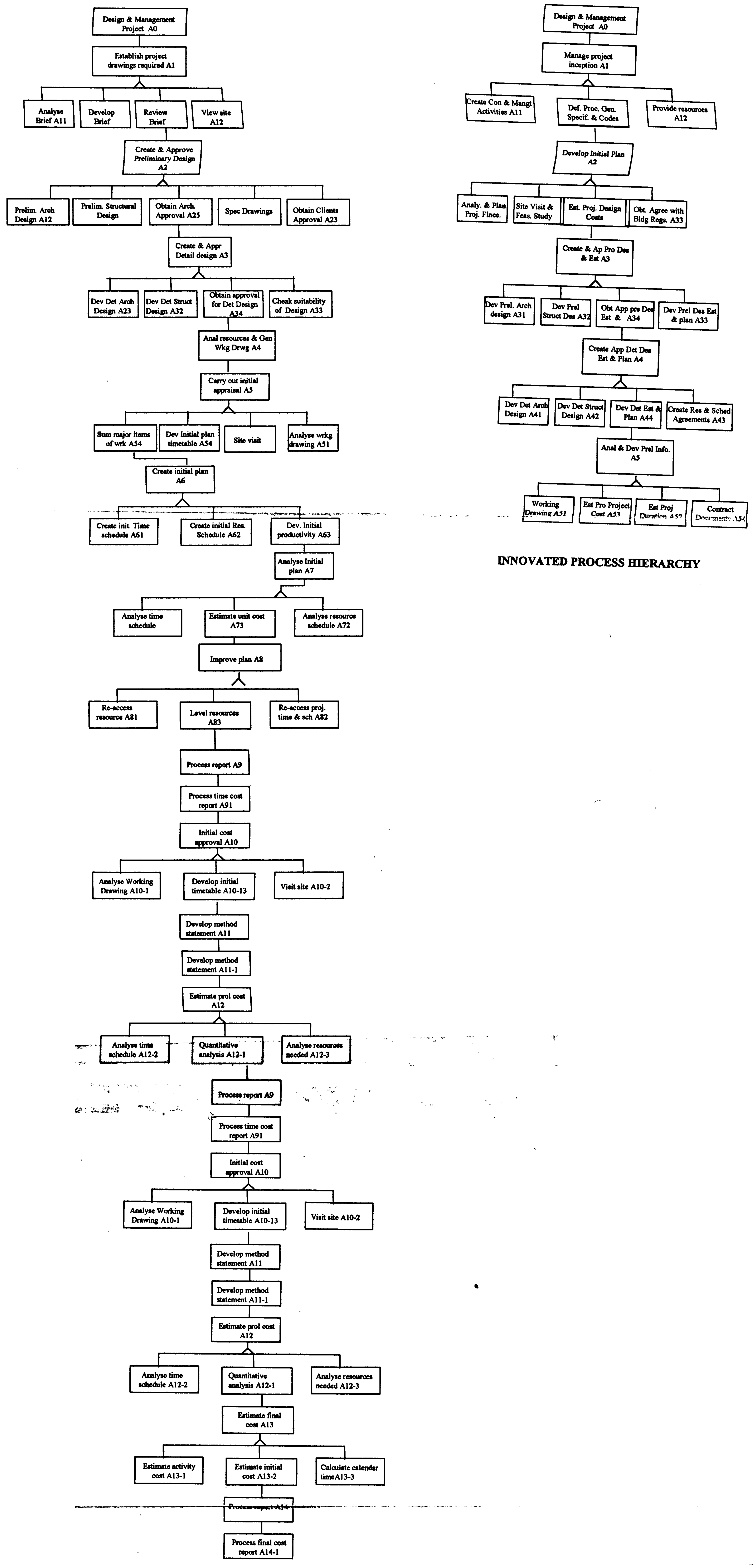
Discussion

The design of the solar façade was constrained by the existing angle of the mansard roof –75° to the horizontal. The client would have preferred the façade to be inclined towards the summer months – between 60-65° to the horizontal. The design proposals did not at any time proposed optimising the tilt angle of the façade in line with the project objective, which as to maximise the power output.

A specialist contractor carried out the removal of the existing asbestos cladding and old water take adjacent to the façade to be re-cladding. The planning and co-ordination of this part of the project was satisfactory. However, the co-ordination of the PV solar cladding installation with the rest of the project works leaves a lot to be desired. Long led times were not built into the project. Poor in-house communication and co-ordination of information within the client's organisation resulted to tactical and operational problems during the project planning and installation stages.

Errors, re-design and rework catalogued the entire project. In Northumberland and Doxford solar projects a sample of the solar cladding was installed on site prior the re-cladding exercise. This set the standard of workmanship that was acceptable to all parties. This was not the case in case study three. The cladding had to be brought down to be re-engineered, re-work and redesign on two occasions. The solar module manufacturer incurred additional substantial cost that ran into thousands of pounds due to re-work and re-design of the modules in terms of technical specification and visual aesthetically appearance.

The client, a corporate organisation, was dissatisfied with the performance of the project team in terms of design, planning and the general co-ordination. The client summarised the experience as harrowing and will be unlikely to embark on PV project in the future. This sort of experience does not encourage the take up of BIPV. The need to develop a system that would assist client and professional who might be involved in a BIPV project cannot be overemphasised.



EXISTING PROCESS HIERARCHY **Figure 10.16: The Innovative Framework for Process Duration & Cost Drivers**