

Integrating Project Estimating, Interim Valuation, Maintenance Forecasting, and Physical Interference Detecting

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Abstract

The AIC (Automation and Integration in Construction) Research Group at the University of Salford has developed the first PC based integrated construction environment for the construction industry in the UK - SPACE (Simultaneous Prototyping for An integrated Construction Environment). SPACE aims to incorporate various construction applications enabling project information to be shared between these applications and allowing the user to run them simultaneously, i.e. concurrent engineering. This paper presents the results of a 2 year research project which has made a significant contribution in the development of this PC based integrated construction environment. The research project has resulted in the development of three fully integrated applications, all of which are implemented in a single object oriented environment. The applications include EVALUATOR; which automatically generates a) project estimates from the design drawings in the form of an elemental Bill of Quantities (BQ), together with all-in-one rates, and b) interim valuation for monthly payments from the construction plan, MAINCAST; which automatically produces the maintenance forecast for a project, and 'Clash Detection'; which detects physical interference between the building structural elements and electrical cable tray elements.

Keywords: Integrated construction environment, project estimating, monthly interim valuation, maintenance forecasting, physical interference detection, structured analysis.

INTRODUCTION

Project Estimating

Project estimating is a construction management function that is interrelated to other functions, most significantly construction planning, both of which have some effect on the other. Current practice usually performs these functions independently, ignoring any interrelationships between them. For example, the project estimator, while assuming rates for construction plant, labour, and temporary facilities, does not usually take into account the activity durations generated by the construction planner (Echeverry, et al., 1991). Also, when estimating the activity durations, the construction planner does not usually take into account, nor is even aware of, the construction plant/labour/temporary facilities rates used by the project estimator. Consequently, inconsistencies between the project estimate and the generated construction plan may arise as a result of the construction methods assumed by the project estimator failing to correspond with those used by the planner (Yau, et al., 1991).

Moreover, the project estimate is also significantly affected by the design. The material costs derive directly from the design descriptions (specifications) and dimensions. Thus, any changes in the design, be they specifications or dimensions, cause a change in the project estimate.

Monthly Interim Valuation

Similarly, dependencies between the function of generating monthly interim valuation certificates and the aforementioned functions, i.e. construction planning, project estimating



and the design, also exist. For example, the activities that have been completed (either fully or partly) can be identified from the construction plan and the project design provides the dimensional information of the building elements to determine the quantity of work completed, etc. Therefore, such sharing of information between non-integrated functions is susceptible to inaccuracies as it is performed by different professionals.

Facility Management (Maintenance Forecasting)

By looking across the entire life cycle of the facility, it was determined that an automated approach to capturing and utilising information generated during the various life cycle phases could result in considerable savings for the facility owner. With 85% of the cost of a facility occurring after its construction has been completed, it is suggested that the additional cost of capturing information needed for maintenance and operation, during design and construction phases, would be significantly offset by the resulting lower cost of maintaining the facility (Scarponcini, 1996; Tucker, et al, 1994).

Physical Interference

Part of a study conducted by O'Connor & Tucker (1986), examining the constructability of a major refinery upgrade and expansion project, the study found that physical interferences as a general rework cause to be the most frequent and serious. In addition, the study found that the root causes of the physical interferences fell into one of two groups - "Visualisation difficulties/inability to accurately communicate a three-dimensional design in two dimensions" and "Human errors". The study concluded that the attitude of design managers to "get it on paper and they can take care of it in the field" may well be the primary root cause of physical interferences.

This paper presents the results of a 2 year research project which has made a significant contribution in the development of the first PC based integrated construction environment for the construction industry in the UK. The research project has resulted in the development of three fully integrated applications, all of which are implemented within a developed integrated environment prototype (SPACE). The applications include EVALUATOR; which automatically generates a) project estimates from the design drawings in the form of an elemental BQ(together with all-in-one rates) and b) interim valuation for monthly payments from the construction plan, MAINCAST; which automatically produces the maintenance forecast for a project, and 'Clash Detection'; which detects physical interference between the building structural elements and electrical cable tray elements.

Initially, a number of structured analysis techniques have been adopted to model the relevant design and construction information involved in each of the application's objectives. The result was the development of an Express-G data model and a IDEFØ process model for both the EVALUATOR and MAINCAST applications, and a IDEFØ model only for the "Clash Detection" application, as the objective of the "Clash Detection" application is principally process based. Subsequently, both the Express-G (where applicable) and IDEFØ models for each application have been implemented into the SPACE integrated environment.

THE INTEGRATED ENVIRONMENT: SPACE

SPACE (AIC Research Group, 1996) aims to integrate the construction applications over the project life cycle with “industry” standard software by holding the project information centrally so that it is shared and transferred amongst these applications/software packages. Figure 1 illustrates the proposed modularised framework for the SPACE environment. Within such a framework, each construction application possesses its own specific module, i.e. data and process models, where the information relevant to the application is held. By implementing these modules into a core object oriented knowledge based system, where the project information is controlled, maintained and manipulated, each application’s information becomes accessible to any of the other applications. Furthermore, each of the individual packages and the central repository can access standard data from external databases. The output of this research project has significantly contributed to this integrated environment where applications such as estimating, valuation, facility management, and clash detection have been developed. SPACE integrates five other construction applications, i.e. CAPE, SPECIFICATION, CONPLAN, CONVERT, and INTESITE.

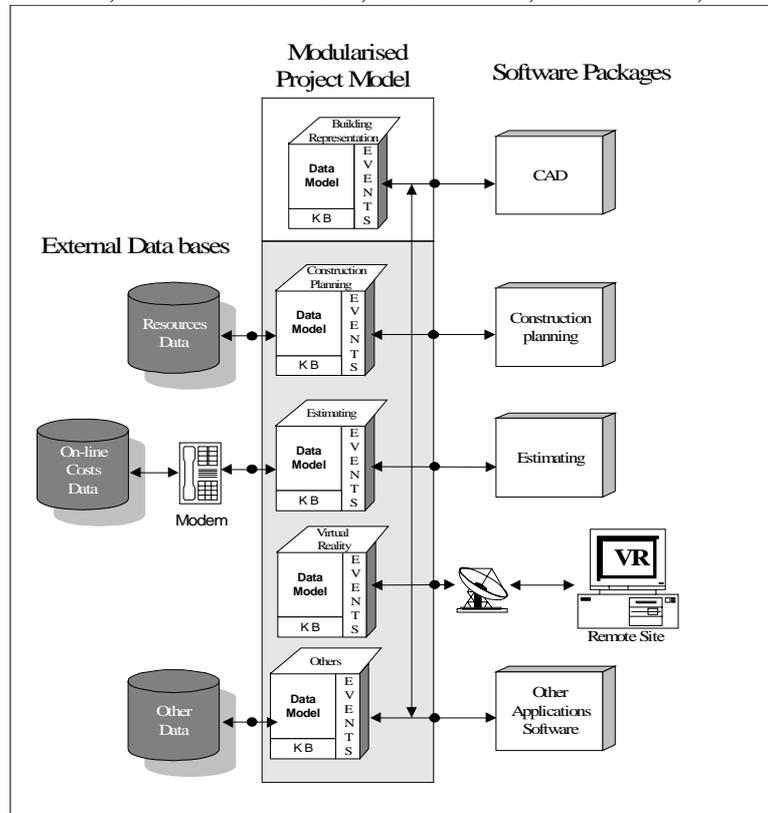


Figure 1. Proposed framework for the integrated construction environment prototype - SPACE.

1. The CAPE application (Construction Application Protocols for Comprehensive data transfer) generates, stores, and controls the project specific information. Its main objectives are to establish a comprehensive design data module in the object oriented knowledge based system (KAPPA) which supports multiple designers’ generic views, and to dynamically translate AutoCAD drawing primitives into meaningful objects in order to serve all downstream software/applications (Che Wan Putra, CWF, 1996).
2. The SPECIFICATION application generates the specification for the design elements which CAPE has created from the AutoCAD drawing primitives.

3. CONPLAN (Intelligent **CON**struction **PLAN**ning generator for design rationalisation) is a generic data module whose main objectives are to dynamically generate construction planning information from the design drawings and to examine the constructability of the design (Hassan, 1997).
4. CONVERT (**CON**struction **Virtual EnviRonmenT**) generates virtual reality models for the design elements created by AutoCAD/AEC, at real time using World Tool Kit. In addition, CONVERT enables the virtual objects to be interrogated (Alshawi & Faraj, 1995).
5. INTESITE (**INTE**lligent **SITE** Layout Planning) automatically produces site layouts, i.e. the positioning of the appropriate temporary facilities for the selected resources specified by the project manager, in AutoCAD by integrating design, construction and site information (Alshawi & Sulamain, 1995).

STRUCTURED ANALYSIS

In order to model the relevant design and construction information involved in the objectives of each respective application, e.g. to generate project estimates, monthly interim valuation certificates (EVALUATOR), and maintenance forecast valuations (MAINCAST) within the integrated construction environment (SPACE), etc., a number of well established structured analysis techniques were adopted (Underwood & Alshawi, 1996; Underwood & Alshawi, 1997). The aim was to model each application as an integral module within the overall integrated construction environment. Therefore, the information presented in the resulting data and process models, which represents the information required by each application, includes not only its own but also the necessary information retrieved from the other modules.

Express-G Models

Express-G (Schenck & Wilson, 1994) is an entity modelling technique that provides numerous graphical notations, enabling the static model of the proposed domain (system/application) to be developed. Figure 2 presents the Express-G data model for the proposed EVALUATOR application. For this technique rectangular boxes are used to represent entities which correspond to real world items of interest. When an entity has attributes, i.e. specific properties of interest, relationship lines are used to connect an entity with its attributes. Each line is labelled with the role name of the attribute, followed, if necessary, by a cardinality specification. Supertype/subtype inheritance hierarchies are also supported in the form of thick solid lines that connect the relevant entities.

IDEFØ Models

IDEFØ (Ross, 1977; Ross & Schoman, 1977) is a structured technique that combines blueprint-like graphic language with nouns and verbs of any other language to provide a hierarchic, top-down, gradual exposition of detail for expressing the happenings of a subject in the form of a model. Figures 3 illustrates the A0 IDEFØ (2nd level) diagram for the MAINCAST application. The fundamental building blocks of IDEFØ notation is a box with four sides. The subject matter (process) is placed inside the box where its relations with other processes are shown by arrows which go from an OUTPUT (left) of one box to the INPUT (right) or CONTROL (top) of another. Labels allocated to the INPUT and OUTPUT convey the idea behind the transformation process, i.e. from a “before” to an

“after” state of affairs. The CONTROL interface interacts and constrains the transformation to ensure that it applies under the appropriate circumstances. Finally, the MECHANISM support (bottom) provide means for realising the completed subject matter represented by the box.

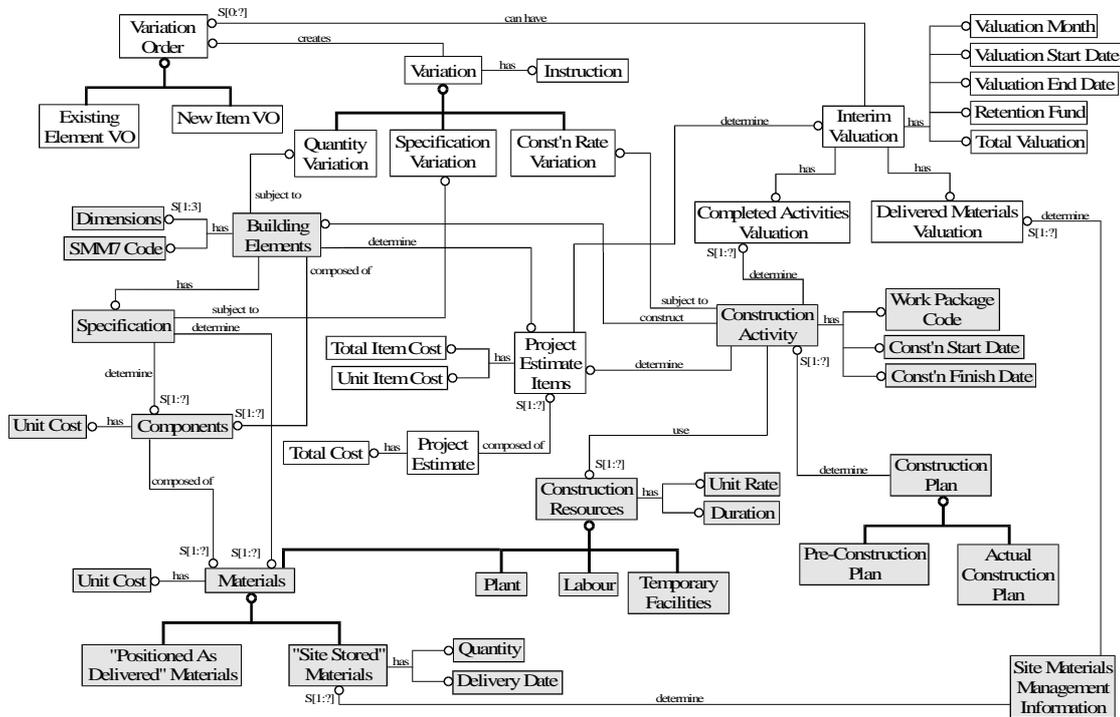


Figure 2. Express-G Model for EVALUATOR.

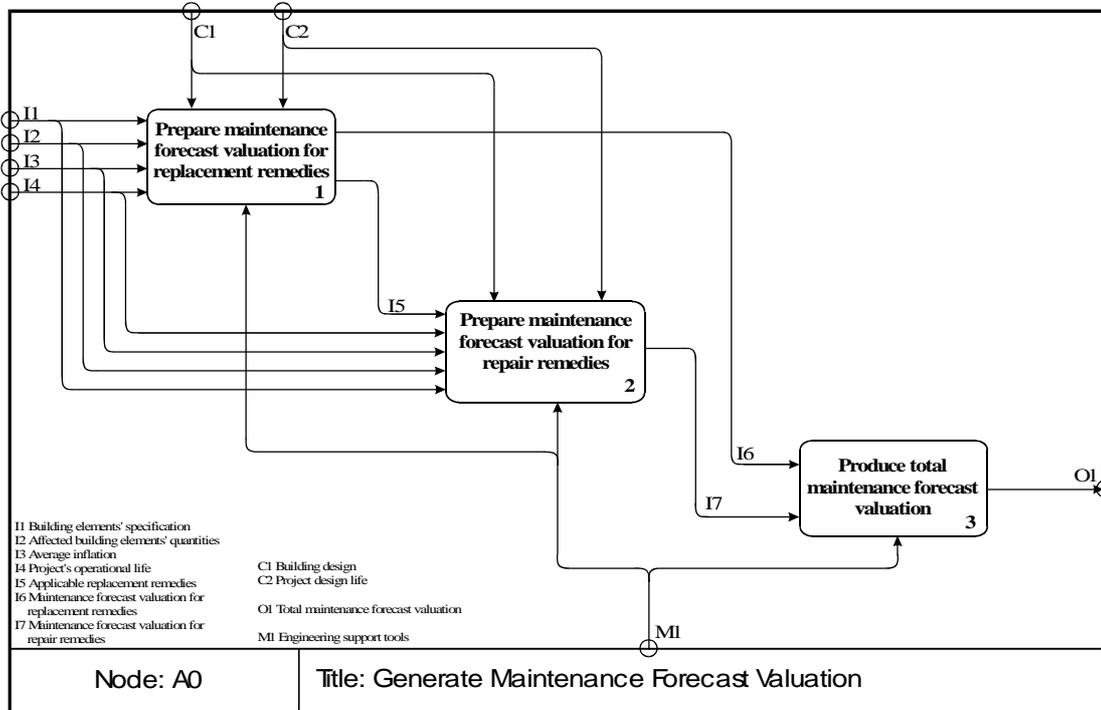


Figure 3. Diagram A0 of the IDEF0 Model for MAINCAST.

IMPLEMENTATION INTO THE ICE

Following the development of the Express-G and IDEFØ models for each application, their respective models were subsequently translated into the relevant object oriented concept structures, within SPACE's core object oriented development environment (Underwood & Alshawi, 1996; Underwood & Alshawi, 1997). This in turn, led to the development of the application specific modules, i.e. Project Estimating and Monthly Interim Valuation Modules (EVALUATOR), and the Maintenance Forecasting application module (MAINCAST).

From the SPACE main interface, which appears along the top of the screen (Figure 5), the user initiates the various applications, by selecting the relevant button, i.e. CAD (which initiates AutoCAD and the CAPE application), Planning, S.Layout, VR, etc. In addition, each of the EVALUATOR applications (estimating and monthly interim valuation) and the MAINCAST application are represented within the SPACE interface by individual buttons, i.e. Estimate, Evaluate, and MAINCAST.

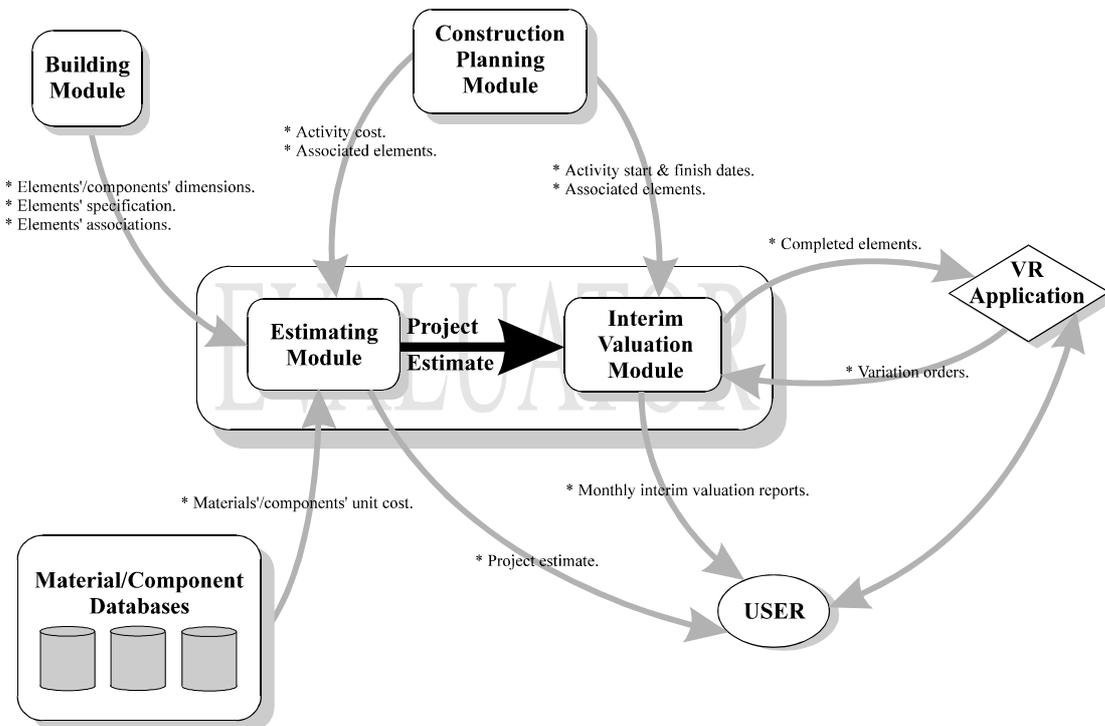


Figure 4. Schematic overview of the EVALUATOR application.

EVALUATOR APPLICATION PROTOTYPE

Figure 4 schematically represents an overview of the EVALUATOR application and its required interaction with the other application specific modules. Initially, the estimating module builds-up the design elements' material/component unit-rates. Firstly, the design elements' individual materials/components are identified from their specifications described in the design and specification modules. Next, EVALUATOR links to an external cost database, and retrieves each individual material's/component's unit-rate to build-up the total (material) unit-rate. From the information generated by CONPLAN,

which is stored in the construction planning module, EVALUATOR identifies the activity associated with each element ('Associated elements') and the cost to construct the element ('Activity Costs'). From the design elements' dimensions and their associated elements, e.g. doors, windows, etc. embedded within a cavity wall, within the design module, EVALUATOR calculates the elements' quantity, which in turn, is used to calculate the all-in-one unit rate for the project estimate items. Figure 5 shows a screen dump which displays the first page of the elemental BQ generated for a case study project. As shown, each estimate item is listed by its type, i.e. beam, column, etc., and is labelled with the name of the item's associated specification. In addition, the unit of measurement, the total quantity of the associated building elements, the all-in-one rate, and the total cost for each estimate item are displayed. Although not shown, the total project estimate is displayed at the bottom of the last page of the BQ.

	MEASUREMENT	QUANTITY	UNIT RATE	TOTAL COST
BEAM				
Beam_Spec_1	cubic metre	51	264.83	13505.55
Beam_Spec_2	cubic metre	11.88	290.97	3456.68
CAVITY_WALL				
Cavity_Spec_1	square metre	1792.8	45.57	81574.2
Cavity_Spec_2	square metre	136.2	23.94	3259.73
COLUMN				
Column_Spec_1	cubic metre	1	757.50	757.50
Column_Spec_2	cubic metre	6.2	264.19	1637.98
Column_Spec_3	cubic metre	6.2	289.24	1793.28
DOOR				
Door_Spec_1	tan	2	73.42	146.84
Door_Spec_2	tan	2	79.07	158.14
Door_Spec_3	tan	2	84.27	168.54
FOUNDATION				
Foundation_Spec_1	cubic metre	24	416.82	10003.28
SLAB				
Slab_Spec_1	cubic metre	127292	109.17	13911724

Figure 5. Generated elemental BQ.

The interim valuation module requires the activity's start and finish dates from the construction planning module. Firstly, these dates are used to identify the activities that are completed (either fully or partly) during each particular valuation month and, secondly, to determine how complete (percentage) each activity is. Next, the element associated with each completed activity is identified from the construction planning module before retrieving the element's quantity and all-in-one unit-rate from the estimating module. From the element's quantity and all-in-one unit-rate, together with the completeness of its activity, the element is valued. The interim valuation certificate generated for valuation month 3 of the case study project is illustrated in Figure 6. As shown, the certificate is titled with the certificate number ("INTERIM VALUATION REPORT 3") and the last date on which the certificate has been calculated. The total valuation for the work executed in the construction of each type of building element is displayed, i.e. "Beam",

“Cavity_Wall”, “Column”, etc., together with the retention fund and the total valuation (less the retention) for the valuation month.

Furthermore, the EVALUATOR application has been linked with the VR application (CONVERT) not only to exploit VR’s visualisation capabilities but also in order to use VR as a graphical interface to EVALUATOR. With such an interface EVALUATOR enables the user to, 1) instantly reveal the cost of any design element by selecting it in VR (estimating module) and 2) simulate the construction sequence for each valuation month in virtual space (interim valuation module).

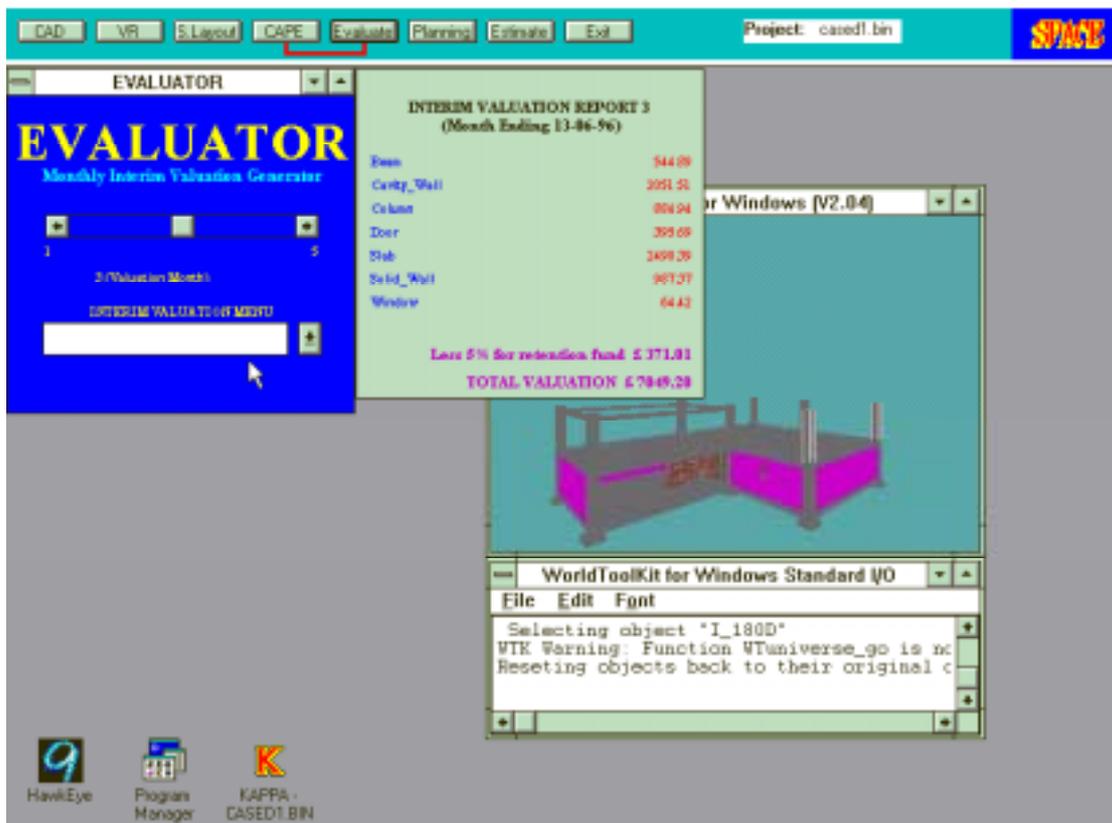


Figure 6. Generated monthly interim valuation certificate.

MAINCAST APPLICATION PROTOTYPE

In order to avoid redundant information being stored within the ICE’s central repository “project model”, two external remedy databases, based on H.A.P.M. component life manual (H.A.P.M., 1992), were created to hold the relevant repair and replacement remedy information. Therefore, only those remedies relevant to a particular building design are retrieved from the databases and consequently stored within the maintenance forecasting application module. By linking MAINCAST to these external remedy databases, the application initially identifies the applicable replacement and repair remedies in turn, by cross checking with the building elements’ specifications referenced in the design module (CAPE) and described in the SPECIFICATION module. For each applicable replacement remedy MAINCAST identifies, the remedy’s replacement period is retrieved from the replacement remedy database, while its unit-cost is acquired from the estimating module. Conversely, for each applicable repair remedy that is identified, both the remedy’s replacement period and unit-cost are retrieved from the repair remedy database. Finally,

from the building elements' quantities stored in the design module, and the project's operational life and annual inflation provided by the user, MAINCAST calculates the annual maintenance forecast valuation for every appropriate year during the operational life of the project, as well as the project's total maintenance forecast valuation.

Figure 7 shows a screen dump displaying the maintenance forecast graph for a case study project, in the form of a X-Y graph, i.e. cumulative maintenance valuation against maintenance year. Figure 7 also displays the maintenance forecast valuation for the 30th operational year of the case study project. The displayed maintenance valuation shows, the cumulative maintenance valuation up to and including the selected year, the total maintenance valuation for the selected year, together with a breakdown of the individual remedies and their associated costs.

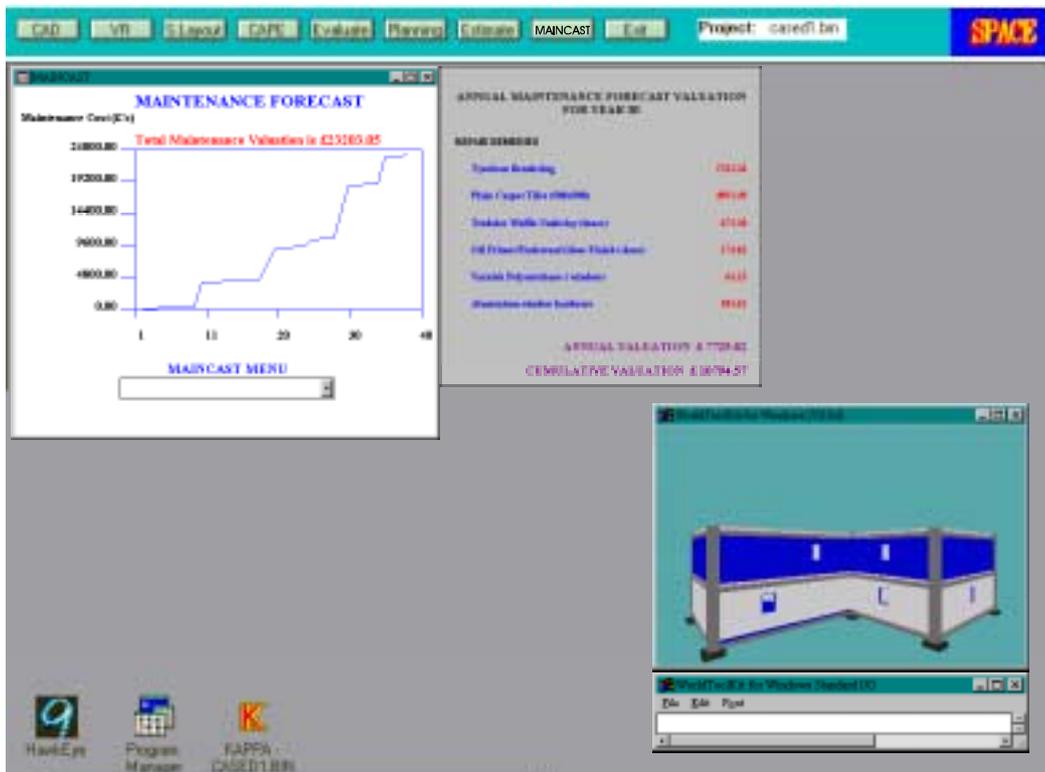


Figure 7. Generated maintenance forecast valuation for an operational year.

As with EVALUATOR, the MAINCAST application has also been linked with the VR application, providing potential benefits for MAINCAST. For example, during an operational year the building elements that require some type of maintenance are highlighted within VR (using separate colours to differentiate between replacement and repair maintenance), enabling the areas for maintenance to be instantly identified (Figure 7).

“CLASH DETECTION” APPLICATION PROTOTYPE

Initially, the application compares the level, (its level in the AutoCAD drawing), Z coordinates (actual vertical position) and Z dimensions (depths/heights) of each structural element with that of each electrical cable tray, from the design module, to determine

whether the elements interfere with one another in the vertical ('Z') dimension, i.e. vertical analysis. Once the application finds a vertical interference between a structural element and electrical cable tray, the application then horizontally analyses the two elements. By comparing the elements' X and Y co-ordinates, X and Y dimensions (lengths/widths), and rotational angles from the design module, the application determines whether there is actual physical interference between them.

Figure 8 shows the "Clash Detection" interface menu for a case study project within which each detected physical interference is presented as an option. This figure also illustrates a particular physical interference between a beam and a 'horizontal' electrical cable tray highlighted in VR, following the selection of the relevant option from the interface menu.

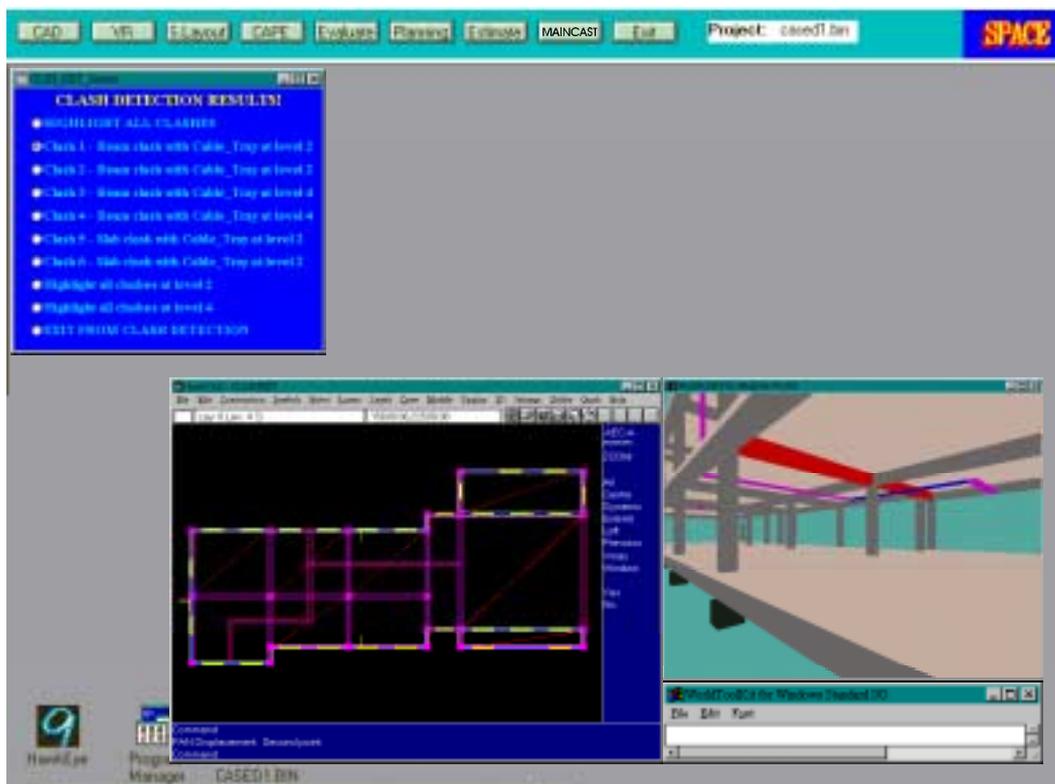


Figure 8. Clash between a beam and a horizontal cable tray highlighted in VR.

CONCLUSIONS

This paper has presented the research work resulting in the development of three applications, EVALUATOR, MAINCAST, and "Clash Detection", within a fully integrated construction environment prototype - SPACE. EVALUATOR generates project estimates from the design drawings and monthly interim valuation certificates from the construction plan. MAINCAST generates the maintenance forecast (valuation) for a project from its design information and "Clash Detection" examines a project's design in order to detect physical interferences between structural and electrical cable tray elements.

The implementation of EVALUATOR as part of an integrated environment enables the automatic generation of the project estimate (BQ) and monthly interim valuation certificates, i.e. reduction in the overall time required to process them. Furthermore, it

eliminates any susceptibility to inconsistencies and inaccuracies through the passing/sharing of information between the application's estimating and interim valuation functions and the other applications. From the point of view of estimating, unity and consistency has been created between the plant/labour/temporary facilities used in the production of the project estimate and those used by the construction planning function to generate the construction plan. The effects of any changes to the design (project information) are reflected by the other applications including EVALUATOR. Thus, "what if" scenarios are able to be run on the project estimate and monthly interim valuations. The interim valuation function can also enable clients/contractors to forecast their expenditures from month to month. Finally, the integration of EVALUATOR with the VR application has shown to provide particular benefits. For example, construction sequences from month to month can be visualised, while building elements can be interrogated from within virtual space to enter variation orders, reveal cost/variation/completeness status information, etc., while any construction areas for making claims can be instantly identified.

The implementation of MAINCAST as part of an integrated environment enables the facility manager/client to automatically identify the necessary maintenance at annual stages in the project's operational life. Furthermore, the effects of any changes to the design (project information) are reflected by the other applications including MAINCAST. Therefore, "what if" scenarios are able to be run on the project's overall maintenance. This enables facility managers/clients to forecast their maintenance expenditure prior to the construction phase of the project's life cycle commencing. Finally, particular benefits are shown to be gained from the integration of MAINCAST with the VR application. For example, the building elements which would be subjected to maintenance during a particular operational year, are instantly visualised. The building elements can also be interrogated from within virtual space to reveal information such as details of the maintenance work, the cost of the maintenance work, the details and time of the next expected maintenance, etc.

Finally, by implementing the "Clash Detection" application as part of the integrated construction environment, any 'illegal' physical interference, e.g. between a structural element and an electrical cable tray element, can be instantly detected at the design stage. Therefore, such problems can be highlighted and emended prior to construction, thereby avoiding the possibility of later costly construction rework. In addition, the integration of the "Clash Detection" application with the VR application enables the designer to visualise the detected physical interferences.

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