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COMPONENT SPECIFIC EXPERT SYSTEM AND ROBOTIC APPLICATIONS FOR BUILDING - TOTAL LIFE CYCLE INTEGRATION THROUGH KNOWLEDGE BASES

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ABSTRACT

Modern building comprises the assembly of discreet and diverse systems for their structure, fabric and services. Each system comprises manufactured products, building design and construction skills and a completed element that requires maintenance in use. The success of the total building is dependent on how well the design, construction and operational processes comply with the general fundamental "rules" of each specific system in a particular application and integration with other systems. The control of these processes must therefore be rule-based and interrelated over time so that consistent decision-making can be achieved throughout the life of the system in the building.

This paper proposes that through the application of Artificial Intelligence techniques in computers in the design, construction and operation processes and Robotic techniques in the construction and operation processes, the required management control can be achieved. It will take a specific component system used in modern building construction - dry-wall partitioning - as an example and suggest how AI and Robotic techniques can be appleid to its design, construction and operation processes based on current experimental research. Conclusions will then be drawn on the implications for the other systems in the building, the total building itself and feasibility for use in practice.

Introduction

An essential problem in modern building construction is ensuring that what is designed can be economically constructed and satisfy in operation the explicit and implicit requirements of the client's brief. This problem is compounded by the fact that for most buildings of any complexity and size the design and construction processes are under separate responsibilities and over the life of the building in use its operational needs can change many times. It is therefore important that a tracability of design decisions exists so that the subsequent construction and operational processes can be carried out to fulfil the design intentions, and the implications of any subsequent required change of the original design for constructional or operational reasons can be fully understood. It is also important that these design decisions are made with reference to generally accepted good practice concerning the various criteria that the elemental parts of a building have to satisfy and the material, component and system characteristics of which they comprise.

As the general knowledge of building technology is essentially derived from the project experience of building design and construction, it would be useful if project knowledge bases could be defined in such a way so that a general knowledge base could be established concerning every aspect of building technology. This would have the reciprocal benefit of enabling the technology of a proposed building design to be comprehensively assessed against a general standard and that general standard to be continuously up-dated from the experience of practice. To be comprehensive, the project knowledge base should control and receive feedback from both the constructing and operating processes of the design, so that this information is contained in the general knowledge base.

It is possible to illustrate this proposition by considering just a narrow domain of building technology. This is because the same fundamental design, construction and operation relationships exist for a single element comprising a specific component system as they do for every other element and the building as a whole. The particular technology chosen for the illustration is the dry-wall construction system because it is common to many developed countries; offers speed during the construction phase; offers planning flexibility during the operating phase; has to satisfy a range of diverse criteria; is comprised of components of diverse characteristics, different combinations of which produce a range of element types; and design and construction specification data is well documented by the suppliers of the system's main material producers - notably US and British Gypsum Ltd.

Research experiments for the application of Artificial Intelligence techniques for design and Robotic techniques for construction have been carried out for this particular system of construction. It forms a critical element in a building with regard to facilities management because of its impact on the space use quality, relationship and flexibility potential.

The Technology of Dry-Wall Systems

Dry-wall systems of construction are mainly used for providing non-loadbearing partitions or though more recently they have been used to provide the main load-bearing elements of low-rise commercial and domestic buildings - primarily in the USA. The essential features of this form of construction are:-

- it comprises protected cold-rolled steel supporting structural studs and channels, plasterboard sheeting quilted insulation and all necessary mechanical fixings, taped joint sealing materials and element junction materials. As a generic form of construction it can be considered "light and dry".
- it will satisfy a range of sound, fire and strength performance requirements by various combinations of different size and material types of the above components depending on the floor to ceiling height of space it is required to divide.
- as a building element, this system relies on the integrity of site assembly joints and junctions to surrounding fabric are satisfied in use and the alignment of the board finish for aesthetic appearance. Although limited amounts of stud-framing can be pre-fabricated, all components are usually manually assembled at the location of the element in the building. Because of its capability of carrying services, careful integration of programmed installation is required when this is required by the design.
- as a building element, this system offers flexibility of space use over the life of the building through de- and re-mounting relocation with minimal component wastage due to its "light and dry" nature and the fact that the elements are usually non-loadbearing.

In the UK, design, specification and installation information is well documented by British Gypsum Ltd., based on their experience of practice and research and development (2). This information is the basis of detail design advice given to building designers and installation advice and training for the specialist contractors who erect the system on site. There is a constant need of up-dating information as new building design requirements continue to demand the need for new dry-wall design and specification to meet higher performance grades and increased floor to ceiling heights.

The Application of AI Techniques in Design and Robotic Techniques in Construction - and Combination of Both in Operation

A pilot study was carried out (8) to consider the possibility of developing a knowledge-based "expert system" to cope with British Gypsum Ltd's need to give up-todate advice to building designers during the design phase of a building project. When the appropriate solution had been selected, there was then a need to rapidly produce a hard copy of design details and installation specification for the specification, tendering and constructing phrases of a building project. This need was most acute in order to meet the demand of "fast track" projects in the rapidly growing commercial development areas of London and the South East of the UK - especially as architects were increasingly relying on the component manufacturer to produce the project information. The pilot "expert system" comprised the following parts :-

- a "standard" selection module that would enable the user to define a reasonably "normal" set of Sound, Fire, Weight, Height, Strength and Width requirement grades and then be presented a range of "standard" design specifications already categorised form current knowledge of practice. A final selection could then be derived based on ascribing design and ease of construction priorities.
- a "special" selection module that would suggest possible new combinations of components to meet "special" requirements for increased performance grades to meet the specific conditions of a particular building design. This sort of situation was increasing due to the demands for building innovation from legislation and fashion conscious clients and architects alike. This module would have to rely on the acquisition and representation of the Company's specialist experts and research and development results data to produce a continually up-datable knowledge base. Results of successful "new" design specifications could then be passed to the "standard" module.
- a "graphics" selection module that would generate a set of junction and general layout design details and installation specification to suit the selection made in either of the first two modules. The advantage of the "expert system" approach to producing project information would be that only the representation of individual components would need to be stored because the computer based system could "assemble" them according to pre-determined "rules" and the user would always be questioned about the particular project circumstances before an appropriate set of details could be demonstrated.

This pilot study demonstrated that a general knowledge base about a dry-wall partitioning system could be formed from which a project knowledge base could be derived i.e not only the "drawn" and "textual specification" and component "quantities" would exist but also the reasoning why the design decisions were made and what the implications would be if the construction and operation in use conditions varied from that which was originally intended. The existence of the general knowledge base would also provide a common data structure which would allow feedback from past projects to be processed and passed on to future projects - a critical aspect in achiving quality in design, construction and operation of building projects (6).

In the USA, experiments are being carried out (12) in using site robots to the assembly of dry-wall partitioning. This has been achieved by isolating the specific assembly tasks required - placing and fixing channel tracks, installing studs, applying and fixing board finish - and accepting some simplification of the partition geometry on plan. As with all construction robots, the laser sensing facility (13) is critical to deal with the "dynamic" environment of the site but this in turn will ensure precise alighment, stud spacing and fixing centering which are all vital to the performance and appearance to the fininshed element. Apart from the direct - and indirect through faster construction - cost savings that have been estimated with its application, robotizing dry-wall partitioning offers a more precise assembly of the element to achieve the quality intended in its design. As it is not yet possible for the robot to cope with every part of the assembly - e.g. doorways, corners, curves on plan etc. - so a combination of manual and robotic applications would still be required. However, with the growing shortage of skilled site operatives, this sort of arrangement might prove quite attractive with the "machine" rapidly carrying out the long-run operations and the "man" being able to give more time to to the remaining operations.

A direct interface with the "design/specification" expert system formerly described with the robotic "construction" application latterly described, presents the possibility of a CAD/CAM capability for the dry-wall construction system used in modern commercial buildings. If sensing devices can be applied in concrete cladding panels (1) to monitor performance-in-use, there is no fundamental reason why they cannot be applied in dry-wall partitions to the same end to see, for instance, what sound reduction performance grade the partition really had to cope with or, in the extreme, exactly how a partition withstood a real fire in use. The fact that a continuous physical link through the stud framing would exist - at least on floor by floor basis - means that it would be possible to link up the "sensed" partitions to a computer knowledge-based expert system in much the same way as a building energy management system operates (11).

If the operating and designing computer systems were also linked, the information "feedback loop" would then be complete. Only the incentive for doing so would remain and this ultimately depends on whether the modern industrial society deems a medium to long term view of the buildings that it is constructing to be necessary.

The Implication for Other Systems and Total Building

A building comprises both physical material "systems" and conceptual "systems" and its nature is such "that it is both a process of conceptualization (design) and realization (construction) and a product of physical systems that enclose and control an entironment to create a particular desired effect" (5).

All the physical systems of which the building is comprised have in common that they are assembled from components with distinct material characteristics; the components combine to form elements which have to satisfy a range of performance (- and aesthetic if they are visible) requirements; the elements are assembled and finished to various degrees on - and - off site through the application of particular manual skills and equipment aids; the conditions of use vary from time to time due to climatic and operational changes; the performance in use may be affected by the performance of other system(s) depending; and in total the combincation of all the systems produces the overall building system.

This suggests that if the application of artificial intelligence and robotic techniques can be beneficial to the design, construction and operating processes of one system, the same should be true of their application to all the systems in a building. This is because these techniques are addressing the management processes of design, construction and operation and influencing their "quality" - i.e. how well the requirements are being fully met from the inception of the building project to its operation in use - and therefore the fact that the physical product of each system is different is inconsequential.

If these techniques are applied to every system in the building - then because of the interdependence of one system upon another - the benefits to each system should accrue to the whole building. Some specific examples of this, starting with the dry-wall construction system already described, would be as follows:-

- in design the application of integrated "expert systems" for dry-wall partitioning and suspended ceilings would ensure that all fixing and junction "sealing" combinations had been considered before the final decision was made to select a particular type of each system (10).
- in construction the application of robotic techniques to the erection of steel or concrete frames and laying of slabs of screeds, should radically reduce the induced dimensional deviation of those systems and hence the risk of misfit at the base and end junctions and general alignment of dry-wall partitioning (3).
- in operation the application of robotic "sensing" with "expert systems" interpretation of the thermal insulating charactristics of dry-wall partitioning and external wall dry-lining in combination with a building energy management system (11), would

provide a continual comparison of "design predictions" with actual performance in use.

The concept of a building having its own technology knowledge base now starts to become possible and - within the limits of any inanimate object - truly "intelligent" buildings can become a reality with not only the services but also the structural and fabric systems being fully integrated (7).

The Feasibility for Implementation in Practice

The increasing use of computer-based systems in building design in order to co-ordinate its "graphical" representation with its "data" resource and performance requirements through Integrated CAD is currently being practised by leading architectural consultancies. They are also using this medium to extend their service into facilities management and providing the client with computer software and hardware to understand the designed building (4). The improved CAD systems with "windowing" facility allows the visual superimposition of data over drawing and with the introduction of "expert" modules concerning the various performance aspects of a drawn design, will all improve understanding of "what happens if ?" when variations are proposed to either design, production or operating requirements. It is also likely that building designers in the future will have to depend on computer information systems jsut to cope with the complexity of legislation, standards, codes and technical innovation in building technology.

The use of robotization on building construction sites - still essentially limited to Japan (9) to replace manual methods for primarily health hazard operations such as "sprayed applications", are now increasingly being considered for many other "component application" operations such as the one described in this paper. This trend is likely to increase with the growing shortage of skilled human construction operatives in the developed countries - and with the increased use of sophisticated building technology, robotization is likely to be the only way that site production requirements can be effectively and efficiently met. The development of building energy management systems (11) is starting to combine artificial intelligence techniques with the traditional "sensing" control mechanisms of maintenance management - and there is no fundamental reason why the same approach could not be adopted for every other "system" of which modern buildings are comprises.

It may therefore become feasible to depend on these techniques for the designing, constructing and operating phases of a building project because there will literally be no other option as higher and higher standards are required of buildings with lower and lower manual design, construction and operating capabilities available to achieve them.

Conclusion

In conclusion, it can be seen that the possibility exists of controlling the design, construction and operating phases of a building project by using artifical intelligence and robotic processes. The advantage of this would be that quality could be assured to a far greater extent than is currently achieved because the defining of and conformance to operating, design and production requirements would be co-ordinated and controlled from briefing to maintenace through the building's knowledge base.

As it is neither likely to be technically possible in the foreseeable future - nor socially desirable - for the whole project process to be completely automated, the practical way forward will with a partnership between man and machine - both in the design office, construction site and managed facility. A change of practice methods that encourages more rigour in the setting and meeting of requirements in all phases of a building project is a pre-requisite of increased automation - which in turn will help to ensure that these requirements are being fully met to the client's and user's satisfaction.

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