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CBRefurb: A Case-Based Building Refurbishment Cost Estimator and Decision Support System.

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Abstract. This paper highlights the strategic importance of the cost estimation of building refurbishment work and the need for IT tools to support managers in their decisions to go for refurbishment or redevelopment. An investigation amongst the North West councils has confirmed this need and has shown that the domain is too complex to be elicited and to design an expert system using model-based reasoning (MBR). As a result, an expert system (**CBRefurb**) which estimates the cost of refurbishing buildings and provides decision support for construction managers in their decisions is designed. This system is being implemented using a relatively new paradigm called Case-Based Reasoning (CBR). CBR is chosen for several reasons. The complexity and the uncertainty that characterise building refurbishment domain makes it difficult to estimate the costs using model-based reasoning. In addition, the refurbishment estimators by using previous similar work to estimate the costs makes it ideal for CBR.

1. Introduction

Refurbishment represents a substantial part of the UK construction programmes and is seen as an economic alternative to new build. It reduces lost commercial and residential space and infrastructure expenses, and safeguards the social relations and architectural value of properties [4]. An investigation amongst the North West councils and contractors has shown the strategic importance of estimating the costs of refurbishing houses and the need for a tool to support the managers in their decision to go for refurbishment or redevelopment [Ref]. This is supported by results of research undertaken in the Department of Surveying at the University of Salford which has been involved in the development of Expert Systems (ESs) since the mid 1980's. Under the Alvey Community Club Programme it was the first to develop a commercially available ES for the construction industry [1]. The ELSIE system provides strategic budget estimates for commercial office development. This system has been followed by the ELI system and a system for estimating the cost of cyclical maintenance for housing association [10]. Two other system have followed, one for the strategic budget estimation of housing development [9] and the second for the prediction of a construction project's cash flow [13]. The availability of an ES with several hundred users presented a unique opportunity for the department to be aware of the problems faced when designing such a system. These systems are difficult to modify and maintain as knowledge changes [11,12]. They contain hundreds of rules that represent a causal model of the problem domain. In a complex domain like refurbishment which involve quantitative and experimental judgement, eliciting and encoding this knowledge into a rule set can present great problem for the knowledge engineers. Also, unlike new building, in this domain there are two interrelated source of complexity: the building's condition, which may not be accurately known until after a detailed building condition survey and the client's requirements, which may not be completely defined at the feasibility stage. Due to the complexity and the uncertainty of the domain most of the expert use previous similar work in estimating current refurbishment work.

This paper highlights the complexity of the domain and presents the design of an expert system (**CBRefurb**) that estimates the cost of refurbishing buildings and provides decision support for construction managers. This expert system is being implemented using a relatively new paradigm called Case-Based Reasoning (CBR) [Ref]. CBR is a fresh reasoning paradigm for the design of expert systems in domains that may not be appropriate for other reasoning paradigms such as model-based reasoning. It is a new paradigm that is more akin to the human way of solving problems and therefore more close to the way the experts estimates the costs of refurbishing houses. It has consequently been claimed that CBR systems will be easier to design and develop than model-based expert systems [Ref].

To this end, the second section highlights the complexity of the building refurbishment domain and the way the expert in this domain solve the problem of estimating the cost. The third section presents the design of the expert system (CBRefurb) which estimates the cost of building refurbishment and provides advice and support in decision making for the choice of redevelopment and refurbishment options. The conclusion is devoted to ask if CBR does really addresses the problems met by model-based expert systems.

2. Refurbishment and Cost Estimation

Refurbishment is work carried out on existing buildings in the attempt to improve and to update them to modern standards whilst retaining their current use. An investigation amongst the North West councils and contractors has shown that :

- this domain is characterised by nuances, variations, exceptions and large number of interrelated factors that have an impact on the work costs, and
- the approach used by experts to estimate refurbishment work relies heavily on previous similar work.

In new build work costs depend on quality, size and time, and cost planning allows the clients to optimise the price in these explicit terms. However, in refurbishment work these terms are supplemented by many other features, or even outweighed, by major secondary features which have an impact on the price. Even the emergence of a single dominant secondary objective, such as the safety of the structure, may have consequences which cut across normal procedures, particularly those for efficient construction methods or financial control [3,4]. Moreover, if the factors can be identified their impact on the cost of most refurbishment factors can neither be rigorously assessed. Indeed, there are hundreds of factors whose impact on the price is unpredictable e.g. the age and the situation of the building, the client requirements, the security of the building. Other problems may occur, unknown features of, or defects in, the existing building can arise at any stage of the refurbishment work adding to the cost. This high level of uncertainty has been highlighted in one instance where we found an organisation that would actually refurbish one property from a scheme to derive an estimate of the cost for the entire scheme.

Knowing the uncertainties that characterise refurbishment, it is very difficult to undertake the project on the basis of lump sum competitive tenders for the whole of the works. Also, such uncertainties do not allow the application of the elemental cost method as in new build. Instead the cost will depend on the state of the individual building in relation to what is proposed to be done with it. From this remarks, other more collaborative methods of estimating the price should be envisaged [4]. The estimator in this domain will require more skills and further knowledge to those used for new work [3]. He should have a good understanding of building practice and construction techniques used in the past, to be familiar with the most economic ways of marrying present methods and new materials with those existing. The ability to find alternative for materials which do not exist and adapting them to new situation depending on the aim of the client. These requirement that bases on past and present methods, and taking care of uncertainty can be tackled only by the use of a new technology that covers success and failure from past experience and adapt it to present situations. Such requirements can be satisfied theoretically by the CBR paradigm contrary to a static model that can not continually move and cover past and present experiences. This claim is supported by most quantity estimator who confirm that the result of using previous similar cases in the estimation is more accurate and close to the reality than using any other techniques.

3. The Case-Based Expert System (CBRefurb)

> *A case-based reasoner solves new problems by adapting solutions that were used to solve old problems* [Riesbeck & Schank, 89].

The processes involved in CBR can be represented as a cyclical process comprising *the four REs[Aamodt &Plaza 94]*:

1. RETRIEVE the most similar case(s);
2. REUSE the case(s) to attempt to solve the problem;
3. REVISE the proposed solution if necessary, and
4. RETAIN the new solution as a part of a new case.

A new problem is matched against cases in the case base and one or more similar cases are *retrieved*. A solution suggested by the matching cases is then *reused* and tested for success. Unless the retrieved case is a close match the solution will probably have to be *revised* (or adapted) producing a new case that can be *retained*.

CBRefurb system follows this cyclical process to estimate the refurbishment costs and to support the managers in their decisions. To translate the way the expert estimate the costs, the design of this expert system requires:

- a case representation that encapsulate building accurate description as well as details of each to be repaired,
- an flexible indexing scheme to fit the continual changes in the importance of the factors that have impact on the cost that should be used to classify cases for efficient retrieval of similar cases,
- a multiple cases and multiple features retrieval to respond to the fact that cost estimation may need different pieces of previous work.
- an adaptation or revising process that imitate the domain expert way of adapting old cases mixing computation techniques, rules and previous experiences.

3.1 Case Representation

A case is a contextual piece of knowledge representing an experience. It contains the past lesson that is the content of the case and the context in which the lesson can be used [Alterman, 89, David, 91; Kolodner, 93]. Typically a case comprises:

- the *problem* that describes the state of the world when the case occurred,
- the *solution* which states the derived solution to that problem, and/or
- the *outcome* which describe the state of the world after the case occurred

In the refurbishment case the factors that have an impact on the costs will constitute the problem part of the case. The problem component comprises the following information:

- the *building specification features* which describe the age, the items to be repaired, the occupancy, the site access and the quality of refurbishment work required,
- the *decision support factors* that describe the arguments that lead to the decision to refurbish,
- the *external features* which reflect the state of the market, technological innovations of new and cheaper materials, the bidding season and the personal experience of the estimator, and
- the *item specific features* which describe the type, size, the current state, the type of repair required and the quality of materials used for this repair for each item that have been broken down in the specification document.

However, the case *solution* and *outcome* components contain information on the real costs of the repair work, the lessons that can be learned from the decision to go for refurbishment and advice on the work itself.

Due to the large amount of information in such a case, most estimators break down a project into items or components of independent small work, such as the foundation, the roof, the external walls, windows, doors and services. Then the cost of each item is estimated using prices from previous similar work. As a result, each case in the CBRefurb system is composed of two main parts (Fig. 1). A flat representation for the generalised features of the building. This include the building specification features e.g., the type of building, and the items involved in the work and the real cost of the work, the external factors e.g. the state of the market and finally the factors used for decision support purpose. A hierarchical representation for the specific features of each item of the building and the parameters involved in the previous decision for refurbishing or rebuilding the item. Hence, each item is represented as a sub-case. This hierarchical organisation is achieved using the case field of ReMind's case representation, thus creating a case-base for each item.

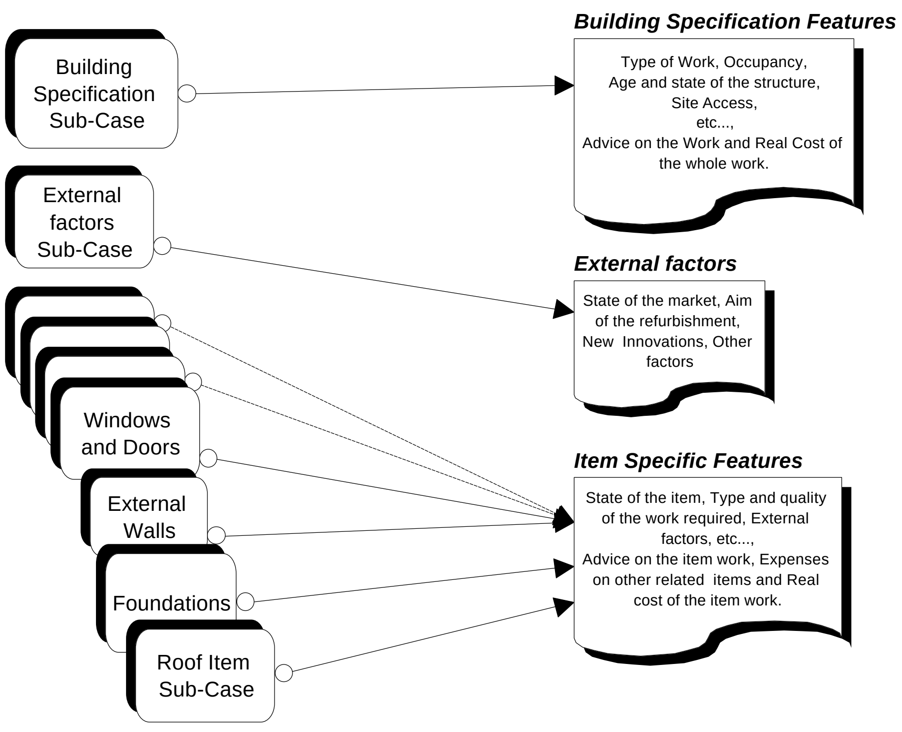

Figure 1: CBRefurb Case Representation.

3.2 Case Indexing

Case indexing involves assigning indices to cases to facilitate their retrieval. In the same line of the structure used to represent the refurbishment case, two levels of indexing schemes have been provided on the top of this case. The top level consists of the building specification, external factors and the general knowledge of the domain. This top indexing is associated to the case as a whole and is represented by a ReMind inductive decision tree and rules implemented using ReMind C library. It is also used to classify similar cases into sets of *Context-Cases* that share similar knowledge. The bottom level consists of the item specific features, external factors and specific knowledge of the item. It is associated to each sub-case and is represented by rules and additional mechanism that enable weights to be associated with each feature of the item. In addition a mechanism has been implemented to improve the flexibility of the indexing schemes. This mechanism allows changes to the importance of the features and the rules and thus changes to the classification of cases as the knowledge evolves in the domain of building refurbishment and redevelopment.

3.3 Case Retrieval

The strategy of retrieving a single *best* or *most similar* case as the basis for a solution will not be appropriate for the refurbishment domain due to the fact that the cost estimation of a new building may involve pieces of several old cases. Therefore a strategy of multiple features and multiple case retrieval is used (Fig. 2). First context-cases are retrieved using the general knowledge of the domain represented by the inductive decision tree. Then follows further selection among the context-cases based on the specific knowledge of each item and the performance of the nearest neighbour techniques that uses the weight provided for the items specific feature. In the event no sub-cases match, a mechanism was implemented for backtracking up the hierarchy to return to previous selected context-cases or its nearest class of cases and perform search for cases that match the remaining unmatched features.

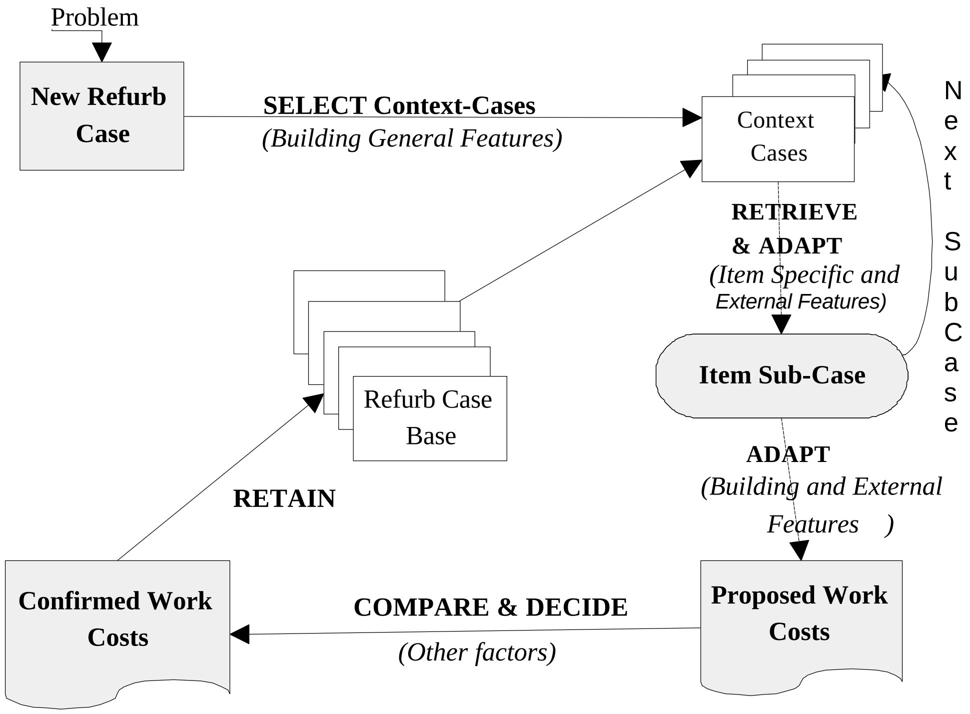

Fig. 2: CBRefurb Reasoning Process.

3.4 Case Adaptation

It is rare to find a *perfect* previous case that matches *exactly* the new case. For this reason a case adaptation process will be implemented using a combination of procedural programming, rule-based and CBR techniques. In this system, the adaptation process starts at the level of the item sub-cases. If the item is similar then readjustment of the price can be performed (Fig. 2). However if no similar sub-cases exist, a computation technique that implement one of the new building cost estimation techniques such as cost functional unit, square meter method, approximate quantity or a source of reference will be used [8]. The outcome from this sub-cases adaptation process will be not only the estimated costs of the item but also any strategic advice related to the work on the item. The same process will be performed for each item sub-case and extended to the whole case.

4. Case-Based Decision support

The decisions on redevelopment or refurbishment as competing alternatives are largely a matter of assessing the comparative costs of the two options, and placing the costs in relation to current and future market potential in rental income. Decision on redevelopment or refurbishment depends on several economical and social aspect of the region where redevelop/refurbish will take place, the aim of the construction or refurbishment and the type of the building. Some cost-benefits analysis methods that help in taking such decision are presented in [2]. In the housing domain where major investigation has taken place, several advantages of refurbishment have been advanced by managers. For example, avoids the Plot ratio control Act that increase the area of new houses thus reduces the number of houses. This will have negative effect on the demands and the rent entry of the council. There are also architecture advantage like for example historical buildings, social advantages by avoiding breaking up community spirit. Reducing costs by avoiding housing infrastructure, like roads, gas, electricity, water supply and telephone lines. There is also the risk of taking a decision of refurbishing a building while previous similar cases have failure. Most of the mangers recognise the importance of this decision and welcome tools in that direction.

To support the decision maker on whether to go for a redevelopment or refurbishment, **CBRefurb** will be enhanced with a comparative process over refurbishing or redeveloping the same building. This can be done based on several parameters such as the cost, rental investment and maintenance of the building, using new building cost estimation expert systems such as Elsie, LC-Plan and LC-Budget developed in the department [1,9,10].The process of advising on refurbishment or redevelopment depends on the level where the decision will be taken i.e. at the building level or at the building item level . This can be specified at the beginning of the process. First the building cost estimation expert systems Elsie, LC-Plan and LC-Budget estimate the cost of the building or one of its items that have has to be redeveloped or reconstructed. The cost estimation of new build will be taken as an input features for the case-based support system which will follow the same process as for the building refurbishment cost estimation process. For this it uses the appropriate scheme of indexing already mentioned above to retrieve and adapt similar cases and sub-cases involved in previous decisions. The result of this first step will be the cost of refurbishing the item or the building accompanied with advice and previous decision on similar situation. Both advice and results can be compared on several parameters such as the cost, rental investment and maintenance of the building for the manager to take final decision.

5. Conclusion

This paper emphasises on the complexity and the uncertainty that characterise the building refurbishment domain where the problem of cost estimation is difficult to solve using model-based reasoning. This claim is consolidate by the fact that experts in this domain use previous refurbishment work to estimate new work. Moreover, they claim that such a method gives more close estimation to the reality than other estimation techniques. This fact consolidates the aim of CBR paradigm as a psychological theory of human cognition and one that provides a cognitive model of how people solve problems [6]. These findings are translated into the design of CBRefurb.

CBRefurb case is represented into hierarchical structure to allow efficient management of the enormous number of features that have an impact on the cost estimation and to reflect the fact that the building work breaking down into independent small work. This approach of representing cases is useful for several reasons:

- it avoids large case representation with hundreds of features which, may have a negative effect on the retrieval process,
- it saves space for item fields when the item is not involved in the refurbishment work.
- it preserves the existence of generalised and specific features in each path of the hierarchy and more importantly:
- the cost estimation and decision support can be performed both at building level using the main case base and building item level using sub-cases.

To consolidate the aim of the hierarchical structure of the case, two levels of indexing schemes have been provided. The organisation of each indexing scheme in an inductive tree allow the classification cases into similar cases or context-cases that share most of the knowledge they contain. This classification of cases reduces the scope of the searching process for similar cases and therefore allow efficient retrieval process. These different levels of indexing have been connected to allow backtracking up in the hierarchy to return to previous selected context-cases or even to its nearest class of cases and perform search for cases that match the remaining unmatched features. In addition a mechanism has been provided to allow flexibility and dynamicity of the indexes by allowing the user to change in the importance of the indexes and the rules as the construction domain evolves.

In addition to the efficient retrieval process that follow the hierarchical structure of the refurbishment case and its indexing scheme, it also facilitate the adaptation and the decision support processes. The adaptation will be easily performed at the item level as most estimator do by mixing cost estimation techniques, rules and previous works on similar items. The process of accessing and adapting building items can help managers in their decision on refurbishment and redevelopment at both building and items of the building levels.

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