CBR Based Problem Diagnostics Application as a Decision Support System in the Cultural Heritage Objects Restoration

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Abstract: In the field of Construction Industry (CI), identification of the appropriate activities for the built objects restoration, particularly cultural heritage objects depends highly on the previous experience of the involved workers and companies which is mainly transferred from one to the next generation in the form of tacit knowledge. The increasingly high number of restoration projects imposes a need to support experience-based problem diagnostics and to facilitate identification of the appropriate restoration measures. It appears that Case-Based Reasoning (CBR), as a problem solving approach that uses specific knowledge of previous experiences for solving new problems, in a very similar way to how humans rely on their previous experience, is a very promising approach. A CBR-based problem diagnostics application, proposed here, is intended to support CI workers on the restoration site in problem solving in the specific area of the built stock restoration in a fashion resembling the experienced workers' approach.

Key-Words: Cultural Heritage, Restoration, Problem Diagnostics, CBR, Decision Support System

1 Introduction

Within the field of construction industry (CI), the nature of the building restoration and maintenance work requires mainly small, highly competent and flexible organisations, i.e. specialised Small and Medium Enterprises (SMEs). The practice of "knowledge and business expertise heritage" followed through generations in the traditional SMEs which dominate this area, deals mostly with tacit knowledge, built on work experience, which can and is only passed on from experienced workers to apprentices by working together for longer periods of time. In order to facilitate and support knowledge transferring, a sophisticated ICT system for structuring that tacit knowledge and making it available for later reuse is highly necessary. Such a solution should allow for storing tacit knowledge and encountered problems in a structured form so as it can be later used as a decision support in different built stock restoration projects.

The Case Based Reasoning (CBR) based application proposed here attempts to facilitate and increase efficiency in diagnosing and solving the complex restoration problems by less experienced people or restoration workers lacking expertise in specific restoration areas. The idea is to make available problem diagnosis and corresponding problem solution, based on a tacit knowledge collected by the generations of restoration specialists. As shown in the next sections, the Case-Based Reasoning approach is well-suited for such an application.

CBR is an approach to problem solving that, unlike other AI techniques, uses the specific knowledge of previous experiences in order to solve new problems, or *cases* as problem situations are known in CBR applications [1].

The CBR technique is intuitive because it is similar to the way humans attack new problems they're confronted with: by making analogies between the new problem and previously encountered problems. When presented with a new problem, a system using the CBR paradigm, like humans, will search through its database of stored problems for similar cases, which can be then reused for solving the problem at hand. Usually the CBR applications are implemented as interactive tools, applied as decision support systems, allowing for the final decision of a human. The cycle of work for a CBR-based application can generally be represented in a more formal way as follows [1]:

– **Retrieve** the most similar case or cases from the repository of cases
– **Reuse** the information and knowledge in that case, to a possible extent, to solve the problem
– **Revise** the proposed solution
– **Retain** the parts of this experience likely to be useful for future problem solving

After successfully solving a problem, the case describing it is stored in the database and kept for future use (or, in some cases, it might make sense to also remember that an approach was not successful for solving a particular type of problem). A useful advantage of CBR-based systems [3] is the fact that learning does not involve generalization of the problem to be "learned", or stored in the database; in any case, a certain structuring of knowledge is necessary in order to extract the relevant features of a case and make it reusable for the future. This leads to good results in domains where there is no strongly defined domain theory and where the methods based on modelling the domain have lower efficiency. This flexibility translates also in the ability of CBR-based systems to work with exceptions to the usual problems, which can happen in the built stock restoration projects.

1.1 Related Research

Usage of CBR in the CI has been investigated in several applications. However, supporting the problem-solving process by use of the CBR approach is very rarely mentioned in CI applications. A CBR-based application for building defects diagnosing is presented in [2] and [13]. The way of defining the current problem is different than the one proposed in this paper. The difference in the two approaches lies in the target audience; in this paper, it is conjectured that such a CBR-based approach is most useful to workers who don't have enough experience of their own. For such workers, the questions used to describe the problem in [2] might be too daunting.

In [4] the use of analytical hierarchy process for weighting of features in a CBR application used in estimating pavement maintenance costs is investigated. In [8] the way CBR can be used for the process of contractor prequalification is presented, and in [5] the probabilities of winning for bid prices are evaluated applying a CBR approach. In [6] is described the application of the CBR-based approach to the problem of selecting risk management techniques in CI.

The decision support tool described in [10] is intended for construction companies as an aid in international market entry decision. Reasoning based approach for decision support system in car recycling domain is described in [7].

Another CBR-based approach has been proposed in [3] with a prototype applied to the aeronautics and space activities, where the user describes a problem in the form of a query; this description is used to find similar problems (or "lessons"), which have been stored previously in the database, and suggest their solutions to the user.

In [9] and [12] are described CBR based decision support systems for problem diagnostics in manufacturing systems, based on the cases composed of the processed signals from different sensors.

In [11], a way is described to extend the so-called "fault dictionaries" (which allow detecting only faults which have been considered beforehand) towards a CBR, in order to detect new faults in electronic circuits.

1.2 Proposed Approach

The problems commonly encountered by SMEs specializing in building maintenance and restoration can be rather complex even for highly specialised workers, such as e.g. restoration of the building declared as cultural heritage object, for which a detailed building materials list is not available, the building period is not precisely identified and the history of previous restorations and/or any other constructive changes is not fully known. Even apparently rather ordinary problems, such as excessive walls humidity without obvious cause, can be sometimes hard to diagnose.

In addition to the decision support regarding the problem causes – problem diagnosing – further benefit of applying a CBR based decision support system can be the proposal for solving the diagnosed problem, based on the saved previous "cases". Such a solution proposal can include applicable contemporary materials which perfectly substitute the unavailable original one in terms of functional characteristics and appearance.

Typical problems that the SMEs encounter are relatively well-suited for structuring as cases in a CBR-based application. When solving such problems, the expert worker relies heavily on his own previous experience in analysing the situation; furthermore, there is high variation in the factors involved in each new situation (problem), making the domain well suited for a CBR-based approach (as opposed, for instance, to a rule-based approach in a domain where higher-level patterns can be more easily investigated and identified).

The application presented in the next chapters is designed as a CBR-based decision support system that acts as a helper for the human solving the problem. The diagnostics application allows the user to describe the current problem; then, it offers him similar cases, previously stored in the database together with the actions taken in those situations, thus helping the user to identify the likely cause of the found defects/faults in the building and appropriate remedial actions. The application is described in more technical detail in chapter 4, *Implemented Application*.

2 Targeted Problems

As seen above, the problems encountered by the CI SMEs are often characterised by several symptoms which can be perceived by a person directly, for instance by sight, smell or touch. However, the observed symptoms are not always sufficiently descriptive of the real underlying problem, so the situation of the built object in which the symptoms have been identified needs to be defined in a more detailed way. In a number of restoration projects, not limited only to the cultural heritage objects, particular details about e.g the following characteristics need to be gathered:

- **Environmental conditions** applying to the building, such as frost, flooding, pollution
- **Location** of the observed symptom, describing the problematic area (walls, roof, etc.), the impacted element (roof framework, exterior / interior wall, etc.), as well as any specific features of the impacted element.
- **Detailed function** of the impacted space might be of relevance (whether a room is a bedroom or bathroom, for instance), and the floor in the building where the symptom has been located.
- **Materials** involved in the affected elements, as well as details about their surface finish, if applicable.
- **Period** of building

The further detailing of these raw categories is described in more detail in the next chapter.

3 Knowledge Structuring

The structuring of knowledge regarding CI problems has been done in two major steps: first, the raw data has been collected, and then, using an iterative process, appropriate data categories have been established, data was classified into these categories, and feedback from the end-users as well as new raw data have helped refine the chosen categories and their hierarchy.

The raw data describing practical problems encountered by the CI workers has been gathered in an unstructured form. This form reflected the learning and diagnosis processes currently in place and a basic categorisation of the most important entities used by the restoration actors was applied, as follows:

- Building element, such as wall
- Materials, such as stone
- Material blocks size and format, where applicable
- Features of the building elements, where necessary
- Diagnostic analysis, like visual inspection, chemical analysis, drilling, etc.
- Identified condition

A list of the most relevant symptoms, together with the diagnosis method used to establish them, was also provided. This is material provided by end-users, lacking the necessary structure for modelling the problems. It provides insight, however, into the way of working of the SME employees. Fig.1 below shows part of the raw information gathered from the SMEs.

This granularity was, however, not fine enough for applying a structured approach in order to determine a degree of similarity between two problems. This is why the raw data gathered had to be analysed in order to find new entities, as well as the relations between the various types of entities. Furthermore, categories and entities of knowledge which were used intuitively by the employees were not present in the original categorisation.

The refining process led to a more detailed hierarchy of entities describing a problem, as follows:

- **Condition/appearance** which is perceived directly, like mould, cracks, draught, etc.
- **General impacted element/area:** the generic type of building element involved, such as wall or roof.
- **Particular impacted element** further details the type of element involved, for instance interior wall or roof framework.
- **Features:** if applicable/necessary some specific features of the impacted element can be documented; for example, a wall that is monolithic, or a gable roof.

General Impacted Element	Observed problem	Diagnosis
Church Wall	mould stains	visual inspection
	mould in corners	drill-core

Fig.1 Portion of raw data delivered by SMEs

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Condition / appearance (specific features, damage, infestation)	Problematic element/ area	Impacted element (Affected element)	Features	Location	Material	Surface finish	Surface finish type	Year of construction/ completion of the element
Humidity	Wall related	Exterior wall seen from outside	Exposed masonry	Other	Stone	None	None	Around 1750
Cracks		Exterior wall seen from inside	Monolithic wall construction		Brick	Paint	Dispersion paint	After 1870

Fig.2 Partial example of the structured knowledge

- **Location:** this refers to the location within the building (e.g., cellar), which can be relevant in some cases (for humidity, for example).
- **Material:** this describes which material the impacted element is made of. For a wall, this could be e.g. stone, brick, or cellular concrete.
- **Surface finish:** for materials which can have a surface finish; potential surface finishes are, for instance, plaster or paint.
- **Surface finish type:** for further detailing the kind of surface finish used, if applicable, e.g. dispersive paint.
- **Year of construction/completion of the element:** relevant because, even though the building itself might have been finished in a certain year, an element could have been added / modified later. Knowing the age of an element can help identify whether certain harmful materials might have been used in its composition.
- **Format:** for materials which conform to certain formats, for instance dimensions of bricks.
- **Environmental (local) conditions / influences:** in this category, influences such as vibrations (from nearby roads) or temporary conditions such as flooding are included.
- **Diagnostics method and result:** describe actions taken to investigate the problem and what has been observed; for instance, by performing a borescope inspection, ascending humidity can be observed. Multiple pairs of diagnostics methods and observed results can be attached to a problem.
- **Proposed Actions:** describe the actions which have been taken when this particular problem was encountered.

After restructuring the raw data structure, further knowledge was collected. Fig.2 shows part of the table containing restructured data.

The marked entries, when taken together, show how an example problem was reduced to its components.

4 Implemented Application

As shortly mentioned in the section 1.2, the implemented application is following a CBR-based approach to find similar problems and helping thus the CI worker with solving of a new problem.

The user describes the problem by selecting appropriate values for the categories making up the problem's description, as described in the chapter 3, *Knowledge Structuring*. In the following, this process is illustrated by way of showing some steps in the process of defining a sample problem, by selecting the appropriate values in the application.

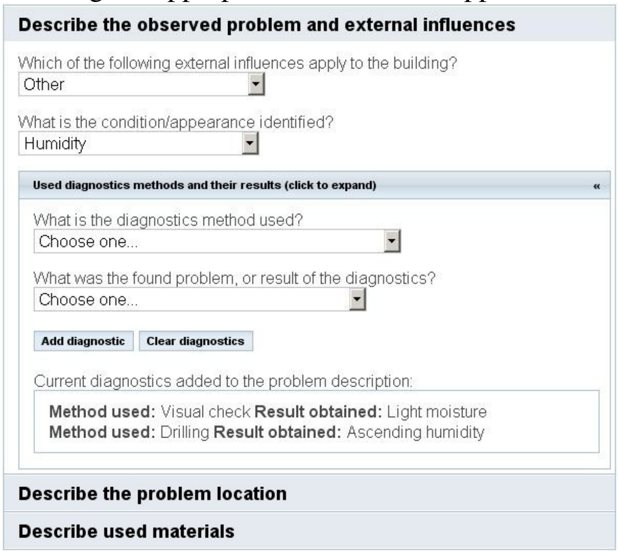

Fig.3 Describing the observed problem

As can be seen in Fig 3, first the actually observed problem, as well as any external influences, are described; furthermore, the diagnostics methods used are documented. Multiple diagnostics methods and obtained results can be associated with the problem.

Next data set (not illustrated) details the location of the observed problem in terms of general area, specific impacted element, and location within the building. Thirdly, details regarding the material that the impacted element is made of are to be given. These details can be seen in Fig.4.

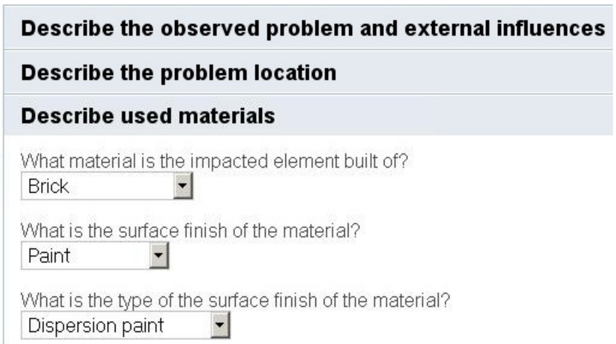

Fig.4 Describing the material used

After the problem has been described, a list of similar problems can be seen; this is a list of previously solved and stored problems, ordered decreasingly by the similarity to the problem described by the user. Fig. 5 shows two results from such a result list, having similarities 66.67% and, respectively, 55.56% with the problem described by the user; the more similar problem has been expanded in Fig. 5 in order to see its details. The proposed solution (re-insulating the interior of the wall with mineral foam sheet) can be used as guideline or starting point for solving the current problem.

The similarity is computed by weighing every attribute with the same weight; so the final similarity is a measure of how many similar attributes the two problems have in common. Chapter 5 presents as further improvement two ways in which the weights could be modified by the user.

It appears that the amount of data inserted into the tool, as can be expected, significantly impacts the reliability of the problem diagnosis. This makes sense given the non-uniform type of problems stored in the database. Future improvement of the current approach foresees a better structuring of the problems by identifying general, “prototype” problems; this would lead to more appropriate structure in the description of various problem types.

The currently obtained results, however, have proven satisfactory; the granularity of the defined problems allowed for the recall, with high similarities, of previous problems which provided for the most part useful knowledge and directions for solving the current problem.

The application is implemented using the Java-based web application framework JBoss SEAM (http://www.seamframework.org/), v.2 and is deployed for testing on the JBoss Application Server (http://www.jboss.org/jbossas/) v.4.2.3. The CBR framework used is jColibri (http://gaia.fdi.ucm.es/projects/jcolibri/), and for the database management system MySQL (http://www.mysql.com/) was used.

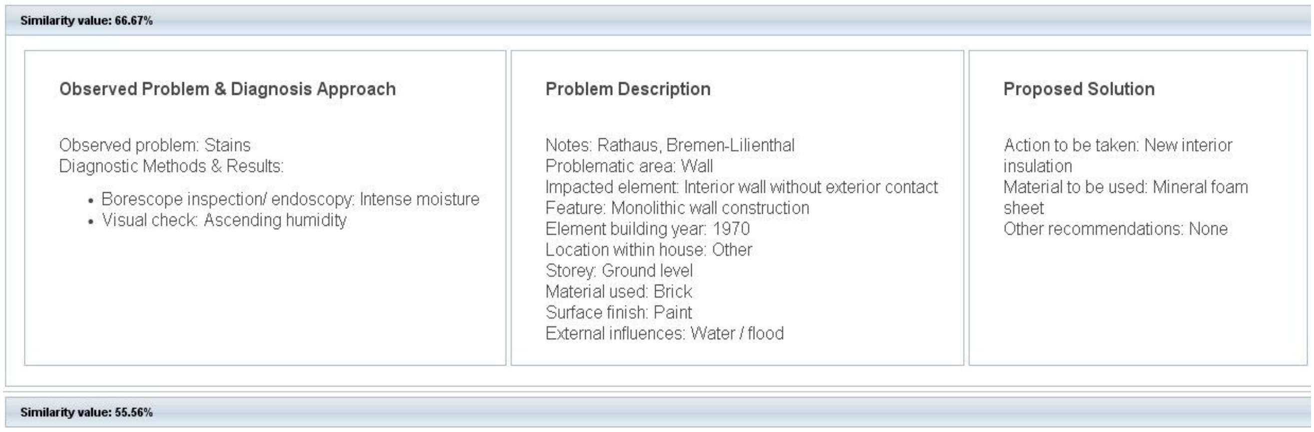

Fig.5 Part of similarity search results

5 Conclusions and Further Developments

The solution presented and results obtained in its current testing provide a good basis for identification of the correct problem causes, i.e. are allowing for a more efficient identification of the problem and appropriate restoration actions. It was justified that one of the most important benefits is in enabling a quick access, on a construction site, to problems which have been solved previously.

As known, the reliability of the diagnosis in CBR is directly proportional to the number of previous problems stored in the case base and therefore one of the future directions considered for extending and improving the current approach is the investigation of the usage of so-called prototype cases, which, as described in [2], express generalisation over a set of

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related cases. Using groups of similar problems might be a related area of improvement.

Furthermore, the weights allocated to the case components on which the similarities are computed could be adapted to previously stored weight profiles, which are defined in advance by experienced workers; profiles oriented to the cultural heritage aspects should assign larger weights to the building elements associated with the original building period while e.g. energy-efficient restoration could award larger weights to elements involved in energy efficiency (window and roof insulation, for instance). An additional option for more experienced users could be the manual adapting of weights for each attribute, in order to learn how each attribute influences the search results.

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