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# A building elements selection system for architects

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**Abstract**

This paper explains the development stages of an expert system BES for the evaluation and selection of the building elements. The work covers all kinds of building elements that are available in building construction including retaining walls, foundations, external walls, internal walls, floors, external stairs, internal stairs, roofs, external chimneys, internal chimneys, windows, and external doors and internal doors. The selection is based on the importance of performance requirements of the building elements and their expected performances. The selection is achieved by SMART Methodology, and the expert system shell "Exsys Corvid" is used to construct the expert system. Use of computer and Internet with its advantages in handling vast amount of data makes the system widely applicable and a useful design aid for architects. The decision-making feature of the system provides a suitable selection among numerous alternatives. The paper explains the experience gained through the use of this method and discusses further development of the system.


*Keywords:* Building elements; Performance requirements; Exsys corvid; Architectural design; Design aid; Smart methodology and expert systems

## 1. Introduction

The selection of building elements correctly among a vast number of alternatives is an important problem in architecture. Selection of building elements depends on different factors. Wrong building element selection causes serious problems concerned with economy, construction functionality and appearance, which will not be easy to correct. This paper deals with an expert system proposed for this purpose. The architecture of the building element selection system is shown in Fig. 1.

As already known, expert systems are computer programs which are composed of knowledge about one special field and are used for solving the problems as human experts can solve. In expert systems there are a number of advantages. Firstly, expertise of human is perishable because human may change jobs, become ill or even die. However, computer expertise is permanent. Secondly, human expertise is difficult to transfer. Expert systems can be shared in many places at the same time. Finally, human expertise is very expensive, the salary of an expert person is more than the cost of personal computer and the related software. Expert systems are therefore much more affordable. There are some disadvantages of expert systems compared to human beings. Firstly, human is creative and inspired; however, computers are uninspired. Secondly, human is flexible and easily adapts to other domain knowledge; however, computers are not very flexible. Thirdly, humans possess common sense, however, expert systems cannot apply knowledge to a problem beyond their domain, because expert systems have got a rather narrow focus about a particular problem. Fourthly, human learning is more advanced than the expert system learning [1,2].

Expert system building tools, called "shells", allow users to develop an expert system in an easy way. The "shells" are also expert systems that have been emptied of their rules so that the knowledge engineer concentrates on entering the knowledge base without having to build everything, including the inference engine and user interface. It is very easy for non-programming experts to be familiar with them. The shells are also not flexible. Therefore it is not easy to change or modify the way they work. In the literature there are a number of expert system shells in the market [1]. Any expert systems developed with EXSYS asks questions to the system designer about the subject or domain. The designer

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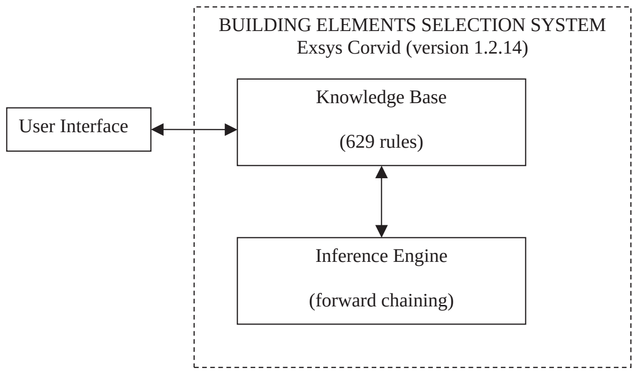



Fig. 1. Architecture of the building elements selection system.

responds by selecting a single answer or multi-answers from a list. The program will ask questions till the conclusion. Conclusion is sometimes the selection of a single solution or a list of possible group of solutions arranged in the order requested by designer. The program on request, can explain how it arrives at its conclusion [3,4].

There are also some expert systems for selection making. Rivard et al. [5] proposed a shared conceptual model for the building envelope design process in order to provide communication between the different members of building design team. The wealth of data in this area are organized into major envelope entities, which are then decomposed into cohesive sets of data called "primitives" to form the conceptual model. This study focuses on modeling the user requirements and does not address the modeling of the building envelope design. In addition, the grades of the building elements in terms of performance specifications are collected from the expert people by a survey. SMART methodology is used for this selection [6–8].

Mohan had made a review of expert systems in building construction area at its infancy [9]. After this review many more expert systems were introduced. It is worthwhile to mention the most important ones.

Altunay [10] proposed a model for the selection of internal finishes. This model handles floor covering materials made of wood, stone, ceramic, metal, concrete, plastic, carpet, partition walls, plastering and painting materials. The factors that are taken into consideration are: strength and durability, maintenance, ergonomic, health and safety, acoustic, fire resistance and aesthetics. In order to evaluate the importance of the factors Paired Comparision Scoring Matrix Method was used. The functional spaces included in this model are bathroom, kitchen, laundry, entrance, bedroom, living room, corridor and lobby. The user of the system establishes the weight of importance for each factor. Then the system integrates this input with knowledge and proposes some material alternatives with the highest score.

Mahmoud and Al-Hammad [11] proposed another model for the 'evaluation and selection of floor finishing materials'. In this model there are three filters. The first filter narrows down the material options considered for evaluation and selection. Second filter has two parts. The first part determines the performance requirement criteria weights via paired comparison scoring matrix methodology. In the second part, the determined performance requirements criteria weights for each of building's functional space will then be used in evaluation matrix. The third filter is about the cost analysis of the selected materials. In this stage the selected materials from the previous filter are examined and ranked according to their costs. As a result, the one with the lowest cost is recommended.

Cheung, Kuen and Skitmore proposed a model for the selection of architectural consultants [12]. The model is based on multi-criteria evaluation model.

In summary, none of the existing methods for building element selection cover all the building elements. The selection criteria used are not complete. None of the existing methods tackled the problem of performance requirements since they are different for each building element.

## 2. The proposed system

The expert system proposed in this article is called Building Elements Selection System (BES). It is a design aid for architects in selecting building elements during the early stages of design process. Any wrong decision without an expertise knowledge at this stage cannot be corrected at the later stages in an architectural design. The professional architects and the students of architecture will be able to benefit from this design aid. This separation is necessary because both types of designers have different levels of knowledge about building elements and their performances. The system will aid in international building construction arena and will also be available via the internet.

The method for the selection of building elements consists of the performance requirements of building elements, knowledge acquisition and knowledge representation. The architects who will use BES will be asked to input important weights for the performance requirements. Simple Multi-Attribute Rating Technique (SMART) is used for changing the weights of importance of the performance requirements, to the normalized weights. It will also help in selecting the best alternatives. Edward developed Smart Methodology in 1971 as a basic method for assisting the decision-makers by simplifying complex decisions through a series of stages [6]. In this method, even if there are two competitors at minimum, with equal weights of importance, the selection can be made. However, there is another selection method called Analytic Hierarchy Process or Paired Comparison Method. As its name implies, this method cannot give any result between two equal weighted competitors. It works for a pair to select the one with greater priority. Smart is preferred to BES because of this attribute.

Exsys Corvid version 1.2.14 was chosen as an expert system shell for BES because it can be used via Internet as well.


Fig. 2. List for “external walls”.

Exsys Corvid supports “jpg” files that are useful for providing users with the building construction details and information about selected sub-building elements. Exsys Corvid delivers knowledge not just as information, it also delivers advice and recommendations. Exsys Corvid has got a very easy user interface that does not require special training in computer science.

There are six different user interfaces in BES. The default values in these user interfaces can be accepted by the inexperienced architects and the students of architecture. However, they can be changed by experienced architects due to their preferences and experience. Therefore, all of these interfaces are same for the experienced and inexperienced architects. The first user interface is a welcoming menu. The second user interface is for the selection of main building elements out of nine different types. The third user interface is for the selection of sub-building elements (Fig. 2). This user interface has nine menus. The fourth user interface is for listing the performance requirements of each main building element (Fig. 3). There are different lists of performance requirements for each building element types. For example, if designer selects “wall” and then external wall from second user interface, the alternative external wall types will be seen in the third user interface and the performance requirement lists will be seen in the fourth user interface. The expert system will rank the performance requirements in terms of importance according to the preferences of the designer. For this purpose, the designer will be asked to give a grade to each performance requirements out of hundred. Since every performance requirement gets a separate importance grade, these grades should have a normalized weight. SMART will normalize these weights. The grade given by the designer will be added to each other and total grade for all performance requirements will be found. Later the grade for each performance requirements will be divided by the total grade to get the normalized weight. For example, if the designer attributes 90 to fire resistance, 80 to cost, 95 to strength and stability and zero to the rest of the performance requirements the total grade will be 265. The normalized weight for fire resistance will be $90/265 = 0.33$ and so on. The highest normalized weight will indicate the most important performance requirement of the designer. The total of the normalized weights will always be equal to 1. The zero-graded performance requirements will be eliminated.

The fifth user interface is about the grading of expected performance of the selected sub-building elements. This step gives different chances to professional architects and to students of architecture depending on their knowledge

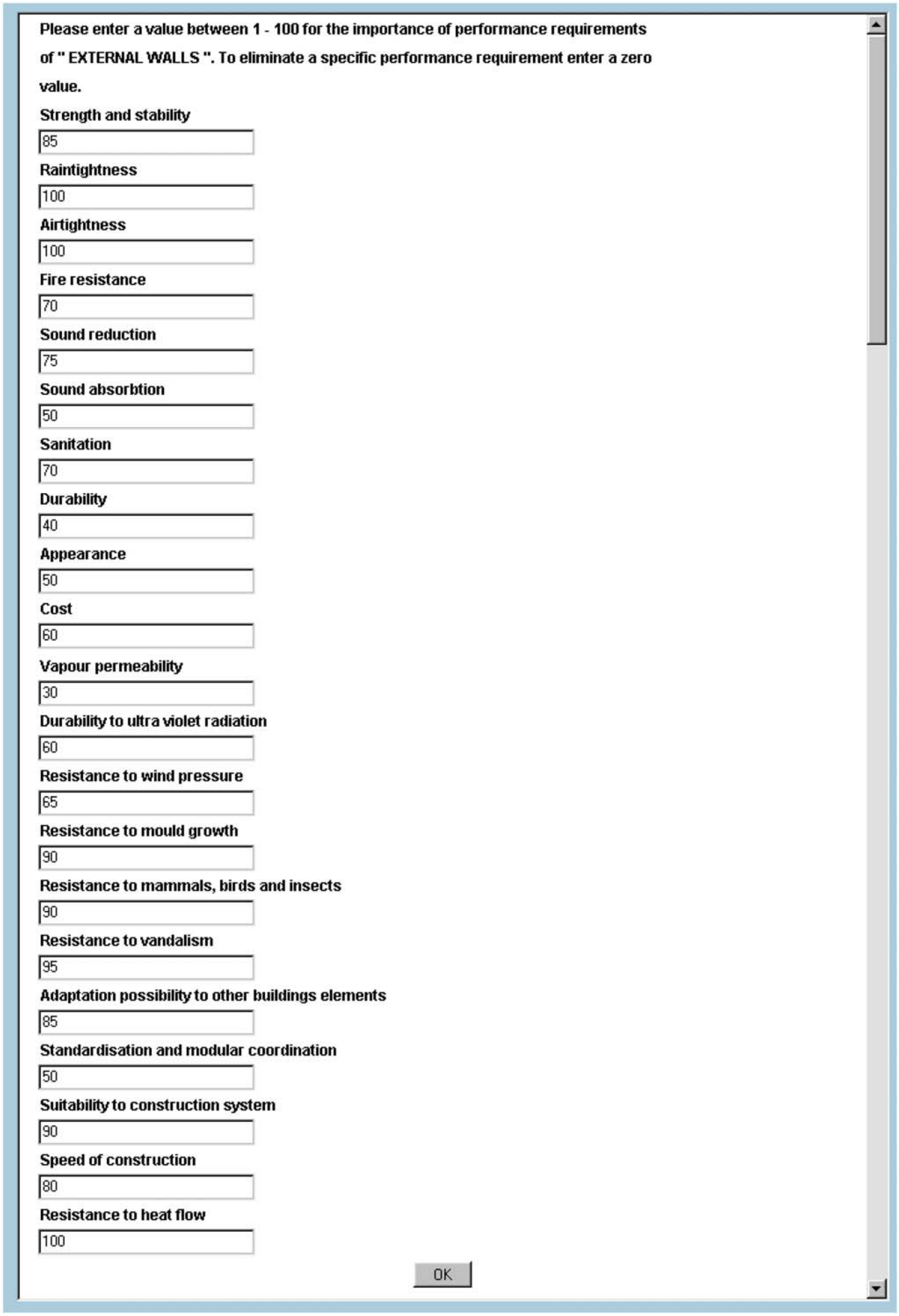
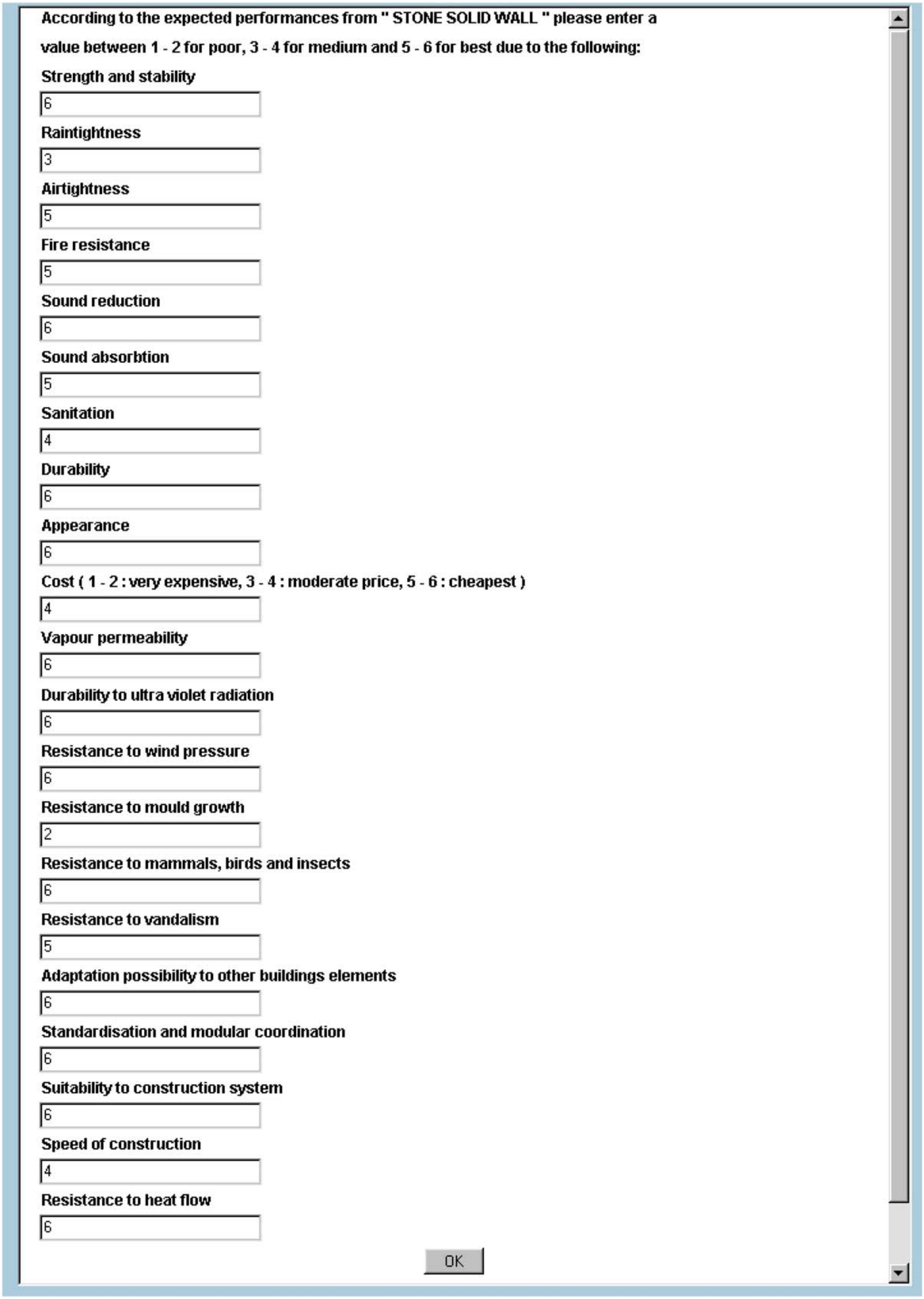



Fig. 3. List for the performance requirements of "external walls" with the edit box for default values.

background. They may accept or change the default values (Fig. 4). These data acquisition categorizes the building elements as poor, medium and best according to the performance expected from them. This knowledge is acquired from the expert people and integrated to the expert system. Structured interview technique is used while acquiring the grades of importance for the performance requirements and grades of expected performance from the sub-building elements from the expert people. For each grade the average grade of all expert people is used. These experts are selected from the universities and from the construction companies in North Cyprus. The expert system will ask questions with an edit box continuously. In the categorisation, poor will be graded as 1 or 2, medium as 3 or 4 and best as 5 or 6. For



According to the expected performances from " STONE SOLID WALL " please enter a value between 1 - 2 for poor, 3 - 4 for medium and 5 - 6 for best due to the following:

Strength and stability

6

Raintightness

3

Airtightness

5

Fire resistance

5

Sound reduction

6

Sound absorbtion

5

Sanitation

4

Durability

6

Appearance

6

Cost ( 1 - 2 : very expensive, 3 - 4 : moderate price, 5 - 6 : cheapest )

4

Vapour permeability

6

Durability to ultra violet radiation

6

Resistance to wind pressure

6

Resistance to mould growth

2

Resistance to mammals, birds and insects

6

Resistance to vandalism

5

Adaptation possibility to other buildings elements

6

Standardisation and modular coordination

6

Suitability to construction system

6

Speed of construction

4

Resistance to heat flow

6

OK

Fig. 4. List for the grading of performances expected from "stone solid wall" with the edit box for default values.

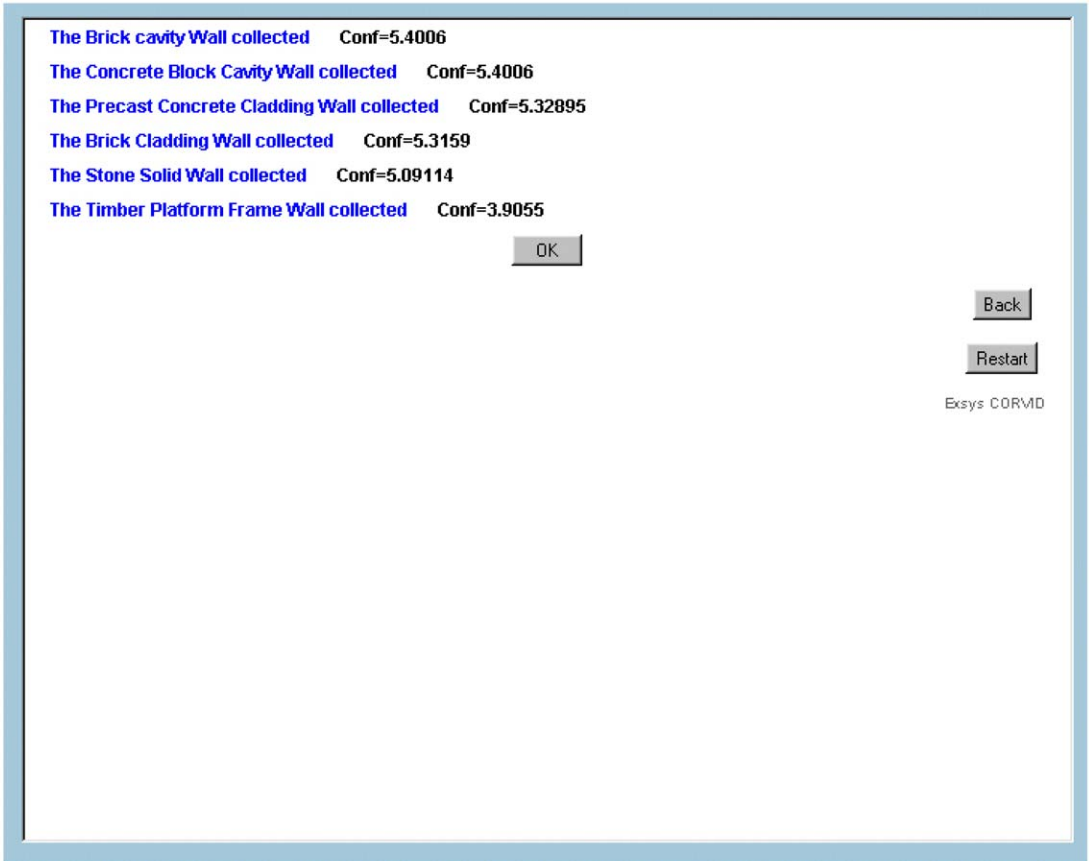



Fig. 5. Results page of building elements selection system for external walls.

example, grading the wall for fire resistance will require the architects to think about the performance of walls as poor, medium or best. The expected performance grading will be multiplied with the normalized performance requirement weights for fire resistance. Each result of the multiplication will be added to establish the final grade. When all external wall types are graded, BES will show the external wall alternatives with the highest grades in descending order.

In the sixth user interface, the expert system will list the grades for the advised building elements so designer can think about them before clicking (Fig. 5). Although, the building element with the highest grade is the most appropriate one, the second or third highest graded alternatives can be considered as well. Clicking on the name of each alternative will bring their drawings and details as "jpg" files (Fig. 6). On every "jpg" file there are three buttons called Performance Specifications, Cost Calculation button and CPI Calculator button. Performance Specifications button allows architects to reach the documentation of building elements. Cost calculation button is used for finding total cost of the building element or building itself. CPI calculator button is used for standardization of the cost of building elements so that they can be compared in different times. For the whole BES, 307 user interfaces are prepared. In Figs. 2–5, only the user interfaces about external wall are shown as an example. The flowchart of BES is given in Fig. 7.

## 3. Discussion

BES offers a list of building element types through a user-friendly interface, which makes it easy for the user to interact with the system. It allows the user to make selections among alternative main building elements and sub-building elements easily by a single or multiple check clicks. Checking will be beneficial for the selection of building elements because the unchecked element types will not be considered by the system any more (Fig. 2).

BES is designed to offer a list of performance requirements for building elements in which the user can modify easily. SMART Methodology is used for normalizing the grades of importance of the performance requirements according to the designer. As a result, the proposed system will yield the selected sub-building elements in a ranked order starting from the best choice. The final selection of building elements by the designer will depend on this rank.

BES is designed to show a list of constructional advices for the building element alternatives. Thus, depending

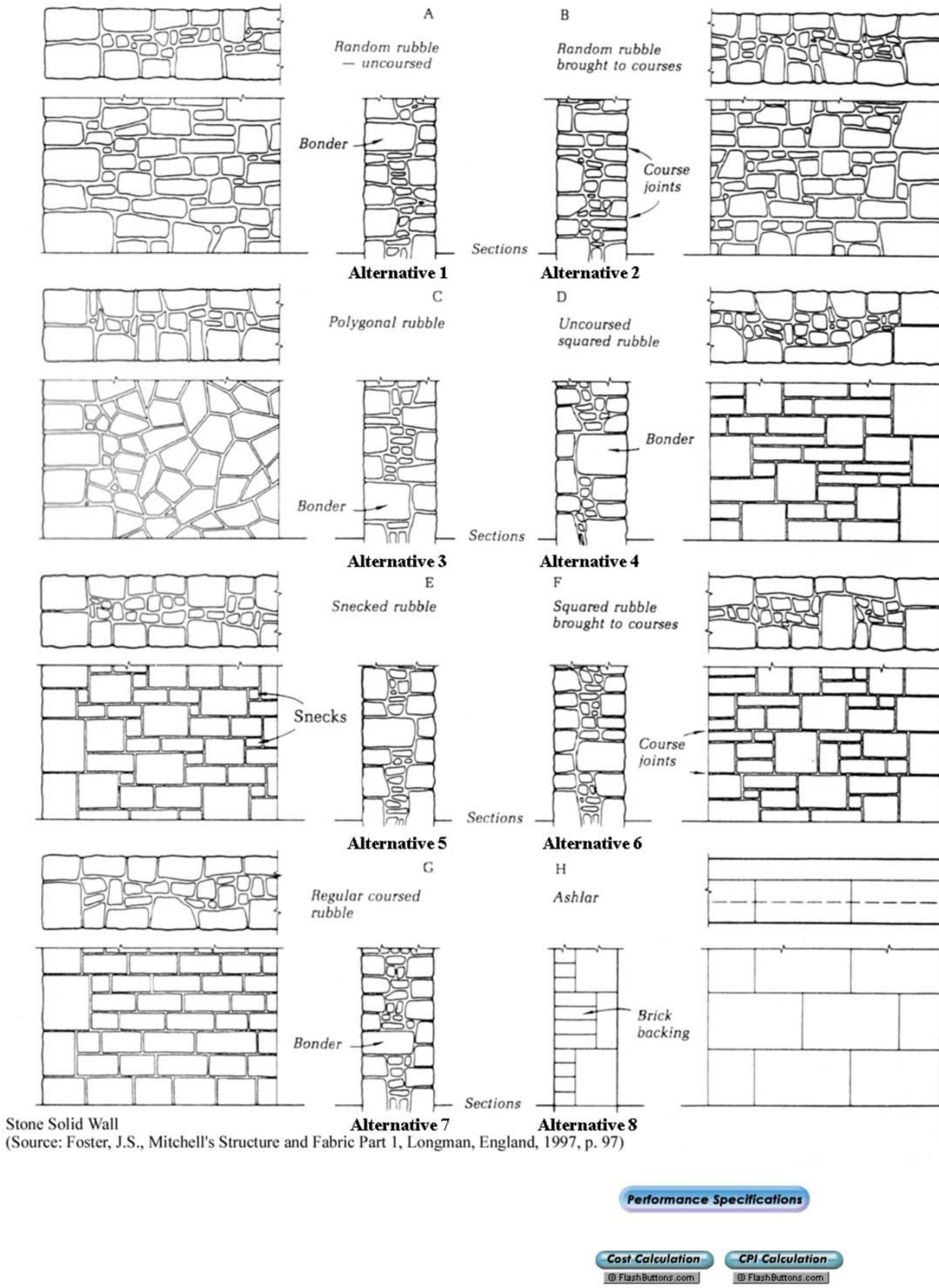



Fig. 6. "jpg" construction detail page for stone solid wall.

on these advices the designer can make the final selection among the most suitable alternatives.

Performance requirements are related to the expectations of the people from buildings. The performance requirements may differ from person to person and none of them can have certainty. Some of the performance requirements can be more important than the others. However, performance specifications deal with information about the underlying requirements. For example, with a broader concept of performance specification, selection of an external wall needs adequate fire resistance, good appearance, strength and stability, vapor permeability, reasonable cost and so on. For a user, appearance may be less important than the cost. Performance specifications for the buildings can describe the

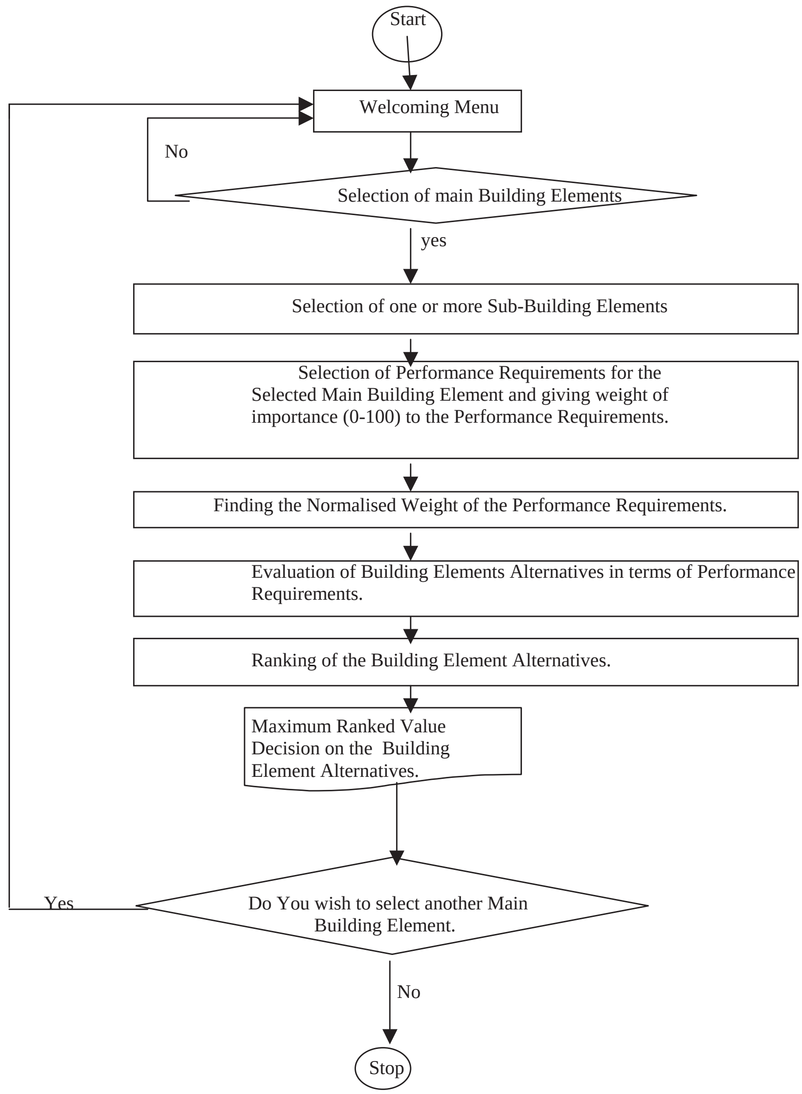



Fig. 7. Flowchart of building elements selection system.

works to be done and standards to be achieved after design has been finished. Performance specification tells us about the sizes, materials of the building element and type of finish to be used and so on. Performance specifications can be in the form of written documents, drawings and instructions.

There are changeable default values for the importance of “performance requirements” and the expected performance of the building elements. The designer may select the default value or an alternative one according to his own expertise.

One of the reasons for selecting the Exsys Corvid shell is its ability to support images. In BES, construction details of the building elements are represented as “jpg” files. These are prepared to be shown at the sixth user interface where the suggested ranked sub-building elements are shown to the architects. The clicking of the sub-building element will lead to the “jpg” files. These figures include information about the building types in which they can be used. Moreover, very detailed analysis about their cost is given on every “jpg” file via “Cost Calculation” button. All the costs were given with February 2002 prices. In order to compare them with the cost of new building elements in future all the prices are standardized with consumer price index (CPI). Consumer Price Index predicts the price changes during a time interval. It considers predicted inflation. The CPI in BES can estimate the future expenses of the building elements. This calculator works for the years between 2002 and 2010 [13,14]. Thus, any cost added in the future can be comparable.

Hardware requirements of BES is a PC with Pentium and Internet Explorer 5 (minimum). BES is designed to use the forward chaining, inference method. There are three types of rules in this system. The first type is for finding normalized weights for the importance of performance requirements. When the normalized weights for performance requirements are found, the user interfaces for every clicked sub-building elements appears. The second type of rule is for multiplication of normalized weights with the expected performance grades of sub-building elements. Third type of rule is about connecting first type of rule with second type of rule in order to give ranked results for a number of best sub-building elements.

BES can always provide the user with a result, unless all the grades of importance for the performance requirements are not entered as zero. The grades of importance for performance requirements are between "0" to "100" because "0" means the elimination of the performance requirements.

In order to develop BES, two different prototypes were prepared and tested. The first prototype was separate for the experienced and inexperienced architects. The critics of the experts were integrated to the system and the second prototype was prepared.

The students and architects who tested BES found the number of questions good and efficient. BES is found to be more attractive for the 4th year and 3rd year students than the 1st and 2nd year students, because 1st and 2nd year students were not aware of the problems of building elements selection. Besides, the 3rd and 4th year students enjoyed BES because of its educational features and showing "jpg" images in detail.

As stated earlier, SMART is preferred in BES for selecting the best ones among the competitive alternatives. In order to make SMART work, designers' preferences should be known. These preferences can be different from person to person. In order to avoid problem, the method was tried on many specialized people and their averages were included in BES as default values. The default values in BES give chance to inexperienced designer in selecting the building components. Any user of BES may accept or change the default values. It is also possible to accept some of the default values and change the others.

BES contains 13 building elements, 308 sub-building elements and 248 performance requirements. There are different performance requirement lists for each building element although some of the performance requirements are common. For example, fire resistance is a common performance requirement for most of the building elements. Every building element has different advice page produced by system. One of these is provided as an example for external walls in Fig. 5.

The experienced designers' grades of importance for the performance requirement were also identical. This shows the consistency of designers about importance that is given to performance requirements. However, the inexperienced designer's grades were too different. This shows the unawareness of the inexperienced designers about the importance given to performance requirements and BES can also be used as an educational tool.

Grading of building elements in terms of performances expected from them was identical for the experienced designers, though, in many cases they commented about the default values. However, inexperienced designers gave different grades. This is a very normal situation because inexperience designers do not know much about the building construction materials and elements. In this manner, the default values are found very useful in BES.

Generally, the professional architects found BES as an experimental invention for building elements selection. The professionals tested their judgements and discovered some different results by changing the default values. Some of them discovered that several sub-building elements could be used safely in building because there was a wrong interpretation in their mind before. Frequently asked questions and general reactions can be stated as follows: (1) Can the client be integrated to BES? (2) When we grade cladding wall, will we grade the main structure of the wall as well? (3) When we grade timber for fire resistance shall we consider natural timber or fire proofed timber? (4) Is it logical to ask rain-tightness for roof in BES? (5) Why structural glass was not included as a building element? The following answers are given to these questions: (1) The architect can show and explain the alternative building element proposals of BES to the client and use the clients' preferences in final decision. (2) When we grade cladding wall we only grade the cladding itself not the main structure of the wall. (3) When grading the building elements, the materials should be considered as in their natural form. (4) All the performance requirements of the building elements were taken from the list of CIB, which is an authoritarian organization in this respect. (5) Any new building element can be added to BES.

## 4. Conclusions

BES is intended both for experienced and inexperienced architects and for all kinds of building types. It can be used during the preliminary design stage when the small mistakes of designers may cause big problems in later stages of the design. It will help the designers in selecting the building elements rationally. It is an ideal design aid for all architects with its simplicity and decision-making.

Normally, in designing the building element selection is made according to some decisions of the designer. These decisions are sometimes correct but sometimes they are totally wrong and do not satisfy the client needs. Precise decision-making needs knowledge, rapid reasoning and accuracy, which is not an easy thing to obtain most of the time.

A survey of existing expert systems was also made. All of them were found to be local works so they are not widely applicable systems like BES. Most of the existing systems can be used with personal computers but BES can be used anywhere in the world via the Internet.

While using BES, the architects and students found it very easy to interact through its simplified user interfaces and the internet. Moreover, the system is defined to be portable because it could be transferred to any personal computer through HTML files that are installed in a CD.

If an architect wishes to include the client's preferences that are related with cost in building element selection, it can easily be done with BES. This may be necessary for taking decisions on the building elements with different costs of sub-building elements. BES is an open-ended expert system. It is possible to change the list of performance requirements, add new building elements.

BES gives the opportunity to the users to rank their sub-building element selections. The benefit of ranking is selecting the sub-building elements according to the most important performance requirements. All of the above advantages of BES and manual selection of building elements with similar reasoning would take 2 weeks while with BES it will take only several minutes. Thus BES can be regarded as an effective tool in selecting the sub-building elements.

Additional work planned for the future is to develop multiple comparable "documentation method for building elements" so that specifications of building elements in terms of thermal resistance, acoustics, fire, moisture, strength, durability, etc. can be achieved easily. This is needed because CIB's master lists for the documentation of building elements aim the manufacturers rather than the architects.

BES can be used as an educational and design tool as well. Building construction education is a very important issue involving building elements selection. Knowledge about constructional aspects of building elements and comparison of building elements in terms of performance requirements and specifications are the main areas for this future research.

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