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ES_HXWall: An Expert System for Maintaining External Walls in Heritage Buildings

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ABSTRACT

Historic assets, as a part of cultural heritage of a country, reflect traditions, knowledge and beliefs of different communities. It adds distinguished meaning to places where we live and provide source of identity. Accordingly, Historic environments need to be conserved and sustained while enabling people to enjoy those assets and make beneficial use from it. However, continuous guidance and support need to be available to assist in sustaining such environments. This paper presents an expert system, named *ES_HXWall*, that can be used as a decision support tool for conserving and maintaining external walls of heritage buildings. The proposed *ES_HXWall* takes the needed criteria in a form of rules coded using CLIPS shell. *ES_HXWall* knowledge is extracted from two main resources; Historic Scotland Inform Guide and domain knowledge of experts who are specialist in historical sites restoration.

Keywords: Expert Systems, Heritage Buildings, Wall Restoration.

INTRODUCTION

One of the fields that is witnessing a great booming and development nowadays is the Artificial Intelligence field. One of the applications of AI is the development of Expert systems. Expert systems are used in order to aid human experts or replace them. Not only does it model human expert knowledge, but also, it simulates their inference. Expert systems were used in many fields as; agricultural, business, manufacturing, and Civil Engineering. The purpose of this paper is to

present a primitive expert system (ES_HXWall) that can be used as a decision support tool for conserving and maintaining external walls of historical buildings.

HERITAGE BUILDING DETERIORATION

The deterioration of heritage building can be divided into three main categories. Those categories are; Mechanical deteriorating, Physic-Chemical deteriorating and Biological deteriorating [1-2]. Each category of them will be described in the following part.

Mechanical Deteriorating

Mechanical deteriorating category consists of four main causes: *1) Wind, 2) Rain and torrents, 3) Earthquakes and lightening and 4) Storm factors and human damage factors.*

1) The wind cause is considered as one of the main factors of deterioration and erosion of all existing materials in historical buildings. The destructive effect increases when it carries sand particles with high hardness level (hardness 7). Wind speed can be evaluated/measured by its ability to carry bigger or heavier particles of sand. It has severe effect on buildings with sand stone or lime stone. The rate of historic building deterioration significantly increases when building materials whether stones or bricks, lose its hardness when it is under stress of high changes of temperature through day and night or across the four different seasons for long time [3-4]. why restoration of historical buildings in desert climates considered being very challenging.

2) Rain and torrents cause affect heritage and historical buildings since they are located in low rainfall regions are more consistent and coherent of grasping rather than buildings located in heavy rainfall regions and humid areas. Heavy continuous rain and special cause severe damage for monuments and historical buildings whether built with stone or bricks. The rain and floods use the disintegration of slurry walls falling, losing patterns and colors. It may also cause movement of foundations and melt or drain the bonding materials of stone blocks and granules dissolve salts and carry them to different places of the walls. after drying its solutions, it leads to flake stone blocks and fragmentation of surfaces and the downfall of inscriptions, decorations and cap badges [3,5]. Besides, floods cause great damage to the old buildings when soaked for too long. And finally, soil movements may happen in some mountainous areas when soil is soaked with water which may cause unstoppable sliding for buildings.

3) Earthquakes and lightening are one of the most serious mechanical damage factors, as they affect buildings with severe damage, and many cities become ruins. Earthquakes may be so severe that they can destroy the building completely. Sometimes it only leads to the fall of the upper parts, such as domes, minarets and balconies. It is noticeable that the impact of earthquakes on stone buildings overweighs the impact on brick buildings in many stages. As for the lightning, it causes damage to the side that has been directly hit. Sometimes, it makes Fires breakout in flammable parts. It is fixed that buildings in the high mountains and heights are most affected by lightning.

4) Human damage cause is considered one of the major reasons behind heritage deterioration that includes man made fire, wars, demolition and sabotage, and faulty repairs [6]. These factors are explained as follows:
   - Fire; causes serious damage to various types of construction materials. It eats up the first to devour the wood used in the manufacture of doors and windows. It causes chemical and metal transformations in other building materials, whether they are stone or brick, and in particular, limestone, which is transformed by high heat into a low-hardness, fast-turned, and easy-to-drain lime, and chemical and mineral shifts lead to the loss of stones to The hardness of its surfaces is caused by cracks and flaking and the fires generally cause the buildings to crack and may collapse completely [3,7-8].

- Wars; the most serious human consequences of ancient civilizations. The danger of war grows as the tools of warfare and weapons advance. Wars and invasions since ancient times have been a demolition and sabotage of all aspects of urbanism. If the enemy resorts to fire or work on it and sabotage it with the means of sabotage available from catapult and cannons. In modern times, air weapons have become the most dangerous weapons of destruction, with heavy bombs, incendiary and rockets. During the Second World War, thousands of historic buildings were demolished, and treasures and cultural riches were impossible to compensate.
- Demolition and Sabotage; In many cases, individuals or authorities to demolish historical buildings or distort and change its parameters, for reasons including: the desire to renovate the old building for modern architecture to be more useful. However, they neglect or ignore of the value of historical building or asset because of the deterioration of the general cultural level. in other cases, the poor oversight and lack of awareness among citizens encourage them to take abandoned historical buildings and archaeological ruins as quarries taking their stones and building materials which lead to the increase of its havoc and trapping. On the other hand, thieves may tend to sabotage the historical decorative elements stolen and traded. And finally, there are the dangers that accompany growth and development in urban planning projects and when major construction projects like dams and rail lines and roads and pipelines and create the Airports and seaports and other projects imposed by modern life style.
- Faulty repair; one of the hazards to the archaeological and historical buildings, is the mistakes that restorers with less experiences make while renovating these buildings. Poorly studied or prepared repair plans might lead: either to blur some of the features of the building or change its elements. It may also change or remove already existed items either by introducing other elements or distort the distinctive features and style [3,8].

Physic-Chemical Deteriorating:

Physic-Chemical Deteriorating category consists of three main causes: 1) High variance in temperature, 2) Fluctuation in the water level of leaching, and 3) High changes the relative humidity.

1) For high variance in temperature, it is known that external surfaces of the walls, which is exposed to weather and direct sunlight, are more affected by this factor rather than internal surfaces and especially in covered buildings. when the outer layers of the surfaces exposed to direct sunlight, it absorbs and stores it as high heat energy because of infrared rays (as a result of the inability of building materials in general to conduct heat) and the high thermal energy storage will lead to a significant rise in temperature. However, throughout the hours of daylight leaked a large portion of the heat stored in the outer layers of the skin and slowly inside and when the night comes and cuts off the heat source, which is sun, the temperature and the outer layers become colder than the inside and rapidly lose temperature because of being in a direct contact with cold air. Accordingly, it is obvious that the outer layers surfaces are exposed to high change in the temperature of the weather in comparison to internal layers [9]. The existence of heritage buildings under the influence of this factor for long periods of time result in patterns of damage [5,7,10-11,18-19] as follows:

    - Breakdown of the bonding between the metal granules forming the outer layers of the surfaces of the metamorphic stones. forming the outer layers of the surfaces of the metamorphic stones. As a result of their different mineral components in their thermal reactions to the rise and decrease of the degree of the surface and resulting in the disintegration of these mineral granules due to the expansion and contraction that accompanies the rise and decrease in temperature and then fall by other factors such as wind and storms.

- Breakdown of the cohesion between the outer layers of the surfaces of the Igneous rocks and metamorphic stones and laminated limestone and between the inner layers because of the storage of high thermal energy in these surface layers. This results in the separation of these surface layers one after another and the recurrence of this pattern of damage for extended periods of time not only cause the distortion of the archaeological surfaces and the loss of the inscriptions and writings, but also perhaps the imbalance of the heritage buildings themselves.
- Breakdown of the bonding between the plastering of the walls. especially if it is of a polished and colorful with Low porosity and between the surfaces of the exposed walls as a result of the storage of high thermal energy. Consequently, separation of the mortar layers take place from the walls and fall either in the form of large blocks or in the form of crusts separated consecutively over time.
- Cracking and peeling the outer layers of the exposed surfaces due to the phase shifts of the metallic granules in the Igneous rocks, metamorphic stones, bricks and plastering of walls. due to the phase shifts of the metallic granules of these surfaces for the high temperature rise as a result of exposure to direct sunlight and this pattern of damage usually occurs in the Igneous rocks, metamorphic stones, bricks and plastering of walls, especially if was made of gypsum.

2) Fluctuation in the water level of leaching cause is one of the most factors of deterioration of historical buildings and shows its extremely dangerous effect in the sites close to the rivers or near the seas or located in the middle of farmland or those found in the old residential neighborhoods that are usually lacking in the means modern sanitation. Some of the most striking patterns of damage associated with the occurrence of historical buildings under this factor are:

- When the water of the leaching and the starch is accumulated around the base of the buildings, it rises in the walls by the capillary characteristic to distances depends of course on the porosity of the building materials and its permeability and also on the amount accumulated around the foundations and resulting in the washing and dewatering of the bonding materials for the granules of stone blocks and moons. Which leads to their transformation with time into fragile, weak, cohesive bodies that are easy to break down by damage, other factors of wind, storms, etc.
- When the water of the leaching and the earth is accumulated in large quantities in the soil that embraces the buildings of the archaeological and historical building, it is causing serious damage in these buildings. may lead with time to imbalance and possibly to collapse. The occurrence of this pattern of damage is associated with the changes caused by the water of the leaching and the starch in the soil components, especially if the children.

It is fixed that the fluctuation of the level of leaching that gather in the soil leads to the creation of it by washing and dewatering of some of its components and on the other hand to drink the soil and especially the parasite in the water of leaching and the baby causes the swelling of its granules and the receding water from it with the fluctuation in the level leads to Its natural size. Naturally, this swelling and contraction results in the occurrence of large consecutive and irregular movement in the soil and as the foundations of archaeological and historical buildings and although loaded with large loads are usually deep. These movements will cause the walls, doorsteps and columns to crack if they have the time to do so.

3) For high changes the relative humidity, it is worth noting that fluctuation in the water level of leaching cause the effects of maintenance professionals studying manifestations and patterns of damage associated with change in relative humidity in various types of archaeological and historical buildings. High relative humidity may lead to:

- Dissolve soluble salts in water and typically found in sedimentary rocks (limestone and sandstone) and bricks and building supplies and slurry walls and carry it to the exposed surfaces as crystallized in the outer layers of these surfaces when the

dryness of its solutions by evaporation. And by the enormous pressures that accompany the crystalline growth spot for external surfaces disintegrate salts stones and bricks and detaches the grout on the walls and what might be lost from inscriptions and cap badges and decorations.

- Melt bonding materials of sedimentary stone granules, especially sandstone (whether of iron or calcium compounds and carried it to the surface when dry its solutions consisting of the so-called hard crust.

Whereas, Low relative humidity may lead to the following:

- Phasic shifts in some components of the slurry walls particularly if gypsum which turns into a mutant. And this transformation is accompanied by loss of water chemically United with calcium sulfate and thus shrinking the dimensions of structural cell gypsum produces very passionately in grout leading to occurrence and irregular cracks and crystallized salts as a result of the significant decrease in the relative humidity to u It fixed inside the buildings. And in this case the surfaces of patterned walls and colorful slurry layers attraction solutions of salts. And when dry brine evaporation the salts crystallise and cause massive erosion leads to localized pressure surfaces of stone and mortar walls and losing their inscriptions and decorations
- The hardness of rocks and bricks and mortar and masonry walls pantry. the power of bonding materials and its effectiveness both in sedimentary stones blocks and bricks or construction slurry walls and pantry depend on these construction materials contain a certain percentage of humidity and in extremely dry atmosphere lose their strength and effectiveness of the Association article losing moisture. And is a natural for weak bonding material significant impact on rigidity of these kinds of building materials.

Biological Deteriorating:

It is meant to be damage factors associated with plants and animals and insects and microorganisms. Plants damage wall in which rain water or water seepage and leaching in soil that embraces the foundations of historic buildings, plant seeds carried by wind and birds and usually resides in the cracks and breaks live and grow and become real trees, causing these plants (particularly when penetrating breaks and cracks) Cracked buildings if its time for it and on the other hand, it was observed that the built foundations of stone mounds eroded by acidic secretions that are secreted by cells of the roots as this square looks marked termed name marks the roots [12-13]. On the other hand, animals related to the damage include [6]:

- Bats which are animal's distortion of historical buildings. Especially those in remote areas away from the landscape. The bats take of these buildings and when they menstruate dormitories, they deform the walls and their inscriptions and motifs with dark brown stains are difficult to remove.
- Mice could infest a monumental building and settle in. They endure damage may be difficult to overcome, especially as they breed in large numbers. The mice take existing cracks usually old buildings and dormitories might dig holes extends to great distances in walls or under the foundations. Which may lead to imbalance of building and fragment it if time. On the other hand, the proliferation of rats with old buildings into smelly dirty places
- Insects; the termite insect destroying monuments. They are usually spending digs under foundations and causes a disturbance in the soil (which may lead to an imbalance of buildings). And in the case of mud buildings, the termites attack the bricks and clay slurry and pantry and fragmented to feed on hay the pureed. And termite attacks as well as timber used in buildings to take them food, fragmented and lose texture and consistency and may lead to cracked buildings if these woods laden with weights or constitute an important structural element. Wild bees don't directly damage monuments but (especially in existing buildings in remote areas away from urban action) builds on the walls severe rigidity and cohesion of mud and some organic secretions cause distortion in appearance and destroy the engravings or decorations [3,6].

- Microorganisms occur due to decomposition of organic substances normally found in soil which embraces a lot of historic buildings by microorganisms into building materials in the foundations of these buildings are located in the middle of severe or very alkaline pH either leading to activate interactions Chemical building blocks and the surrounding medium is soil in addition to analyse precious stones and other building materials by the enzyme acid secreted by these objects and these chemical reactions usually fragmented building materials and loss of consistency and texture and natural to have this effect Obviously in the process damage the archaeological and historical buildings [14-16].

ES_HXWall System

The Knowledge base is the Expert System component that acts as a database that stores knowledge specific to the area which the expert system is targeting [17] ; Knowledge in this project is represented as a set of IF/THEN rules. Knowledge acquisition was done by extracting knowledge from available literature concerning potential damages to Historical Buildings' Walls, how to repair these damages, and how to maintain the repaired Walls. Specifically; Eroded Stone Walls. The ES_HXWall prompts the user to answer questions related to the presence of: loose stone, water leakage, fractures, concerns about the structural capacity of the wall, salt damage, and penetrating holes. While, taking into consideration the integrity of the architectural appearance and the stone wall characteristics.

The Inference Engine is the processor of the Expert system that concludes new information or reaches conclusions through matching facts present in the working memory with the knowledge present in the knowledge base [17]. The inference of ES_HXWall is based on Forward chaining, where the system compares the contents of the working memory with the IF part of the rules. Once it finds a resemblance in a particular rule, the rule is fired and its conclusion (in the THEN part) is added to the working memory. This comparison process is repeated again and consequently; new rules are fired until no more matches are found or a final conclusion is reached. Finally, the final conclusion is added to the working memory. The forward chaining approach is based on system using set of known facts and information in order to draw conclusions [17]. ES_HXWall consists of five modules which are designed to satisfy system's functionality. These modules are (see Fig.1):

- Data Input Module: this module checks the validity of the input answer.
- Gathering Information Module: this module uses Rules to gather information about the subject Wall that shall be assessed using ES_HXWall .
- Status Module: prints and on-screen message clarifying a preliminary recommendation.
- Repairing Module: fires more questions to determine best repair strategy.
- Maintenance Module: fires more questions to determine best maintenance strategy.

It is the interaction between the user and the Expert system. ES_HXWall is build and run the Expert System is CLIPS version 6.3. User interface of the selected shell is simple. The user is simply requested to load the Expert System, reset it and run it. All questions shall be replied to with either Yes or No. To validate the developed expert system, test cases of eroded Stone Walls were run through the set rules. The returned decisions were in line with what was expected.

RESULTS

The session is started by asking about the stone related problems to be able to identify those exact problems systematically; Questions are asked about the visual appearance, color, Functional and structural condition of the stones. Then a decision should be made whether to repair or replace immediately the noted stone. If repair had been selected, then questions are being asked about the suitability of the required repair method to each case. For example, If open joints are present within historical stones, then a repointing procedure should be considered using lime mortar. If that repair method is not needed, then another question is asked about the related repair method and so on. In case of replacement of the original stone, then a question is asked

about whether or not it is significant to reveal the marks of time on the heritage architecture. Then a replacement decision is being taken under governance of the final appearance, to avoid possible heritage loss and to maintain the integrity of the building. Highlighted is the maintenance part for its significance to preserve the heritage stones in the flow chart. Both building maintenance and stone maintenance are required in order to preserve non-faulty stones from deterioration and even after repair to limit further stone deterioration. Maintenance procedures include what should be regularly checked, what to avoid and how to sustain the stone at last. Fig.2 illustrates the designated user interfaces for ES_HXWall system

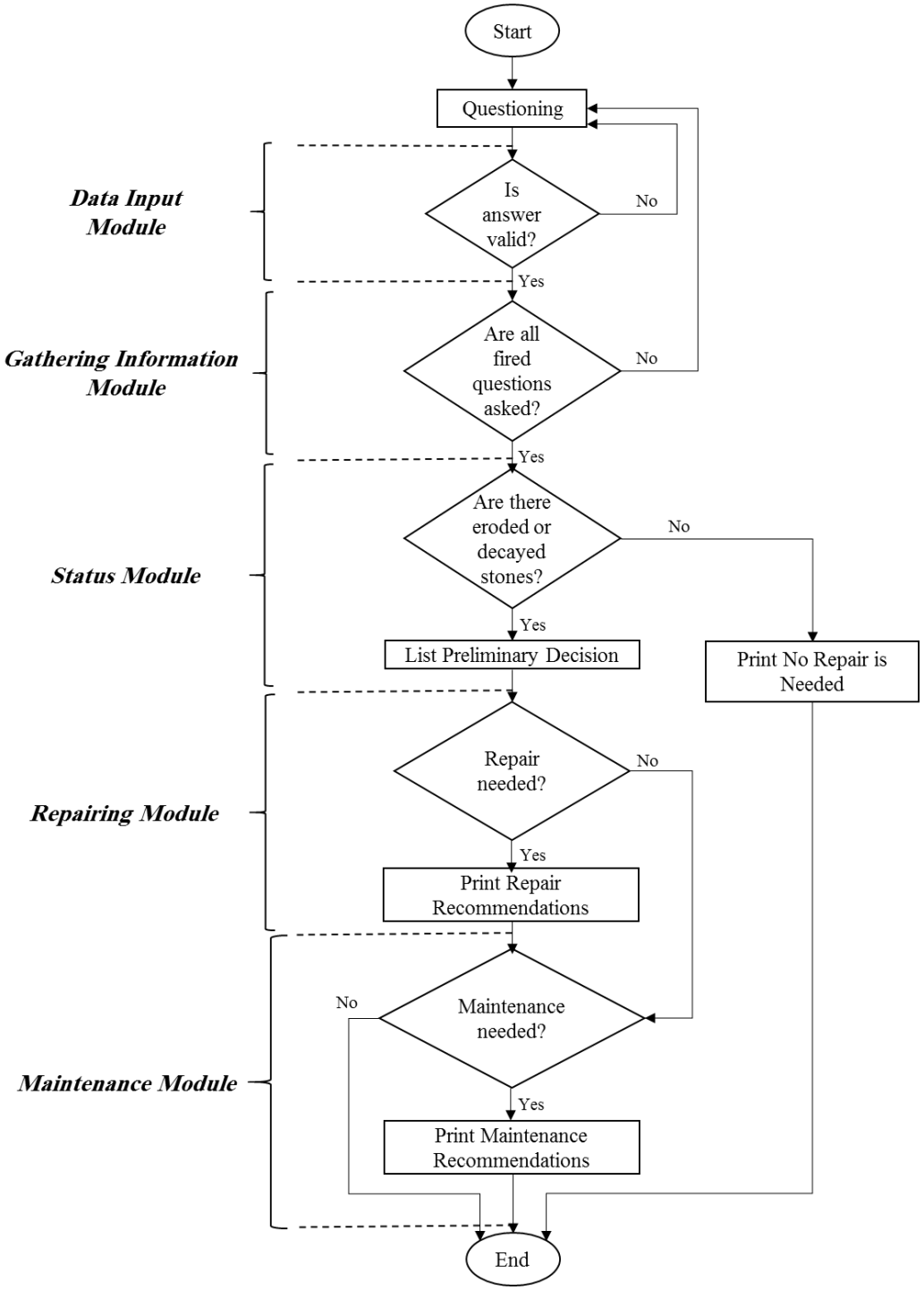

Fig. 1: ES_HXWall system flowchart

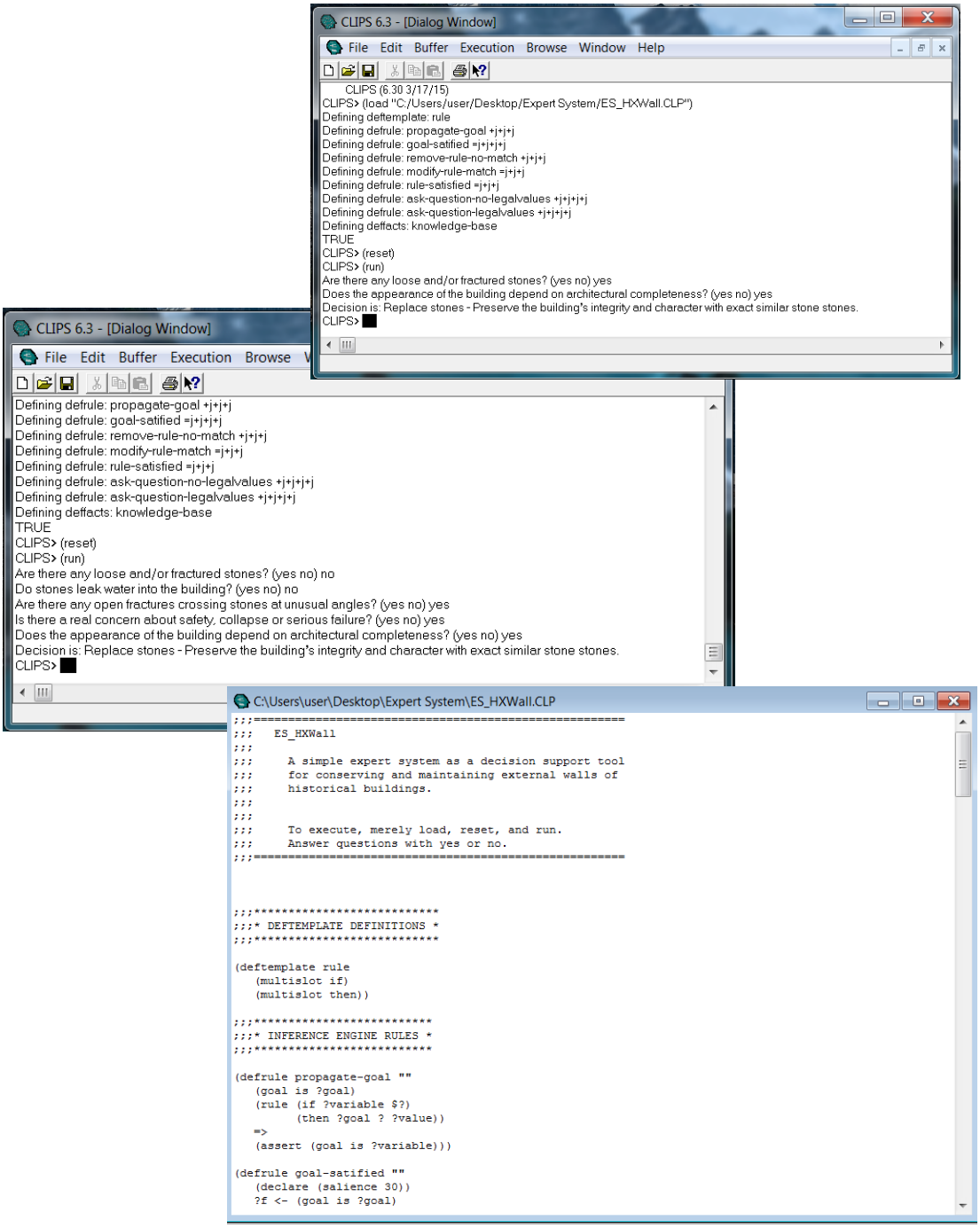

Fig. 2: Designated ES_HXWall user interfaces

CONCLUSION

An expert system for heritage buildings was presented in this paper. The system is essential to aid stakeholders to take decisions for the sake of their conservation and preservation. since heritage should not be treated as regular buildings. A deep understanding of the different deterioration causes that includes physical, mechanical and biological patterns had been reviewed in this study. Such knowledge was build in the expert system in order to identify the related failure in the heritage masonry units and consequently the optimum repair and maintenance procedures are provided in an expert system specifically for heritage.

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