EVENT AND EFFECT MODEL OF BUILDING MAINTENANCE

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People tend to spend about 90% of their time in a form of building for which they require comfort and safety. To this end, building maintenance and repair play an important role. Also, from economical perspectives, the overall contribution of operation and maintenance activities constitute a considerable portion of the overall lifecycle cost of the building. The significance of building maintenance planning has been recognized by all stakeholders within the industry and those peripheral to it, as well as the society, from sustainable environment perspective. There have been a number of attempts to provide maintenance and cost evaluation for the whole lifecycle of projects. However, despite the necessity and the attentions, the current systems of whole lifecycle evaluation and maintenance planning are far from satisfactory. This is to the extent that they are hardly practiced, and the limited scattered activities are reactions to regulatory pushes. These shortcomings are partly due to the uncertainties of the future events and partly because of the complexity associated with the scale of the problem. The development of a realistic maintenance programme involves evaluation of numerous instances and scenarios arising from the interaction of diversity of events and a variety of building components. In this paper, a model is presented which systemizes the relationship between the events that give rise to a maintenance instances and the effects that they have on building components or their parts. To this end, an event-effect model is proposed which is based on the combination of relational behaviour of events and building components, and the implementation of their interaction through the use of an object oriented model. The work here will be instrumental in developing the infrastructure underpinning a broader research programme into an integrated building design and maintenance lifecycle evaluation system.

Keywords**;** lifecycle evaluation, maintenance programme, object oriented modelling.

INTRODUCTION

The occupancy phase that is normally between the practical completion and demolition is by far the longest period in the life of the project. This phase also consumes the biggest proportion of the overall project lifecycle costs (Ball 1988), which has been on the increase (Bon and Pietroforte, 1993). Throughout this period, the costs associated with the repair and maintenance of components are traded against the safety, comfort, and needs of people and businesses. The scale of repair and maintenance is also reflected on the level of activities at the national level. Building Services Research & Information Association (BSRIA 1997) has valued the potential market at £36.4 billion, 60% of which (e.g. M & E maintenance) is being outsourced.

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The average life of a maintenance contract was one year or less in 1989. This increased to an average of three years by 1995.

Traditionally, property maintenance is viewed as the least attractive and least glamorous side of the industry (Kirkwood 1986). With the development of the lifecycle evaluation and facilities management, the attention towards building maintenance has changed by force and by choice. Over the years, the attitude and approaches to maintenance have evolved to meet the increasing complexity of buildings and extent of services required by users. While the improvement in the quality of materials and technology has reduced the need for maintenance, the complexity of buildings and the increasing awareness of the benefits of lifecycle design has enhanced the need for more comprehensive maintenance provisions. This is partly motivated by the increased interests at the governmental and institutional levels and partly imposed by the movement for quality of life supported by pressure groups at local, national and international levels, expressing concerns towards increased wastes, echo systems and the environment. Basically, the actors within property and construction have become receptive towards environmental issue. The prospect of serving the environment while reducing costs seems to appeal to all stakeholders.

However, inadequate planning for maintenance assessment remains as a serious problem in many sectors of construction industry. These shortcomings are particularly acute in the housing sector: Leather and Rolfe (1997) highlight the weaknesses of the building industry to provide adequate level of repair and maintenance for the housing stock. This responsibility is more and more passed on to the owners (Meikle and Connaughton 1994), and the government has minimized its responsibilities by removing the grants that were available prior to the Housing act in 1988 (Bowels *et al.* 1997)

A main barrier to effective implementation of maintenance programming is the lack of confidence and complexities associated with the maintenance planning systems and problems associated with the quantification and qualification of environmental impacts (Flanagan 2002). This is further exacerbated by the lack of understanding about the link between sustainability and business performance improvement (CRISP 1999), on the one hand, and lack of market demand – little pull and resistance to push - on the other (David Bartholomew Associates 2002). Despite their positive intentions, businesses have failed to embrace and implement maintenance planning in an effective manner. Amongst other reasons, the lack of guidance hinders their ability to take positive steps to integrate these issues into their business policies (Johnson 1993).

This work focuses on the practicality of developing a maintenance programme. To this end, hierarchical and object oriented approaches to modelling are combined in order to develop an effective structure for representing the interaction between events that act upon building components and give rise to a form of degradation that requires a maintenance action. The work forms an essential part of a broader research programme the aim of which is to develop an integrated, holistic approach to building design, maintenance and lifecycle evaluation.

BUILDING MAINTENANCE ISSUES

The construction maintenance has undergone three generations of development ranging from the combination of ‘maintenance on failure’ to ‘preventative planned maintenance’ and ‘time-based maintenance’. A systematic approach to maintenance management, supported by computer systems, commenced during early 1970s. However, it was by early 1980s before the use of improved computer technology enabled more sophisticated and complex calculations as well as better use of databases (Pettit 1983). These enhancements continued with the introduction of desktop computing which was instrumental in popularizing the building maintenance management process. The qualitative improvement in the power of computers, in conjunction with the increased participation of wider range of users, resulted in software vendors and in-house developers to engage in new enhanced approaches to the problem. With the establishment of the Building Cost Information System (BCIS) by the RICS in the early 1970s and the establishment of Building Maintenance Cost Information System (BMCIS), providing further focus on the maintenance cost information, the path was paved for a more orchestrated analysis and modeling the building maintenance cost. The provision of data together with the increasing awareness and concern for the post-construction costs resulted in the 1980s to become the era of experimentation and examination of lifecycle costing from several angles. These include Flanagan and Norman (1983 and 1987), Bromilow *et al.* (1984), Spedding (1987) (incorporating several articles on the subject) and Bromilow and Pawsey (1987). The developments in the early periods resulted in a revized and improved systems including the use of centralized databases, incorporation of conditional assessments, repair scheduling and budget development (Jones and Collis, 1996). Since the latter part of 1990s the efforts to improve the acquisition, refinement and management of data have been on the increase. An example is the project OSCON (Aouad *et al.* 1997) where a centralized database facilitates full integration of several construction activities. This project was later extended to include maintenance activities providing and using data from the centralized database. This is paralleled with enhancements in the representation of data with the aid of visualization tools and techniques.

Despite the progress, a widespread discontent has existed within the industry, as all current systems tend to simply automate the process and the level of accuracy has been less than satisfactory. Having identified 9 activities associated with maintenance, Jones and Collis (1996) undertook a survey of companies involved in maintenance and identified that the computer system of over 60% of their respondents used only 3 or less than 3 activities. In a later attempt Jones et.al. (1999) conducted a more comprehensive survey targeting various organizations associated with construction industry and with further association with building maintenance. These consisted of district councils, housing associations, private practice, universities, retail outlets, health authorities & government associations and light industries. With the total sample size of 678, they concluded that the computerized maintenance systems tend to operate well in limited areas of application. However, there are several other areas where advancements are essential. As expected an area that is particularly underdeveloped is the maintenance planning. Indeed, the current systems are little more than a sophisticated calculation machines. The shortcomings are primarily due to the inherent complexities associated with holistic maintenance programming. As noted by some readers (e.g. Bromilow and Pawsey, 1987), the shear scale of the problem and the uncertainties associated with future events make it impossible to develop a model that encompasses all elements and aspects of building maintenance. Subsequently, researchers have searched for more practical solutions. For example, Al-Hajj and Horner (1998) apply the cost-significance method in order to identify those elements that account for the majority of the costs, thus eliminating a large proportion of elements the contribution of which is justifiably insignificant.

Nonetheless, the current best practices are somewhat simplistic. Each component is considered individually and in isolation from other components. Whereas, the interaction of events, on the one hand, and components on the other, is a source of significant complexity associated with a holistic approach to maintenance programming. Further, the current approaches are based on data relating to components from past projects. This implies that the data is also reflective of the total environment surrounding the component, whereas, in reality, circumstances are highly diversified. The changing of even one variable could have a significant impact on the behaviour of the component. This scenario-based approach is possible only when historical data are available for all variety of diverse situations. While there is abundance of data generated by several sources, they are often diluted, as they are gathered in an indiscriminate way, thus rendering them difficult to exploit. In search for an alternative practical method, the paper assumes an elemental approach to the problem. This is implemented through the proposed event-effect maintenance model.

EVENT-EFFECT MODEL STRUCTURE

Building degradation is the product of ‘*events*’ acting upon building ‘*components*’. The events come in a variety of forms and shapes. Examples include moisture, wear, temperature, air movement, long-wave radiation, chemical attack, biological attack, fire, man-made disaster, natural disaster, etc. The consequence of an event acting upon a building component is an ‘*effect*’. Examples of effects include corrosion, colour rendition, surface texture and shape deformation, mortality status, erosion, and loosing reflective, absorption and transmission properties.

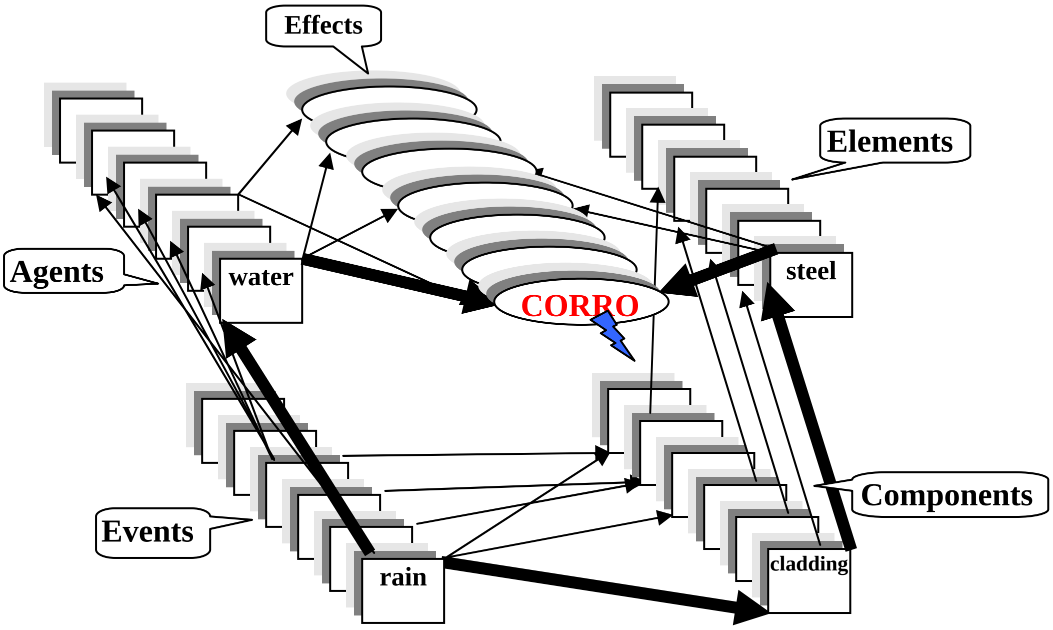


Figure 1: the Event-Effect model of building maintenance

There are two basic methods by which the impact of an event on a building component is modeled - the use of scenarios and the elemental analysis. Current practices are predominantly based on the former: scenarios are used to define a situation and data are used to justify and quantify the effects. For example, acid rain corrodes limestone-based claddings. The alternative approach entails breaking events and components into their basic elemental constituents and examining their chemical and physical interactions. In this approach, each event is decomposed into its constituent '*agents*', which act upon building components. For example, an event like rain is defined in terms of its agent, namely water (other examples of agent are condensation, ice, temperature, radiation). The impact of agents on each component is then manifested through the elements of the component. For instance a particular type of cladding may be made up of steel, thus it is susceptible to corrosion as the result of rainwater. However, for an event to produce an effect on a component, its constituent agents must come into contact with the elements of the component. For instance, if the cladding is made with steel with plastic coating, then the steel part will not come into contact with water, thus the corrosion effect will not take place. Therefore, an effect is '*fired*' only when the relationship between event-agent and component-element is short-circuited. The example in Figure 1 shows that a corrosion-effect is fired with the rainwater coming into contact with the steel part of the cladding.

An event can fire several effects, because on the one hand, it can affect a number of components (e.g. rain on cladding and roof) and, on the other hand, it can consist of a number of agents each triggering a different effect on the exposed elements (e.g. corrosion and erosion inflicted by storm). Also, a component can be affected by different events (e.g. cladding vs. rain and sandstorm)

The model shown in Figure 1 is an accurate general representation of all possible situations, as long as the effect of agents are considered individually. But, in real life situations, the combination of one or two agents can lead to the development of another agent. For example, 'water' is an agent of event 'rain' and 'hydrocarbons and oxides of sulphur and nitrogen' are agents of event 'pollution'. These agents – 'water' and 'pollution substances' - fire separate effects such as 'corrosion' and 'deterioration'. But, the combination of 'water' and 'pollution substances' produces 'acid' which is capable of triggering another effect, namely 'acid corrosion'. Subsequently, as shown in Figure 2, another layer is required to reflect the combined effect of two or more agents. Both layers contain the same original agents, however, when two or more related agents are triggered simultaneously, the resulting '*auxiliary*' agents are also triggered in the auxiliary layer. The implementation of this process requires all agents of both layers to be interconnected.

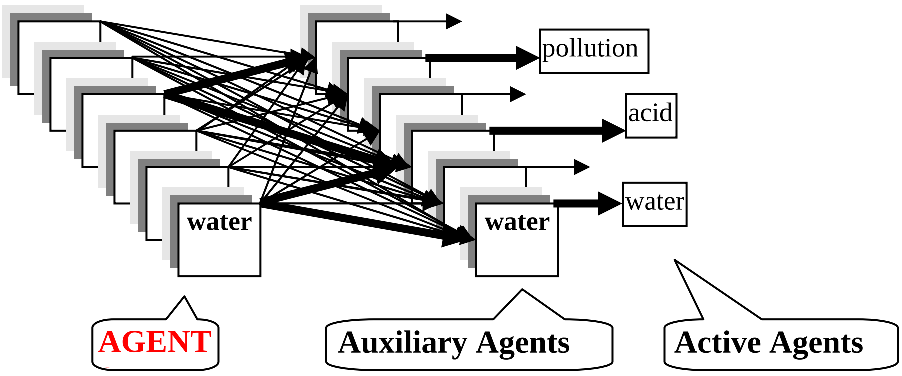


Figure 2: Combined effect of two or more Agents
Example: Agent-water plus Agent-pollution = Active Agent-acid

Similarly, the combination of two or more events can result in the activation of auxiliary elements. For instance, it was earlier stated that if the steel part of the cladding is covered by plastic coating, then the circuit will not close and no effect will be fired. Therefore, despite the fact that a particular type of cladding consists mainly of steel, no corrosion is expected to occur due to rainwater. But, a particular definition of ‘vandalism’ (event) that causes damage to building claddings, exposes the steel element making it vulnerable to corrosion-effect. Figure 3, shows that the introduction of an auxiliary event layer facilitates the incorporation of the impact of combined Events. Unlike the previous case where both layers contained the same agents, here, a new auxiliary event is created every time two or more related events are combined. This process is possible only through the interconnection of all events of both layers.

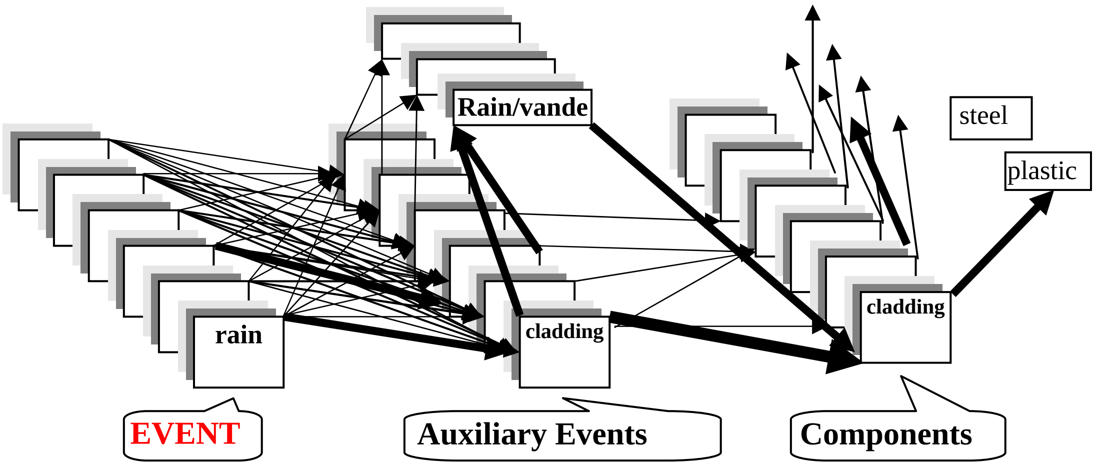


Figure 3: Combined effect of two or more Events
Example: Event-rain plus Event- vandalism-x = Active link to Component-Cladding-Element-Steel

Figure 4, is the schematic demonstration of the new extended model that includes both auxiliary layers into account. Both elements and agents are at a rudimental level. In other words, many components are likely to share a number of elements, just as many events are expected to consist of similar agents. While there is no limit in the number and variety of events and components, agents and elements are expected to be relatively limited in number. New types of building components emerge everyday, but the constituent elements of each category (e.g. cladding) tend to revolve around similar elements (e.g. steel, aluminum, PVC, etc.). Also, an unlimited variety of events are produced by the nature and human activities but, when decomposed into their substances, the majority of them consist of a limited number of agents.

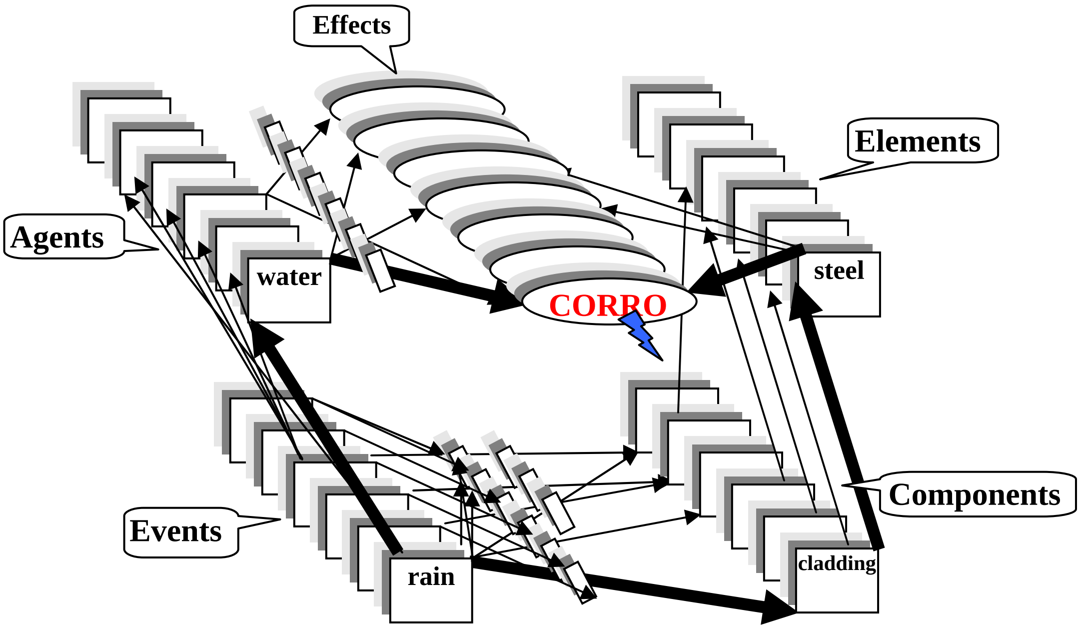


Figure 4: Extended model of Events-Effects

EVENT – EFFECT IMPLEMENTATION MODEL

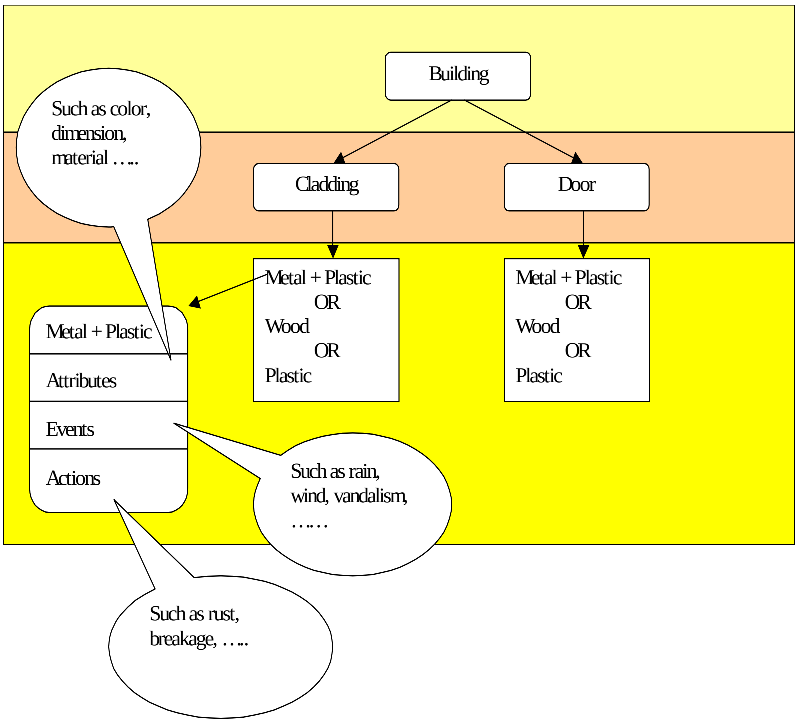
The basic principal of the model is relatively simple – the intricacy is in the large number of events and components, together with the details of the rules governing the relationship between the single and combined levels (agents vs. combined agents and events vs. combined events). Therefore, the complexity of the model lays in the details of the Event-Effect relationships rather than their nature. Subsequently, a flexible method is required for the implementation of the model and its translation into an algorithm.

At first, the problem appears to have a hierarchical structure: on the one side, the highest level object is the building itself which is then decomposed into lower level components such as the foundation, cladding and roof structure. The components are also decomposed into their constituent elements such as steel, aluminum and wood. On the other side, there are events that are translated into a series of agents. What brings the two sides together are the relationship between events and components, and the relationship between agents and elements. Earlier, this was shown to be a complex process. Further complexity was also introduced due to the combined effect of one or more agents or events. Therefore, it is evident that the hierarchical approach does not offer a viable solution for the design of the implementation algorithm. On the other hand, the object oriented approach contains many features that can be used to overcome the above complexity. These include the use of inheritance, creation of instances, implementation of interfaces, definition of instance methods and variables, etc.

In using the object oriented approach, the primary challenge is to determine what constitutes a ‘class’. Extensive examination of the problem revealed that optimum solution is achieved only when the definition of a class is determined loosely. The initial contemplation was to assume that only functional components such as the flooring system could be defined as a class. But, since in any given building, there are several categories of space (e.g. corridor, kitchen, hall and various rooms), each with a different flooring requirement, it seems somewhat complicated to arrange the inheritance to sub-classes and form other classes. The alternative approach was to view the building as a collection of several units of space such as corridors, kitchens, bathroom, hall, various rooms, etc. These units can then be defined as a class, the attributes of which are determined by their relevant flooring and other systems. Since the latter approach does not inhibit the use of classes for the definition of functional components, further advantages can be achieved through the combination of both approaches. This is particularly useful for functional components such as cladding, doors, windows, etc.

Figure 5, shows the object oriented design of the model where certain classes are defined in terms of both functional and spatial components. Typically, it is more comprehensible to define a system from general to specific: a building consists of components (e.g. Figure 6) and each component has a number of sub-components and there can be a variety of types for each components and sub-components. But, the description of the object oriented model is better understood if it assumes a specific-to-general direction: once sub-component are defined, the path is paved towards the construction of classes. This is demonstrated in the following series of sudo-algorithms, which represent examples of class definition. For instance, it is suggested that the *room* class can be made of wall, door, ceiling, floor and window, and various situations are represented by Boolean AND, OR, EXCLUSIVE-OR notations.

Figure 5: Object representation of event-effect



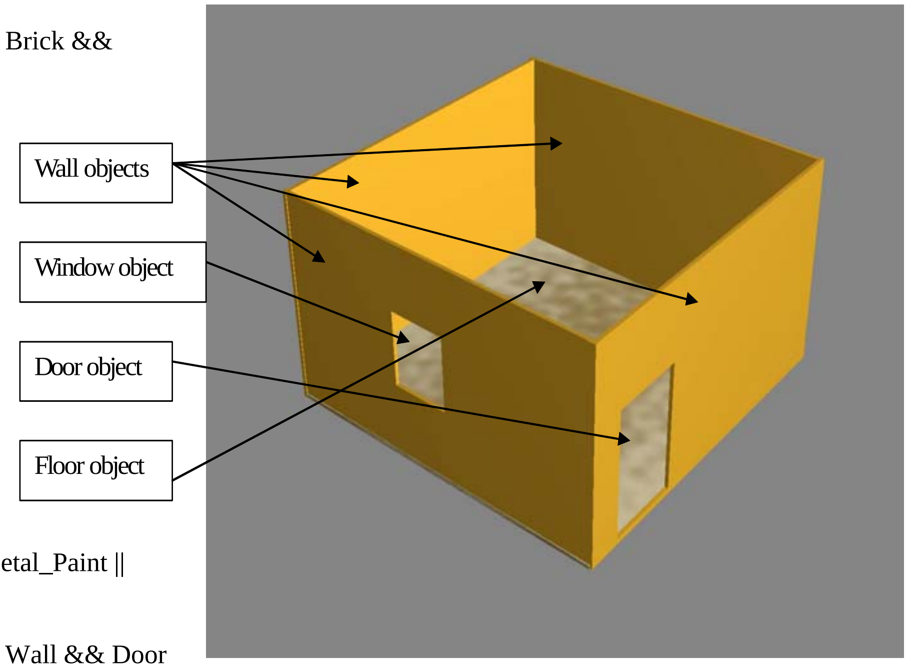
Class: Wood

Events
Actions
CLASS: METAL
Attributes
Events
Actions
Class: Paint
Attributes
Events
Actions
Class: Metal_Wood
Attribute
Events
Action
Class: Metal_Paint
Attribute
Events
Action
Class: Brick
Attribute
Events
Action
Class: Plaster
Attribute
Events
Action
Class: Wall
Subclass: Brick && Plaster && Paint
Class: Cladding

Subclass: Wood || Metal_Paint || Metal_Wood
Class: Door

Subclass: Wood || Metal || Metal_Paint || Metal_Wood
Class: Room
Subclass: Wall && Door && Ceiling && Floor && Window

Figure 6: Object representation of event-effect model



As shown in Figure 7, the implementation involves four basic constructs: events, components, effects and links. A link is a set of pointer that establishes whether or not a connection exists between the elements of events and the units of building components. If the connection exists then the link is live (active), otherwise it is a dead (inactive) link.

Each event object must have its specific generic output so it can be applied to all other objects. This is how it is possible to cater for all numerous possibilities (for example, rain; water, wear - now rain can be applied to all components). Each Component, as an object, is also defined in the same way (e.g. cladding: damage, corrosion, erosion, dirt, etc). So when Rain and Cladding objects interact then an effect is fired.

The combination of the hierarchical and object oriented modelling approach provides an effective method for identifying the relationship between events and components, and implementing the effect of their interaction in a one-to-one, one-to-many and many-to-one situations. This involves consideration of auxiliary events and effects arising from inter-relationship of different events and different component.

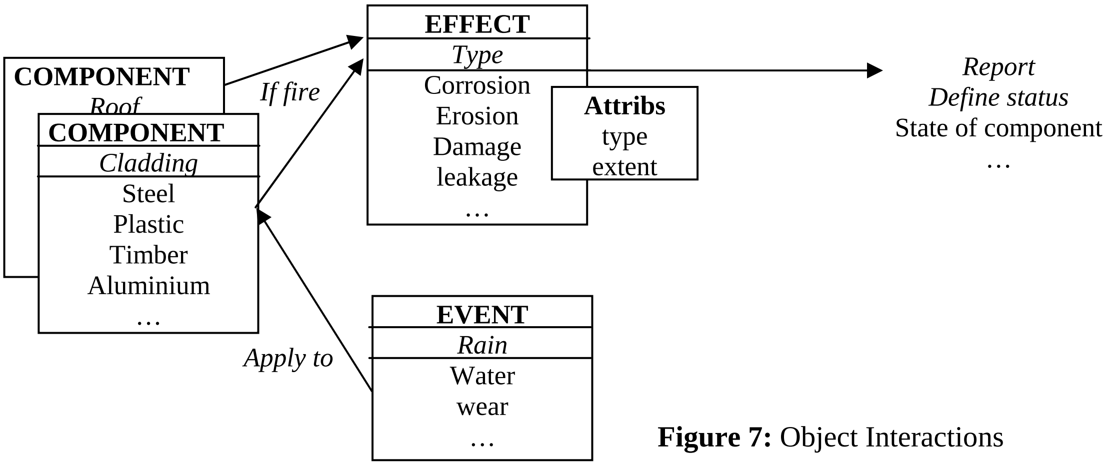


Figure 7: Object Interactions

CONCLUSION

The post construction is an important phase within the lifecycle of any building, yet, due to high level of uncertainties and complexities associated with future events, the development of maintenance planning has remained as a challenge. In recognition of the scale of the problem, many researchers and vendors have diverted attention towards increased sophistication of the maintenance systems, such as development of centralized databases. However, little attention has been rendered to improve the structure of the Event-Effect model. Subsequently, the current models are not capable of coping with the complex interrelations of different events and their impact on building components. The current work forms an independent part of a broader work the aim of which is to identify and simulate the impact of all events acting on all internal and external components of a building. This requires that a generalized model is developed, based on which, all components can be simulated. The contribution of this work is highly important, as there is a need for a systematic and practical way by which the degradation of a variety of building components can be simulated. This is in view of the fact that there are a very large number of events that act upon building components and there are a variety of building components, each with several possibilities.

In this research, the focus has been on developing an elaborate structure whereby the incorporation of various inter-related or chain reactions are simplified. This is achieved, partly through decomposition of events and components into their respective basic ‘agents’. This process is also assisted by a relational model of Event-

Effect for identifying maintenance instances, and an object oriented model for practical implementation of each instance. Having defined the principals of basic object models, the overall Event-Effect model can be cumulatively built by defining objects, each containing the relevant information about attributes, nature and actions that are triggered, once an effect is fired.

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