The development of a knowledge based system to deliver health and safety information to designers in the construction industry

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The development of a knowledge based system to deliver health and safety information to designers in the construction industry

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There is a belief that the poor health and safety record in the construction industry can be improved by encouraging designers to give more consideration to health and safety issues during the design stage. This is in keeping with the principles of the Construction (Design and Management) Regulations 1994.

A prototype Knowledge Based System has been developed by NNC in order to demonstrate how this problem may be addressed. The system provides easy access to relevant health and safety information, either standalone or interactively within a CAD tool. The system also allows the designer to add new properties, which are relevant to health and safety, to building objects in their designs.

The development included an investigation into the viability of a system that will carry out checks on a design to establish if it contains any health and safety risks. A prototype tool checks designs, and any risks found are alerted to the designer, together with information on how to reduce the risk or remove the hazard completely.

Evaluation of the prototype system by a range of potential end users resulted in positive feedback, and it is recommended that a phased approach is used for full scale implementation. There is enthusiasm for the concept of automated checking of 3D models by HSE and by other regulatory authorities. The automated tool would be best implemented within a collaborative project with other national regulatory authorities, for example, the Building Regulations Division.

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EXECUTIVE SUMMARY

The Health and Safety Executive is committed to reducing the number of accidents which occur within the construction industry. There is a belief that the poor health and safety record can be improved by encouraging designers to give more consideration to health and safety issues during the design stage. This is in keeping with the principles of the Construction (Design and Management) Regulations 1994 (CDM) that place a responsibility on designers to ensure that designs are not only adequate in their final state, but can be safely constructed and maintained.

This project’s aim was to prototype a method of providing designers with easy access to relevant health and safety information, by establishing a means of structuring HSE’s information as a Knowledge Based System (KBS) and delivering it to designers. The project was an initial development project to demonstrate the principles of delivery and potential acceptance of a KBS based approach, and to provide recommendations for full-scale implementation.

A knowledge based system is taken to be a system in which human expertise is structured, enabling the system to diagnose situations and provide information and recommendations without the human expert being present.

The development of the prototype system was split into three main areas:

(a) The KBS prototype provides health and safety information, either interactively within a computer aided design (CAD) tool or standalone. The information is structured so that, for example, details about rooflights can be accessed by selecting a rooflight on the CAD tool’s display.

(b) Many building objects’ attributes, such as the fragility of a rooflight or the method of cleaning, are not easily recorded within a design when using standard CAD tools. The KBS prototype allows the designer to add attributes, which are relevant to health and safety, to objects in their designs.

(c) An investigation was carried out regarding the viability of a system which will carry out checks on a design in order to establish if there are any health and safety risks in the design. Any risks found are alerted to the designer, together with information on how to reduce the risk or remove the hazard completely. This work was based on a system currently being implemented in Singapore, which electronically checks designs against building regulations.

The report details a requirements analysis which was made in order to establish in more detail the best means to deliver relevant information to designers, and also to get a better idea of what the ‘relevant information’ is. The report further describes the health and safety data gathering, structuring and delivery methods.

Evaluation showed positive feedback about having easy-to-access health and safety information. The tool which checks designs for health and safety risks has great potential, for checking not only for health and safety risks, but also for other authorities’ regulations. The downside is that generally, designers do not take the definition of construction procedures to be their responsibility, and so the uptake of the KBS may be limited in this area. There is also
an issue concerning whether designers will spend their time accessing and using the KBS, even though it could save them time in the long run.

Recommendations are made for a phased approach to full implementation of the system. It is recommended that the provision of health and safety information and the definition of building object attributes should be implemented first, using the prototype’s structure. The tool which checks designs for health and safety risks would be best implemented subsequently within a collaborative project with other national regulatory authorities, for example, the Building Regulations Division.
1 INTRODUCTION

The Health and Safety Executive is committed to reducing the number of accidents which occur within the construction industry. There is a belief that the poor health and safety record can be improved by encouraging designers to give more consideration to health and safety matters at the design stage. This is in keeping with the principles of the Construction (Design and Management) Regulations 1994 (CDM) that place a responsibility on designers to ensure that designs are not only adequate in their final state, but can be safely constructed and maintained.

Currently some designers may only take health and safety issues into account at certain stages in a project, for example, during design reviews or when the health and safety plan is being written. Ideally, designers should think about health and safety on a day-to-day basis from the beginning of a project, be aware of the relevant information available, have it at hand, and record within their design the attributes which may influence health and safety during construction and maintenance of the structure.

This project's aim is to prototype a method of providing designers with easy access to relevant health and safety information, by establishing a means of structuring HSE's information as a Knowledge Based System (KBS) and delivering it to designers. The project is an initial development project to demonstrate the principles of delivery and potential acceptance of a KBS based approach, and to provide recommendations for full-scale implementation.

A KBS is taken to be a system in which human expertise is structured, enabling the system to diagnose situations and provide information and recommendations without the human expert being present. A KBS emulates the knowledge and the guidance given by health and safety experts.

One phase of the project investigated the viability of a system which will carry out checks on a design in order to establish if there are any health and safety risks in the design. Any risks found would be alerted to the designer, together with information on how to reduce the risk or remove the hazard completely. This work was based on a system currently being implemented in Singapore, which electronically checks designs against building regulations.

This document firstly describes the background of the project, including a previous study and the technical basis of the prototype. The International Alliance for Interoperability's (IAI) Industry Foundation Classes (IFC) were used for structuring the data. Software developed by novaSPRINT in Singapore was used for the design checking mechanism.

The report details a requirements analysis which was made in order to establish in more detail the best means to deliver relevant information to designers, and also to get a better idea of what the 'relevant information' is. The report further describes the health and safety data gathering, structuring and delivery methods. Findings are given following reviews by designers. Final recommendations are made for full implementation of the system.
2 PROJECT OBJECTIVES AND WORK PHASES

The project objectives in detail were:

1. To develop a template for the structuring of HSE information as a database suitable for use in a KBS.
2. To develop a pilot demonstration of how the data could be delivered through common design tools used in the construction industry.
3. To determine the viability of utilising novaSPRINT’s current building regulation checking architecture for testing designs for health and safety issues and alerting the designer.
4. To recommend a strategy for fully implementing a KBS based health and safety guidance portal for construction designers.

The work programme was split into the following phases:

1. Detailed requirements. The overall project objectives included ‘presenting health and safety information to designers’. This needed to be looked at in more detail in order to establish what kind of data designers would find worthwhile.
2. Data Gathering. This phase involved collecting the required data.
3. Data Structuring. In this phase the data was structured so that it could be presented successfully to designers.
4. Data Delivery. This phase implemented the KBS data within the chosen architecture.
5. Findings. Feedback was received from designers.
3 BACKGROUND

3.1 PREVIOUS STUDY

A previous study (Reference 1), an evaluation of simulation based design tools as a means of improving health and safety in the construction industries, concluded that the general CAD and specialist design packages currently in use within construction do not include features directly related to the health and safety aspects of design. Furthermore, there is little evidence to suggest that such features will be implemented in the immediate future.

Consequently, it was recommended that in order to achieve the goal of having health and safety information readily available to designers during project design, the Health and Safety Executive must be proactive in the provision and delivery of such information.

The previous study had also identified considerable interest from within the design sector of the construction industry in the use of knowledge based systems (KBS) to supply relevant information, including health and safety data, during the design process.

The fact that knowledge based systems are seen as having the potential to improve productivity, rather than being yet another overhead in the design process, makes it much easier to encourage take up of the concept. It may also be possible for an individual organisation to customise a KBS with its own knowledge and expertise, further enhancing the usefulness of the KBS and increasing its attractiveness.

3.2 TECHNICAL BACKGROUND

In order to deliver the knowledge based system a suitable technical architecture had to be found. The technical challenge was to find a method to integrate the KBS with standard desktop CAD packages, and to find a means by which designs could be checked to find any health and safety risks. It was found that the International Alliance of Interoperability (IAI) and NovaSPRINT provided the best options.

3.2.1 International Alliance of Interoperability (IAI)

The IAI’s Vision is ‘To enable software interoperability in the AEC/FM industry’. Their mission statement is ‘To provide a universal basis for process improvement and information sharing in the construction and facilities management industries’.

The IAI has developed a file format for data objects called the Industry Foundation Classes (IFC). The IFCs are used for sharing and exchanging information between CAD software applications in the construction industry. The IFC format is non-proprietary and is available globally, not just to IAI members. Many CAD system vendors have configured their packages so that they can import and export IFCs, including AutoDesk Architectural Desktop, Graphisoft ArchiCAD and Bentley Systems MicroStation products.

An IFC object represents an individual building entity such as a door, wall, or window, and includes data relevant to that entity. IFC objects can contain information such as structure, geometry, and the three-dimensional description. They also have other properties, for example, product name, material and cost. IFC Property Sets can be set up specifically to contain the information required for a particular project. It was considered that the Property Sets would be used to set up properties specific to health and safety considerations, such as
lifting equipment, fragility or the cleaning method. The Property Sets could link to textual health and safety information, wherever it may be held.

IFCs are intended to consider the whole life cycle of a structure, including design, construction, operation, maintenance and demolition. An IFC model can be used to store information throughout the whole life cycle, and be accessed by many participants utilising varied software applications.

More details on the IAI and the IFCs are available on the IAI website www.iai.org.uk.

### 3.2.2 CORENET and novaSPRINT

In Singapore, CORENET (COnstruction and Real Estate NETwork) is a major IT initiative led by Singapore’s Ministry of National Development and driven by the Building and Construction Authority in collaboration with other public and private organisations. The objective of CORENET is to re-engineer the business processes of the construction industry to achieve a quantum leap in turnaround time, productivity and quality. CORENET revolves around developing IT systems and key infrastructure to integrate the major processes of a building project life cycle.

With relevance to this KBS project is their initiative to have a mandatory process by which all building designs must be checked electronically against the building regulations. The software is being developed by novaSPRINT. Architects and designers will be able to submit their designs electronically using the CORENET website. The design will be automatically checked for building regulation compliance by the software, and any failures will be reported back to the designers. There is a 3D browser which displays the design and highlights the failures.

The designs submitted for compliance-checking have to be formatted using the IAI IFCs. The regulation checking process only checks IFC objects.

The building regulations compliance checking is analogous to the checking of designs against health and safety risks. It was decided that rather than ‘reinventing the wheel’ as regards the rule checking, modifying novaSPRINT’s building regulations technology was the best option.

More details on CORENET are available on their website www.corenet.gov.sg.
4 DETAILED REQUIREMENTS STUDY

In this phase NNC looked in greater detail at what type of information would be of benefit to designers and with what data they would be encouraged to use the KBS.

A study was carried out to establish what designers’ current behaviour is regarding health and safety issues in their designs, and their attitudes towards the CDM Regulations. Some of this area has been covered before in previous HSE studies, and the need to provide health and safety information for designers is well known (otherwise this project would not have existed!). However, this study was required in this case to establish what kind of tool would be beneficial to them, and what type of information would be worthwhile.

It must be pointed out that the following items are taken from comments made by some designers, including their opinions of the processes carried out by other designers. The bad points are illustrations of what is lacking regarding the behaviour of some, but not all, designers.

4.1 DESIGNER BEHAVIOUR: GOOD POINTS

- Regulation 13 within the CDM regulations has given designers a responsibility which has made them think more about health and safety, for example, avoiding toxic floor glue in confined spaces.
- Designers now ensure that their ‘backs are covered’ regarding CDM.
- Some designers may specify construction methods if an object is ‘unusual’, for example, the lifting method if the position of the centre of gravity is not apparent.
- The health and safety plan picks up obvious risks.
- Site issues such as ground levelling will be in the health and safety plan.
- Some designers provide operational and maintenance manuals which contain particular details such as maintenance areas and roof access, but unfortunately they are not comprehensive. For example, they may not include window cleaning.

4.2 DESIGNER BEHAVIOUR: BAD POINTS

- The general opinion was that if it’s not compulsory to add health and safety features, why do it?
- Adding health and safety items, such as anchor points, costs money and takes up time on the project, so these are the first things to be cut back.
- Time is spent complying with British Standards and Building Regulations, so spending more time on additional health and safety matters is not considered worthwhile.
- CDM Regulations are seen as a burden: “more forms to fill in”.
- Many designers were not aware of some of the very helpful published information on health and safety. For example, one designer did not know that the Health and Safety Executive has a website. It was felt that it is difficult to find out about, and obtain, health and safety information. Also, some information within the publications is not succinct, so it takes too much time to find the facts required.
- Most designers are not trained in construction, do not think about construction methods, and therefore do not enter construction details in their designs.
- In their designs, designers will only specify the manufacturer and item, for example, a make and type of window, but not how it is to be lifted or fitted.
- Designers assume that the suppliers or the sub-contractors know the best way to carry out all the operations required on-site, ‘they are the experts’.
• Designers assume that construction sequencing is the responsibility of the constructors and fitters.
• Designers may not think about the weight of materials, and assume that the contractors will have and use the right lifting gear.
• Clients and/or designers specify a standard that subcontractors must meet within their contract. Once this standard has been agreed, together with agreeing to the contractor’s method statements, this ‘covers’ the clients and designers should anything go wrong on site.
• Designers may misinterpret details which are included in the manufacturer’s catalogue. If catalogues state that the product meets British Standards, it may be assumed that this is ‘OK’ as far as health and safety is concerned.
• All designers spoken to were unaware of the fragility classifications. For example, it was assumed that all rooflights available meet standards, and so are non-fragile.
• Designers often exclude maintenance details in the design. In some cases window cleaning methods were not specified anywhere, or the fact that maintenance strips around a building had to be kept clear in order for cleaning equipment to be used.
• Designers commented that, as far as protection on roofs was concerned, “No-one should be allowed on it”, “guard rails would spoil what it looks like”, and “people shouldn’t be up there”.
• Clients generally do not consider health and safety issues themselves and do not state to external designers what health and safety features, such as roof protection, should be included.

4.3 DESIGNERS’ COMMENTS ON THE PROPOSED HSE KBS

• It was stated that a tool which is a central repository for, or gives a link to, useful health and safety data would be worthwhile.
• It was stated that the tool may be worthwhile for small projects where the designer has more say in the construction process.
• It was thought that a tool is a good idea, especially for picking up health and safety faults in the system, and so cutting time during risk assessments.
• Checking on fragile materials would be worthwhile.
• Generally there is a negative attitude towards changing designers’ behaviour. The tool must give benefit to designers.

4.4 STUDY CONCLUSIONS

The following conclusions were drawn following the above discussions with designers, regarding the content of the KBS:

• The KBS must be a time-saver for designers.
• The KBS must give designers something for nothing, that is, providing information at no cost or time to them.
• There is a general lack of awareness of the health and safety documentation that is available. The KBS must provide this information quickly and easily.
• Forcing designers to consider and define which construction methods should be used will be very difficult. More communication between designers and constructors should be carried out during the design phase, so that constructors can influence, and add construction details into the design. The KBS may have limited use to designers as far as construction methods are concerned. However, making them think about how workers are to be protected during construction will be a benefit.
• The KBS can force designers to think about maintenance operations, and add them into designs and consider protection for workers during maintenance.
• The KBS should alert designers to consider worker protection throughout the whole lifecycle of the building.
• A tool which checks designs against HSE rules and alerts designers to health and safety risks was considered to have good potential.
5 DATA GATHERING

This section describes how the data which were to be included in, and to structure, the KBS were gathered.

5.1 WHICH DATA?

The information required for the prototype KBS was restricted to information concerning the hazards whilst working at height, and accidents due to falling and dropping of objects. It was found that focussing on rooflights covered most of these topics sufficiently. The information was concerned with how the risk of accidents could be avoided or reduced at the design phase.

The data required were split into three different areas:

5.1.1 Textual health and safety information

This is textual information which will be displayed whilst designers are using their CAD tool. The information will be general, or relate to an individual construction object, for example a door, window, opening, roofslab or floorslab. The intention is that when a designer is using a CAD package, for a particular type of object they can view the relevant health and safety data for that object. For example, whilst they are adding a rooflight to their design, they can easily view information about the fragility of rooflights. Linked to this data will be general information.

5.1.2 Health and safety rules

Rules are required in order to electronically check whole building designs for health and safety risks, and to give the relevant warnings to the designer. These rules are similar to those used in the Singapore building regulations system, for example, "Every staircase shall be provided with at least a handrail on one side of the staircase". The health and safety rules for the KBS do not relate specifically to building regulations. Examples of health and safety rules are:

There is an extreme risk if a rooflight is fragile and it has no permanent protection around it.
There is a high risk if a roof slab weighs more than 20kg and it is being lifted manually.

The components of a rule are:
- the parameters which must be checked and the values at which they will fail
- the result if the rule fails, e.g. medium risk or some risk
- guidance for reducing the risk, e.g. place permanent protection around the rooflight; use a crane for lifting roof slabs
- reference to a relevant health and safety publication, preferably to a specific section
- a reference and/or electronic link to the relevant section of the textual health and safety data

5.1.3 Object properties

Designers must be able to record relevant health and safety information within their designs. These data, such as fragility, lifting equipment or cleaning method, are not currently available in CAD applications. These data are also required to enable the implementation of health and
safety rule checking. The extra properties needed had to be defined in this stage of the project.

5.2 DATA SOURCES

5.2.1 Documentation

The major sources of information were:
- Free leaflets and documents available from the HSE, HSC and HSE Northern Ireland
- Free leaflets and documents downloadable from the HSE and HSE Northern Ireland websites
- Free and purchased documents available from HSE books
- HSE research documents downloadable from the HSE website
- Accident summaries, internal HSE documentation
- Purchased documents from CIRIA
- Building Regulations
- British Standards
- Office of the Deputy Prime Minister: Construction Legislation

Other relevant information was found from:
- The National Federation of Roofing Contractors
- Roof product manufacturers’ websites and catalogues
- National Institute for Occupational Safety and Health (USA)
- Electronic Library for Construction Safety and Health, eLCOSH (USA)

The following documents were found to be the best sources of information regarding avoiding risks whilst working at height, and general design:
- Health and Safety in Roof Work: HSG33
- Working on Roofs: INDG284
- Designing for Health and Safety in Construction, HSE
- CDM Regulations - work sector guidance for designers, CIRIA Report 166
- CDM primer. an introduction and first-stop reference for Designers on the Construction (Design & Management) Regulations, Haverstock

5.2.2 Health and safety consultant

A health and safety consultant was employed on the project to assist with the data gathering phase. He is a retired HSE Principal Construction Inspector, and is currently carrying out consultancy work which is heavily biased towards work connected with the CDM Regulations. He has a great deal of experience of inspecting construction sites and being a Planning Supervisor. It is the knowledge of, and the guidance given by, consultants like this which are to be emulated by the KBS.

From his practical experience the consultant helped to identify the major types of health and safety problems which are found on building sites. He also gave examples of what he would look for in a design if he was checking it himself for health and safety risks. He helped to define the object properties of which the values should be checked in the health and safety rules. His input gave the basis of how the data gathered should be structured.
5.2.3 Designers

Talks were held with designers, both internal and external to NNC, about their experiences. Some designers had experience working on construction sites and carrying out the Planning Supervisor role.

5.3 OVERALL COMMENTS

Data gathering confirmed that very good relevant documentation is available, however:

- a time consuming search is required to find out what documentation exists
- often the documentation must be purchased or borrowed from a library

It is difficult, therefore, for designers to have the relevant information readily available.
6 DATA STRUCTURING

In this phase of work the structure of the health and safety information was defined. There are three areas of data, as described in the previous section, that is:

- textual health and safety data
- health and safety rules
- object properties

These data have to be structured at a lower level. Most of the structuring is common to all three areas.

6.1 RISK LEVEL

The HSE definition of risk is “the likelihood that harm from a particular hazard will occur and the possible extent of the harm”, where a hazard is something with the potential to cause harm. The main question here is “what message is to be given to the designers?” As far as health and safety is concerned, there is no clear right or wrong. Rarely can a designer be told “You must do this...” or “Your design is wrong”.

The messages to be given to designers are “The construction of your building will be less risky if you avoid x” and “Your building has a high risk because of y, but you can reduce the risk by doing z”. Designers must be given guidance on what is hazardous, and how the risks can be avoided or reduced for each hazard. The rule checking tool must identify the risks in the design and give specific guidance on how to reduce that risk.

There are several levels of risk. The risk levels can be identified mainly by how much protection is given to an individual worker, or to all workers or members of the public. Whilst structuring the data, the following 6 levels were used. Examples are given for rooflights.

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Risk</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Very high risk</td>
<td>No protection</td>
<td>No temporary or permanent protection has been specified for construction or maintenance of a rooflight</td>
</tr>
<tr>
<td>4</td>
<td>High risk</td>
<td>Personal protection only</td>
<td>Anchor points provided on the roof</td>
</tr>
<tr>
<td>3</td>
<td>Medium Risk</td>
<td>Temporary group protection</td>
<td>Temporary guard rails specified around rooflights whilst roof maintenance is to be carried out</td>
</tr>
<tr>
<td>2</td>
<td>Some risk</td>
<td>Permanent group protection</td>
<td>The rooflights are domed and project above the level of the roof.</td>
</tr>
<tr>
<td>1</td>
<td>Low risk</td>
<td>More than one type of protection</td>
<td>The rooflights are domed and they have a metal mesh layer installed under the rooflight</td>
</tr>
<tr>
<td>0</td>
<td>No risk</td>
<td>The risk has been avoided totally</td>
<td>Rooflight removed from the design</td>
</tr>
</tbody>
</table>

The designer should identify hazards. Firstly they should consider removing the hazard completely. If this is not possible, they should consider how they are going to protect anyone who may be at risk from the hazard. Again, if this is not to be added to the design, they must
think about how individual workers will be protected, for example by specifying fall arrest equipment and state in the design where anchor points or running lines will be installed.

The data had to be structured so that guidance is given to designers in order for them to be able to identify hazards and then make reasonable decisions about how they can avoid or reduce the risks, and to appreciate what levels of risk the hazard presents.

6.2 ACCIDENT CAUSES

The guidance given to designers, and the rules used to check designs, can be split into several groups which were defined mainly by the possible causes of accidents. The groups may overlap in some areas.

Firstly the hazards which exist in a building depend on which phase of its lifecycle it is in. The data can be split into:
- construction
- maintenance/cleaning
- operational
- demolition
- general

Secondly, the properties of a building entity may cause a hazard, no matter what phase it is in. The types of properties are:
- product properties, for example, fragility
- entity location, for example, only 1m from a roof edge
- protection provided on the entity, for example, guard rails

For the prototype, the data was split into the following groups:
- construction
- maintenance/cleaning
- product properties
- entity location
- protection
- general

6.3 BUILDING ENTITIES

Different building entities have different types of hazards associated with them. There are also similar groups of entities which have the same hazards, and so can be grouped together for guidance and rule checking.

The different types of building entities are fairly standard, and are available from architectural CAD packages and from the IFC model. Examples are:
- rooflight
- vertical window
- roof slab
- roof
- wall

Groups of entities which were considered in the KBS prototype were:
- all entities that have a location at height
• windows (vertical windows and rooflights)
• all entities

6.4 BUILDING ENTITY PROPERTIES

For each building entity, there are many properties which can cause a hazard. For example, for a rooflight, such properties are:
• size
• fragility
• protection placed around it
• fitting method
• lifting method

The standard entities in architectural CAD applications do not hold some of the properties that are needed for the KBS, for example, fragility classification. For each building entity a set of new properties had to be defined (a Property Set). For each property in a Property Set the following had to be defined:
• property name
• property description
• data type
• default value
• if necessary, enumerated values, that is, a list of the only possible values

Each Property Set relates either to an individual type of entity (e.g. rooflights) or a group of entities or activities (e.g. construction at height). Each Property Set also has a policy name specified for it. A set of values for the properties may be set according to manufacturer's specifications. For example, the construction methods for a rooflight may be set according to the rooflight manufacturer Ward, so the policy name for the rooflight construction Property Set may be Ward Standard.

Note that a Property Set Definition (PSD) is a definition of the Property Set, as described above. A Property Set Instance is a collection of the actual values of the properties for a specific entity.

6.5 TEXTUAL INFORMATION

The textual information which is to be displayed to designers whilst using a CAD tool was split according to the attributes described above, that is:
• building entities or groups of entities e.g. wall, anything at height
• accident cause e.g. construction

The textual information gives a description of the hazards associated with the entity and accident cause. The text includes the risks associated with the hazards, and guidance to the values of the entity's properties which will reduce or avoid the risk.

6.6 RULES

A ‘rule’ in the context of the KBS is a check which is made on an object or objects within a building design. A rule checks the values of an object’s properties against set values. The object/objects will either pass or fail the rule. However, as discussed above, there are different levels of failure. If a rule fails, an indication must be given as to the level of risk that will occur if action is not taken to reduce the risk.
6.6.1 Rule structure

The rules were split into groups in the same way as the textual information and Property Sets. For example, there are rules for:
- rooflight construction
- rooflight maintenance
- rooflight protection
- rooflight location
- rooflight product details
- rooflight general
- all object construction
- etc

In many cases there are several similar sub-rules within an overall main rule. For example, whilst checking the fragility of the rooflight material, the type of material can be checked, together with the fragility classification.

Using rooflight material fragility as an example, the following section shows how the structure of the rules was developed.

The raw rules initially were of the type:
- Do not build a rooflight out of glass.
- Make sure the rooflight is not fragile.
- It is best if the rooflight material has Fragility Category A

The rules had to be structured so that they became:

<table>
<thead>
<tr>
<th>Check</th>
<th>Result</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>rooflight material is glass</td>
<td>fail</td>
<td>very high</td>
</tr>
<tr>
<td>rooflight material is fragile</td>
<td>fail</td>
<td>very high</td>
</tr>
<tr>
<td>rooflight material has Fragility Category C</td>
<td>fail</td>
<td>very high</td>
</tr>
<tr>
<td>rooflight material has Fragility Category B</td>
<td>fail</td>
<td>high</td>
</tr>
<tr>
<td>rooflight material has Fragility Category A</td>
<td>pass</td>
<td>some</td>
</tr>
<tr>
<td>rooflight material is non-fragile</td>
<td>pass</td>
<td>some</td>
</tr>
</tbody>
</table>

If a rule fails, the user has to be informed about the rule failure. The information which should be presented to the user is:
- what type of check was being carried out
- why the rule failed
- what the risk is
- what could be done to reduce the risk
- references to appropriate documentation
For example:

<table>
<thead>
<tr>
<th>Rule</th>
<th>A check is being carried out on the fragility of rooflight material.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure details</td>
<td>Rooflight id xxx at location x, y, z failed because it is made of material with Fragility Category C.</td>
</tr>
<tr>
<td>Risk</td>
<td>The risk is very high.</td>
</tr>
<tr>
<td>Solution</td>
<td>Replace the material with one having Fragility Category A or B, preferably A, such as heavyweight GRP.</td>
</tr>
<tr>
<td>Reference</td>
<td>Appendix 4, Fragility; tests and specifications, Health and Safety in Roof Work, HSG33</td>
</tr>
</tbody>
</table>

The rules were structured so that the above information will be provided.

### 6.6.2 Acceptable risk

In addition to the above, each rule has been set up so that the user can specify an acceptable risk level. This means that if, say, the user sets an acceptable risk level of 2 (some risk) then rules which find a risk of 2 or less will not fail. This will help the designer to filter out the lower risk items. During the first couple of times that the design is being checked, the high risk failures will be easier to identify.
7 FUNCTIONALITY OF THE KBS

Essential to the success of presenting health and safety information to designers is the means of delivery. Ease of access within the normal design office environment is seen as crucial. This section is a guide to the functionality of the KBS, and describes the actions that the designer can take. Detailed technical information about how the KBS has been implemented is contained in Appendix 1.

There are several actions which, in a full system, would be carried out by a health and safety expert, and would not be part of a designer’s activities. One example of functionality for a health and safety expert is “Write the health and safety guidance”. These actions are included, and are noted as being ‘H&S expert actions’.

Figure 1 is a flow diagram showing the functionality available for creating and viewing the guidance text and Property Sets, and how these are linked to a building design within a CAD tool.

7.1 HEALTH AND SAFETY TEXTUAL INFORMATION AND GUIDANCE

7.1.1 Health and safety expert actions

Create health and safety textual information
The format of the files holding the health and safety guidance information has been kept very simple, so that it is easy to add and modify information. Appendix 1 contains technical details about the format, and Appendix 2 gives instructions about how to make changes. The files contain text, plus links to electronic documents and websites.

7.1.2 Designer actions

View health and safety information
The information can be viewed either standalone, or is available within the CAD tool and the rule checking tool. The information is displayed using Microsoft Internet Explorer. The overall structure is a collection of pages which are linked together, so that the designer can navigate through all the pages easily. Pages may have links to electronic documents and websites.

Figure 2 shows the main index page. The index shows the top level of how the data has been structured. There are sections giving general information about CDM, construction, etc, and there are sections for specific building objects, such as rooflights and windows.

Figure 3 shows a page for general design, where the designer can view the HSE website, and several documents.

Figure 4 is the main page for rooflights. The information for rooflights has been structured at a lower level, to give guidance on, for example, maintenance for rooflights specifically.

Figure 5 shows part of the information for rooflight maintenance. The text contains guidance about the attributes that designers should consider, together with an indication as to the risk levels. The information about the risk levels relates directly to the checks which are carried out on the design in the rule checker. Figure 6 shows information about rooflight product details.
Within the pages of health and safety information, the designer can also view the definitions of the Property Sets (see below).

### 7.2 PROPERTY SETS

#### 7.2.1 Health and safety expert actions

*Create Property Sets, Add link to health and safety information*

The Property Sets are created in Microsoft Excel. A worksheet is set up for each Property Set. Note that two types of file are created, a Property Set Definition (PSD) and a Property Set Instance. A Definition defines the properties, and an Instance is a collection of the actual values of the properties for a specific entity (see Section 6.4).

Figure 7 shows a worksheet for setting up a Property Set containing rooflight specific properties. The top section is the Definition, naming and describing the properties, together with enumerated values. The bottom section contains five Instances, giving values to the properties. Each Property Set has a Policy Name, in this example Policy 1, etc. The instances are what will be attached to building objects in the design.

One property at the right hand side is the DocumentLink. This is a reference to the relevant section of the health and safety information. As can be seen in the CAD tool section, this allows the relevant information to be displayed within the CAD tool.

A macro has been written which takes the information in the Excel worksheets, and then creates separate files for each Property Set Definition and Property Set Instance.

#### 7.2.2 Designer actions

*View Property Sets*

The designer can easily view the contents of the Property Set Definitions and Instances. The files are formatted simply, so that they can be viewed in Microsoft Internet Explorer. The files can be viewed standalone, or from within the health and safety information. The data can also be accessed in the CAD tool when the Property Sets have been integrated (see next section).

Figure 8 is an example of a Property Set Definition and Figure 9 is a Property Set Instance.

### 7.3 CAD TOOL

This section describes the functionality available to a designer whilst using a CAD tool for their designs. The prototype KBS was developed to integrate with the AutoDesk Architectural Desktop (ADT).

*Attach Property Sets to building objects*

After the designer has viewed the Property Sets, and has decided which ones are appropriate for the building objects in their design, then Property Sets can be attached to the relevant objects. The designer selects a Property Set Instance file in Windows Explorer and then ‘drags and drops’ the file onto the design in the CAD tool. A macro has been written which detects this. A display of the Property Set is shown (Figure 10) and the designer confirms that this is what is required. The designer then selects the object or objects onto which the Property Set is to be attached. The colour of the object(s) changes to yellow, to indicate that a Property Set is attached. Many more Property Sets can be added.
View and Modify Property Sets
If an object has a Property Set(s) attached, the values can be displayed using the standard shortcut menu for an object, and selecting ‘Schedule Data’ (Figure 11). The values can be modified here.

The Property Set Definitions can be viewed and modified in ADT by selecting Documentation/Schedule Data/Property Set Definitions from the main menu. Figures 12 and 13 show examples of viewing and modifying one PSD.

View Health and Safety Information
The relevant health and safety information is attached to objects in the design by using hyperlinks. The setting up of hyperlinks is a standard feature on the main menu and shortcut menus in ADT.

When a Property Set is attached to an object a hyperlink is set up automatically. When the cursor moves over an object with information attached, the cursor changes to alert the user that health and safety guidance is available (see Figure 14). The designer then opens the information using the object’s shortcut menu. The information displayed is as described in Section 7.1, with the addition that the first page shown will be one relevant to the object.

Save the design in IFC format
If the design is to be analysed by the rule checking tool, the designer must save the design in IFC format. This is done simply by typing ‘ifc2export’ on the command line and supplying a file name.

7.4 RULE CHECKING
Figure 15 is a flow diagram showing the functionality available when rule checking is being carried out. Appendix 1 contains technical details about how the rule checking tool was implemented.

Note that in some of the displays the word ‘Clause’ is used instead of ‘Rule’. The two words are synonymous in the context of the rule checker.

7.4.1 Health and safety expert actions
Create and load the rules
The health and safety expert must create three files for each rule, containing:
1. The rule, written in a software language.
2. A description of the rule, to be displayed to the designer. This description may contain a link to the health and safety information, or to an electronic form of a relevant document.
3. A list of parameters and values which can be changed using the tool.

The expert will then load the rules into the rule checking tool.

Modify Parameter Values and Acceptable Risk
The expert can modify a rule’s parameter values using the tool. Figure 16 is the display for one rule.

One of the parameters is the Acceptable Risk. The Acceptable Risk can be used to filter out rule failures where the resulting risk is relatively low. The user enters a value from 0 to 5.
(defined in Section 6.1), and any failures of that rule which have a risk less than or equal to that value will not be reported.

7.4.2 Designer actions

Modify Parameter Values and Acceptable Risk
See above.

Load the design into the tool
The designer loads the design into the rule checker, simply by providing the file name. Figure 17 shows an example of the user’s project library.

Start the 3D viewer
Selecting the ‘Viewer’ option on the Project Library screen starts the 3D viewer. Figure 18 shows an example of a design within the viewer. On the right hand side is the 3D image, and the toolbar at the top has several options on how the image is displayed, for example, zooming and rotating. On the left hand side there are three tabs, Object, Clause and Non-compliances. The Object tab, as shown in the figure, lists all the objects in the building model, and gives details about each object. When one object is selected by the user, a menu is displayed giving options such as hiding the object on the 3D display, or showing its coordinates.

View the rule descriptions
The second tab on the left hand side lists the rules. If one rule is selected, a description is displayed. Figure 19 shows one example. The description contains an overall explanation of the rule, together with details of each individual sub-rule. The sub-rule details include:

- description
- possible solution
- risk factor
- rule basis, i.e. a reference to the section of the relevant health and safety document

Also given is a link to online documentation. This can be a link to the health and safety information, an electronic copy of a document, or a website. Thus the designer is given easily available information for them to understand the rules.

The rule descriptions can be viewed standalone, without having to run the rule checking tool.

Select rules and objects for checking
The designer can select which rules are to be run against which types of objects. The default is that all rules are run against all objects. The user may decide, for example, to only run maintenance rules for windows.

Run the rules
The rule checking is run by pressing the red button on the toolbar at the top of the screen.

View non-compliances
After the rules have been run, a list of the rules which have failed are shown on the non-compliances results tab. Figure 20 shows the display. On the left hand side is a list of the rules which have failed. The list can be expanded to show which objects have failed for each
rule. If an object is selected from the list, it can be highlighted on the 3D display (it flashes). A description of the failure is presented to the user, including:

- the risk
- the reason for the failure
- possible solutions
- a reference to relevant documentation

The designer can record remarks for each failure. The purpose of this could be, for example, to explain changes which will be made to the design, or give reasons as to why that particular risk is acceptable.

*Create and display non-compliance report*

The rule checker toolbar has an option to create a non-compliance report. This report is saved in Microsoft Word format. The report can be viewed from the rule checking tool (see Figure 17) or standalone. The report lists the rules which have failed, and on which individual objects the rules have failed on. Any remarks added are also displayed. An example of part of a report is shown in Figure 21.
8 FINDINGS

This section contains a summary of the findings taken from the implementation of the KBS and from feedback given by potential users.

8.1 FINDINGS DURING IMPLEMENTATION

8.1.1 Positive points

The health and safety textual information, the Property Set Definitions and the Property Set Instances can be set up and viewed independently from the CAD application being used. Anybody can view the information, as long as they have a recent version of Internet Explorer installed on their PC.

The designer can create new Property Sets and modify the current ones easily using Excel. The instantiation tool can be run easily from an Excel worksheet.

The format of the health and safety textual information was kept as simple as possible so that modifications and additions can be made to the text by designers, requiring no knowledge of XML. The designer can also add links to any documentation, for example, company procedures.

The rule checking system provides the functionality required for carrying out the health and safety checks on designs, and contains a good user interface for displaying the results.

8.1.2 Negative points

During implementation it was found that the functionality being provided to the designer had to be compromised due to some technical limitations within ADT and the CORENET system.

Ideally, within the CAD system, it is preferable that when a designer is viewing the relevant health and safety properties of an object, guidance text is available immediately, without the designer having to perform any actions in order to see this text. It was intended initially that the guidance text would be included within the Property Set Instances, that is, the text would be a value of a ‘guidance’ property. However, within ADT, when viewing Property Set values, the size of the box displaying property values was inadequate for text display. Also, the boxes displaying the values do not identify URLs, so a link to the text cannot be created. Hence the use of hyperlinks.

In ADT, only one hyperlink can be added to an object. The designer can easily access the health and safety textual information, but may have to navigate through it to find the relevant information.

Within the rule checker, each rule (and its sub-rules) is run independently from any other rule. If one rule fails it may be inappropriate to run, and display the result of, another rule. A rule is run on every relevant object (for example, every window), again independently. The consequence of this is that there may be too much output produced by the rules checker.

In the prototype an ‘accepted risk’ parameter has been set up for each rule so that rules which fail will only be reported if the risk is worse than the accepted risk. This will reduce the output. However, the accepted risk value has to be set up for each rule separately. One value
which covers all the rules would be more practical, but unfortunately this cannot be implemented currently.

Ideally, a rule checking system would run locally on a designer’s computer. Whenever appropriate the designer would press a rule checker button and any non-compliances would be instantly displayed on the screen. The rule checking system from novaSPRINT which was used for the prototype does not do this. It is a client-server system run over the internet, and requires the designer to perform more actions than just pressing a button. An alternative to the novaSPRINT system is described in Section 9.

8.1.3 Potential improvements

During the implementation of the prototype some potential functionality was identified but not implemented. Also, planned changes to the IFC structure could provide additional opportunities for improvements to the system.

A future improvement to the IFCs will be that the value of a property can be a hyperlink, or URL, to text or a document. This would solve the problem described above about having guidance text available immediately whilst the designer is viewing health and safety relevant properties.

It would be beneficial if there was a property set up within a design which states the current phase within a building’s lifecycle, for example conceptual, detailed design, or operational. The health and safety guidance and the rules being carried out could then be tailored to be appropriate to that phase. The same approach could also be carried out when considering the building’s usage, for example, residential, school, office, hospital.

It is anticipated that soon it will be possible to easily include manufacturers’ product details within a design. The mechanism to carry this out would be to drag and drop files from a manufacturer’s website onto the design, similar to dragging and dropping the Property Sets in the KBS prototype. Health and safety information and instructions could be contained within the file.

8.2 KBS PROTOTYPE FEEDBACK

Feedback on the KBS was obtained from staff within NNC, and from people external to NNC who carry out a variety of roles in the construction and manufacturing industries, universities and local government. These roles included:

- architects and architectural technicians
- design engineers
- quantity surveyors
- planners
- technical sales
- academics who specialise in information technology within construction business processes

The general opinion is that the KBS is an excellent tool, but the main negative issue is, will designers give any of their time to use it? Designers may feel that any health and safety risks are picked up during a risk analysis, so why should they spend more time considering health and safety beforehand? Designers may not appreciate that using the KBS early in the design phase may save time later on if they must carry out re-iterations of their design to remove
risks found during a risk analysis. It is possible that the KBS would be used during the risk analysis stage.

The following sections give feedback on the KBS contents.

**8.2.1 Negative feedback**

The only negative response by designers to the KBS contents was the feeling that it is not a designer’s role to be adding construction and maintenance information to their designs. Examples of these types of information are the lifting method for roof slabs, the type of scaffolding that is to be used and the cleaning method. This matches some comments made by designers during the Requirements Study and noted in Section 4.2.

If designers do not add construction data onto their designs, the rule checking tool is then limited as to what it can check for. Valuable checks can still be carried out using the size, weight, location and material properties of building objects.

However, the negative criticism described above is a symptom of the problem that the KBS is aimed to solve. A cultural change is required in how designers address health and safety in construction, and the KBS is part of the toolkit to make this change. Positive feedback, given in the next section, shows how the KBS does make designers think about issues which they previously did not consider.

**8.2.2 Positive feedback**

Overall, there was very positive feedback on the contents of the KBS, with great enthusiasm for the concept of checking 3D models electronically. Currently, many companies develop 3D models, but in order to gain regulatory approval they must submit only 2D paper drawings, which is seen as time consuming and costly. Submitting 3D models was seen as being beneficial. There was much interest in the electronic checking of building regulations in Singapore.

The checking of designs against health and safety rules was seen as having great potential and a positive step in the construction process. This tool was seen as being a time saver, and also providing extra checks which could be missed during manual procedures.

As far as further development of the rule checking tool is concerned, having to submit 3D models electronically via a website, with the rule checking being carried out remotely, rather than locally, was not seen as being a hindrance. Having a checking tool available, no matter where it is located, was seen as being a major benefit.

The KBS’s links to relevant documents and websites was seen as being very useful. Having one location through which all health and safety information for designers can be accessed is definitely a time-saver. Also, using the KBS, it is easier for designers to become aware of publications which they did not know existed beforehand.

Designers stated that generally health and safety guidance can be too unspecific, that is, it does not tell them exactly what to. The information provided in the textual information in the KBS was seen as succinct and relevant. The listing of specific hazards, together with giving them a ‘score’, i.e. a risk level, was considered very useful, and a good method of displaying information.
The textual information displayed is succinct, and this was seen as being beneficial because it makes the designers think about an aspect of the design, and can then refer to the references if more information is needed.

During presentations of the KBS, even though the objective was to demonstrate the functionality of the prototype, the designers picked up the health and safety guidance very quickly, and in some cases acted on it.

Designers feel that their own knowledge of health and safety issues is rather ‘woolly’ and that it is an area that requires expert knowledge. However, when presented with the textual information and the results of the rule checking, the issues were a lot clearer to them and became ‘common sense’ rather than specialised health and safety issues.

Overall, positive feedback was given on the way the health and safety knowledge was structured and presented.
9 FULL SYSTEM DELIVERY OPTIONS

There are several options to be considered in the potential delivery of a full system. The display of health and safety information, together with the provision of health and safety relevant properties, within a CAD system or standalone is mainly independent of how the rule checking is to be delivered.

9.1 HEALTH AND SAFETY INFORMATION AND PROPERTY SETS

The format of the information and the Property Sets requires no modification (this depends on further feedback) following the prototype stage. The work required involves adding more similar expert knowledge.

At the simplest level, the health and safety information and Property Sets can be viewed standalone, not from within a CAD application. The user must have Microsoft Internet Explorer (IE) Version 6.0 installed, or a previous version of IE plus MSXML3.

The HSE would provide CDs and/or a website containing:

- Health and safety textual information
- Standard Property Set Definitions and Instances containing default values
- Instructions on MSXML3 installation

The user would either download the files from the HSE website, or view them on the website.

If the designer is to use a CAD application and utilise the Property Sets and the health and safety information within it, then the HSE would provide, on CD or a website, macros written specifically for particular CAD applications. An example is the drag and drop macro for ADT. Instructions for implementation would also be required.

If the user were to require creating their own Property Sets, modifying Property Set instances and modifying or adding to the textual information, then the HSE would also provide:

- the Property Set instantiation tool in Excel, together with instructions
- the instruction details for text modification (see Appendix 2)

A phased implementation is recommended, following prioritisation of the delivery options and the areas in which health and safety information is provided.

9.2 THE RULE CHECKING SYSTEM

There are three options to be considered whilst regarding the full implementation of the rule checking system:

- A system with the same architecture as the Singapore building regulation system, using the novaSPRINT user interface and 3D browser
- A system carrying out the rule checking on an EDM database (the same as in Singapore), but with a bespoke user interface
- A bespoke program which can be run locally on a designer’s computer
9.2.1 Copying the Singapore building regulations system

This is a multi-user client-server internet based system. The major components on the server side are:

- The hardware, probably a dedicated server system. This would have to be run, maintained and updated
- EDM database with multiple user licences
- Oracle database with appropriate licences
- Server application. This would have to be modified to satisfy the requirements for the HSE system

The user would have to download from an HSE website, or obtain from a CD:

- Customised novaSPRINT user interface and 3D browser
- IFC add-ins for the CAD application. These are also available from the CAD manufacturers’ websites.

The server hardware and software would have to be supported, probably by a commercial support company with assistance from NNC and the IAI regarding software updates.

9.2.2 Customised client-server system

This is also a multi-user client-server internet based system. This is similar to the Singapore system, but with a bespoke user interface which would not require an Oracle database. The major components on the server side are:

- The hardware, probably a dedicated server system. This would have to be run, maintained and updated
- EDM database with multiple user licenses

The user would have to download from an HSE website, or obtain from a CD:

- Bespoke user interface and 3D browser
- IFC add-ins for the CAD application. These are also available from the CAD manufacturers’ websites.

The benefit of providing a client-server system is that the rule checking tool can be updated at any time, and so the users will always be provided with an up-to-date tool.

9.2.3 Bespoke programme for local running

Having implemented the prototype system it has become possible to identify how a standalone bespoke programme could be written to carry out rule checking. This would provide designers with feedback on their designs instantly, requiring little installation. The programme would have to be downloaded onto a designer’s computer and they could run it whenever they wanted.

The HSE would provide a website or CD which contains:

- The programme and any installation instructions
- IFC add-ins for the CAD application. These are also available from the CAD manufacturers’ websites.
The intention is that the designer would:

- Download and install the programme (once)
- Load the IFC add-in for their CAD application (once)
- Export their CAD model in IFC format
- Press a ‘rule checker’ button set up within the CAD application
- The programme would create a report in text which would be displayed on the designer’s screen as soon as the programme has completed

The plus side, comparing this approach to the client-server system:

- Significant reduction in cost
- No server application required
- Immediate response given to the designer

The negative side:

- Maintainability. If rules are added or changed, probably due to changes in legislation, the rule checking tools held by designers will be out of date. It would be a designer’s responsibility to update the tool.
- The programme will have to match the IFC releases being used by the CAD applications. The programme will have to be updated when different IFC releases are implemented.
10 RECOMMENDATIONS

There has been more than sufficient positive feedback on the HSE Knowledge Based System prototype to recommend that it is worthwhile proceeding with further development and delivery of a system to the construction industry.

The major interest shown by the construction industry is in the provision of a system, similar to that which is being implemented in Singapore, where 3D building models can be submitted on-line and checked electronically by the regulatory authorities. This system can check for health and safety risks, and designs can also be checked against building, fire, planning or security regulations. It is recommended that the HSE collaborate with other government departments and discuss the start-up of a programme for development of this system.

The development of an on-line rule checking tool is considered to be a long term project. However, there are several phases that can be carried out in the short term, which will deliver beneficial tools to designers, and will also contribute towards the final system.

As a first step in the development of the on-line rule checking tool, it is recommended that the health and safety guidance information is implemented in full. Having one location by which health and safety guidance relevant to designers can be accessed easily is seen as being very beneficial to designers. The information will have the same structure as in the prototype, and will be available initially standalone, and subsequently from within a CAD tool. The information will eventually have a comprehensive coverage of health and safety issues which are relevant at a project’s conceptual and design stages. It may be practical to carry this out in phases, by first implementing the high priority areas which will give the greatest impact with regard to the health and safety issues of designs. Consideration should also be given to the re-use of the structured information in a construction design risk assessment tool and a computer based training tool.

The Property Sets, which designers can attach to building objects within their designs, should be expanded to cover a wider range of objects (the sets in the prototype focussed on rooflights). The properties included in the current sets need to be reviewed by the HSE and designers, in order to ensure that the properties are those that designers are most likely to utilise. Implementation and delivery of Property Sets is considered to be of lower priority than those of the health and safety information, mainly because it is better to first make designers aware of health and safety issues before providing them with the tools to record property values. The objects for which Property Sets are created should be prioritised and those which will give the most impact will be implemented first.

The full health and safety information and Property Sets should be implemented so that they are useable within the architectural CAD applications used by the majority of designers.
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British Standards Institution 1990

*Code of Practice for the Use of Safety Nets, Containment Nets and Sheets on Constructional Works (BS8093)*
British Standards Institution 1991

*Protection from Falls from a Height. Anchor Devices Requirements and Testing (EN795)*
British Standards Institution 1996

*A Client’s Influence on Health and Safety (Case Study 038)*
Construction Best Practice 2001

*CDM Regulations - Case Study Guidance for Designers, Interim Report (Report 145)*
CIRIA 1995, ISBN 0 8601 7421 2

*CDM Regulations - Work Sector Guidance for Designers (Report 166)*
CIRIA 1997, ISBN 0 8601 7464 6

*CDM Training Pack for Designers (C501)*
CIRIA 1999, ISBN 0 8601 75014
Experiences of CDM (Report 171)
W S Atkins Management Consultants, CIRIA 1997 ISBN 0 8601 7479 4

Protection from Falling, Collision and Impact

Glazing - Safety in Relation to Impact, Opening and Cleaning
DETR 1998, ISBN 0 1175 3389 0

Designing for Safety and Health Proceedings - Papers
ECI 2000, ISBN 1 8738 4448 4

Test for Fragility of Roofing Assemblies (the Red Book)

CDM Regulations: A Design Risk Assessment Manual
Williams, Brenig, Powergen Plc 1996, ISBN 0 6320 4087 4

CDM Primer. An Introduction and First-Stop Reference for Designers on the Construction (Design & Management) Regulations
Haverstock, H. et al ,Miller Freeman plc 1996 (held by British Library)
Figure 1 Health and safety guidance and property sets functionality
Designing for Health and Safety in Construction

HSE's accident statistics for 2000/01 show that 114 people were killed as a result of construction work. This is an increase of over 30% compared with the previous year. It represents 6.0 deaths per 100,000 workers, which is the highest for over ten years. In 2000/01, as consistently in the past, falls of more than 2 metres (41.5%) were the main cause of fatal injuries in construction. Over five years, falls of more than 2 metres accounted for almost half of construction deaths (48%).

There are some cases where a fatality or injury could have been avoided if risks to the health and safety of workers were eliminated or reduced during the design phase of a building's construction.

The CDM regulations state that it is the duty of a designer to "avoid foreseeable risks to the health and safety of any person at work carrying out construction work or cleaning work in or on the structure at any time, or of any person who may be affected by the work of such a person at work."

The objective of the text within these pages is to quickly inform designers about how to identify risks and how to remove or reduce them.

Within this prototype, only the risks due to falls and falling objects have been considered.

General
CDM
Accidents
Design
Construction
Maintenance
Protection

Roofing
Rooflights
Windows

Property Set Definitions

Figure 2 Health and safety information: index
Designing for Health and Safety in Construction

General Design External Documentation

External documentation relevant to design

Websites

HSE - Construction [view]

HSE Documents

HSE - Construction (Design and Management) Regulations 1994: The role of the designer: Construction Sheet No 41 [view]
HSE - Designing for Health and Safety in Construction [view]
HSE - Information on Site Safety for Designers of Smaller Building Projects 72/1995 [view]
Main Page

Figure 3 Health and safety information: external design documentation
Designing for Health and Safety in Construction

Rooflights

For rooflights designers should consider carefully the potential to eliminate or reduce the hazard. The decision on whether to include rooflights should take account of the risks associated with temporary gaps during construction, and the risks when access to the roof is needed later, eg during maintenance or cleaning.

Where rooflights are required designers should consider:

- specifying rooflights that are non-fragile;
- fitting rooflights designed to project above the plane of the roof and which cannot be walked on (these reduce the risk but they should still be capable of withstanding a person falling onto them);
- protecting rooflights, eg by means of mesh or grids fitted below the rooflight or between the layers of a built-up rooflight;
- specifying rooflights with a design life that matches that of the roof, taking account of the likely deterioration due to ultraviolet exposure, environmental pollution and internal and external building environment.

General
Location
Product Details
Protection
Construction
Maintenance
Websites and external documents
Rooflight Property Set Definition
Main Page

Figure 4 Health and safety information: rooflight main page
External Work Area

- Once workers have accessed the rooflight externally, what is their work area? High risk: no special area, or a roof ladder. Lower risk: trolley system.

External Worker Protection

- How is the worker to be protected from a fall when carrying out rooflight maintenance on a roof? High risk: None. Lower risk: Group protection such as safety nets. Also consider the roof edges. Are temporary guard rails going to be placed around the edges? If a fall arrest system is to be used, ensure that all areas of the roof are covered. If maintenance other than rooflight maintenance is to be carried out on the roof, temporary demarcation barriers can be set up to stop workers from accessing an area which contains rooflights. Also take into account that temporary measures such as temporary guard rails reduce the risk but it is still a high risk activity installing the temporary guard rails.

External Cleaning

- Is external cleaning to be carried out? If so, how is this to be done?

Internal Cleaning

- Is internal cleaning to be carried out? If so, how is this to be done?

Relative locations

- When considering rooflight locations, and the protection required during maintenance, the relative positions of rooflights and other entities must be taken into account. If rooflights are less than 2m apart, whilst working on one rooflight the risk of falling over onto another rooflight is high. Also rooflights should be more than 2m away from access areas such as walkways and eaves. If rooflights are less than 2m from these entities, permanent or temporary protection must be placed to prevent falling through the rooflights.

The maintenance property set gives information about each of these areas.

Examples of risks:

- Very High Risk:
  - No protection specified for roof workers. There is no permanent protection around the rooflights and the work area gives no protection.

- High Risk:
  - Rooflights are less than 2m apart and no permanent or temporary protection is provided.
  - Installing temporary guard rails around rooflights.

- Medium Risk:
  - Demarcation barriers have been placed around a roof area containing rooflights, but there is no permanent protection.
  - Only fall arrest systems are to be used during maintenance, and no other protection.
  - Internal cleaning is to be carried out from a ladder.

- Low Risk:
  - No permanent protection measures, but temporary guard rails have been placed around the rooflights.

Figure 5: Health and safety information: rooflight maintenance.
Figure 6 Health and safety information: rooflight product details

-Overall Length, Overall Depth, Overall Height, Weight
  - Designers must think about how rooflights are to be handled. The heavier and larger the rooflight, the more risky the handling.
  - Generally, if an entity is greater than 20kg, lifting equipment must be used. If rooflights are long, say more than 2m, handling on a windy day will be difficult.

- Fragility, Material and Maximum Load
  - Falls through fragile material give rise to more fatal accidents in the construction industry than any other single cause. These deaths occur in both construction and maintenance, involving a whole range of fragile materials. The fragility, and obviously the material, of a rooflight are critical to the levels of hazard caused by rooflights. Designers must be aware that even if a manufacturer states that a rooflight meets building regulations, this does not mean that if someone falls out, it won’t break. The designer must check, and specify in the design, what the level of fragility is and what its maximum load is. Manufacturers will supply these details.

Guidelines on fragility have changed recently, and details are in this document:

Fragility Guidelines

- Product Type
  - There are different types of rooflights, including plane and domed. Fitting rooflights which are designed to project above the plane of the roof and which cannot be walked on reduce the risk but they should still be capable of withstanding a person falling onto them.

- Design Life
  - Rooflights should be specified with a design life that matches that of the roof. This reduces the amount of time which is spent on the roof carrying out maintenance. The designer should take into account the likely deterioration due to ultraviolet exposure, environmental pollution and external and external building environment.

- Frame and Support Fixing
  - The designer may specify that the rooflight is to have a separate frame. The designer must consider how the frame is to be fixed. It is preferable to have a wholly prefabricated unit so that no fixing is necessary. If frames or frames are fitted separately at height they may not be load-bearing, and the risk of someone falling through it is high.

The health and safety file should include relevant information from the supplier, such as:

- test results on the initial material strength
- the effects of ultraviolet radiation on material properties
- fixing specifications, including type, number and position

Very High Risk
- The rooflight material is glass
- The rooflight material is fragile and/or category C

High Risk
- The fragility is category B
- The rooflight weighs more than 20kg and is to be handled manually.
- The rooflight is longer than 2m and is to be handled manually.

Medium Risk
- The rooflight is plane and does not project above the roof surface
- The rooflight has a design life which is less than that of the roof panels.
<table>
<thead>
<tr>
<th>Property Description</th>
<th>PolicyName</th>
<th>Rooflight_MaxLoad</th>
<th>Rooflight_HasLiner</th>
<th>Rooflight_Construction_LinerFitting</th>
<th>Rooflight_PermanentProtection</th>
<th>DocumentLink</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooflight functionality</td>
<td>Policy 1</td>
<td>29.5</td>
<td>Y</td>
<td>Install separately</td>
<td>None</td>
<td>file://N:\HSE\RooflightMain.xml</td>
</tr>
<tr>
<td></td>
<td>Policy 2</td>
<td>17</td>
<td>N</td>
<td>Install separately</td>
<td>Warning notices</td>
<td>file://N:\HSE\RooflightMain.xml</td>
</tr>
<tr>
<td></td>
<td>Policy 3</td>
<td>30</td>
<td>Y</td>
<td>Prefabricated</td>
<td>Metal mesh</td>
<td>file://N:\HSE\RooflightMain.xml</td>
</tr>
<tr>
<td></td>
<td>Policy 4</td>
<td>30</td>
<td>Y</td>
<td>Prefabricated</td>
<td>Clipped harness anchorage points</td>
<td>file://N:\HSE\RooflightMain.xml</td>
</tr>
<tr>
<td></td>
<td>Policy 5</td>
<td>30</td>
<td>N</td>
<td>Prefabricated</td>
<td>Guard rail</td>
<td>file://N:\HSE\RooflightMain.xml</td>
</tr>
</tbody>
</table>

**Figure 7** Property set creation worksheet
PropertySet Definition:

<table>
<thead>
<tr>
<th>Name</th>
<th>PropertyType</th>
<th>3DPropertySingleValue</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoofLightMaxLoad</td>
<td></td>
<td></td>
<td>InMassMeter</td>
</tr>
</tbody>
</table>

**Definition:**
The maximum downward load in N/m² which the rooflight can tolerate.

<table>
<thead>
<tr>
<th>Name</th>
<th>PropertyType</th>
<th>3DPropertySingleValue</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoofLightHasLiner</td>
<td></td>
<td></td>
<td>InBoolean</td>
</tr>
</tbody>
</table>

**Definition:**
Does the rooflight have a liner?

<table>
<thead>
<tr>
<th>Name</th>
<th>PropertyType</th>
<th>3DPropertyEnumeratedValue</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoofLightConstructionLining</td>
<td></td>
<td></td>
<td>EnumRooflightConstructionLining</td>
</tr>
</tbody>
</table>

**Definition:**
Defines how the rooflight lining is to be fitted.

<table>
<thead>
<tr>
<th>Name</th>
<th>PropertyType</th>
<th>3DPropertyEnumeratedValue</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoofLightPermanentProtection</td>
<td></td>
<td></td>
<td>EnumRooflightPermanentProtection</td>
</tr>
</tbody>
</table>

**Definition:**
The permanent protection that has been provided to protect against falls through the rooflight.

Figure 8 Property set definition
<table>
<thead>
<tr>
<th>Property Set Instance</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RooflightMaxLoad</td>
<td>The maximum downward load in N/m2 which the rooflight can tolerate</td>
<td>29.5</td>
</tr>
<tr>
<td>RooflightHasLiner</td>
<td>Does the rooflight have a liner?</td>
<td>true</td>
</tr>
<tr>
<td>RooflightConstructionLinerFitting</td>
<td>Rooflight liner fitting method</td>
<td>InstallSeparately</td>
</tr>
<tr>
<td>RooflightPermanentProtection</td>
<td>Permanent protection that has been provided to protect against falls through the rooflight</td>
<td>None</td>
</tr>
</tbody>
</table>

**Figure 9** Property set instance
Figure 10 'Drag and drop' display for property sets
Figure 11 Property set display in CAD tool
Figure 12 Display of property set definition in ADT
Figure 13 Editing a property set definition in ADT
Figure 14 Display of ADT cursor if health and safety information is attached
Figure 15 Functionality of the rule checker
**Figure 16** Rule checker: parameter value modification
<table>
<thead>
<tr>
<th>Rule Plan Reference Number</th>
<th>Rule Plan Title</th>
<th>Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small Residential</td>
<td>Viewer</td>
</tr>
<tr>
<td>2</td>
<td>Residential with Size</td>
<td>Viewer</td>
</tr>
<tr>
<td>3</td>
<td>Large Residential</td>
<td>Viewer</td>
</tr>
<tr>
<td>4</td>
<td>Large Industrial</td>
<td>Viewer</td>
</tr>
<tr>
<td>5</td>
<td>Small Industrial</td>
<td>Viewer</td>
</tr>
<tr>
<td>6</td>
<td>Warehouse with Rooflights</td>
<td>Viewer</td>
</tr>
<tr>
<td>7</td>
<td>Rooflight testing</td>
<td>Viewer</td>
</tr>
<tr>
<td>8</td>
<td>Modified Warehouse with Rooflights</td>
<td>Viewer</td>
</tr>
<tr>
<td>9</td>
<td>Warehouse with Rooflights Removed</td>
<td>Viewer</td>
</tr>
</tbody>
</table>

**Figure 17** Rule checker: project library
Figure 18 Rule checker: 3D viewer display
Figure 19 Rule checker: rule description
**Figure 20** Rule checker: non-compliance results

- Description: High risk. Assembling at height gives the risk of falling and dropping objects. Assemble at ground level or use a prefabricated unit. Designing for Health and Safety in Construction Page 79.

- Related Object:
  - Windows [10843, 25937, 7162]
  - Windows [20843, 25937, 7162]
  - Windows [30843, 25937, 7162]
  - Windows [40843, 25937, 7162]
  - Windows [50843, 25937, 7162]
  - Windows [60843, 25937, 7162]
  - Windows [70843, 25937, 7162]
  - Windows [80843, 25937, 7162]
  - Windows [90843, 25937, 7162]

- Remark:
  - An investigation is being carried out to find out if suitable prefabricated units are available.
<table>
<thead>
<tr>
<th>Clause Name</th>
<th>ERROR_DESC</th>
<th>WAIVED_BY</th>
<th>REMARK</th>
<th>Location of Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>general_con_1</td>
<td>High Risk Assembling at height gives the risk of falling and dropping objects. Assemble at ground level or use a prefabricated unit. Designing for Health and Safety in Construction Para 79.</td>
<td></td>
<td></td>
<td>(2520.00, 6576.96, 7325.02)</td>
</tr>
<tr>
<td>general_mnt_1</td>
<td>Low Risk Assembling at ground level has the general risk of on-site accidents. Use a prefabricated unit. Designing for Health and Safety in Construction Para 79.</td>
<td></td>
<td></td>
<td>(2520.00, 6576.96, 7325.02)</td>
</tr>
<tr>
<td>rooflight_con_4</td>
<td>Medium Risk No special work area provided on the roof. Risk of falling. Consider using staging/covers with guard rails, or a trolley system. HSG33 Para 130-140</td>
<td></td>
<td></td>
<td>(2520.00, 6576.96, 7325.02)</td>
</tr>
<tr>
<td>rooflight_con_6</td>
<td>Low Risk No lifting equipment is specified. Ensure correct lifting equipment is specified. Health and Safety in Construction: Moving, lifting and handling loads</td>
<td></td>
<td></td>
<td>(7520.00, 6576.96, 7325.02)</td>
</tr>
<tr>
<td>rooflight_gen_1</td>
<td>Low Risk Rooflights are a hazard. Eliminate rooflight completely or move to be vertical windows in walls. HSG33 Fig 34 Para 194</td>
<td></td>
<td></td>
<td>(7520.00, 6576.96, 7325.02)</td>
</tr>
<tr>
<td>rooflight_mnt_1</td>
<td>Extreme Risk No protection for maintenance or cleaning. Add temporary personal or group protection, or use a permanent trolley system. HSG33 Para 14, Appendix 3</td>
<td></td>
<td></td>
<td>(2520.00, 6576.96, 7325.02)</td>
</tr>
<tr>
<td>rooflight_prd_3</td>
<td>Medium Risk Plane rooflights are more dangerous than domed rooflights because they are more likely to be walked on. Project the rooflight above the plane of the roof. HSG33 Para 195</td>
<td></td>
<td></td>
<td>(2520.00, 6576.96, 7325.02)</td>
</tr>
</tbody>
</table>

Figure 21 Non-compliance report
APPENDIX 1 - IMPLEMENTATION DETAILS

1 INTRODUCTION

This Appendix contains technical details about how the Knowledge Based System was implemented. Whilst establishing the best means of implementation, the main objective was to provide a system which will be usable to the majority of designers with a standard desktop computer, and at no extra financial cost to them. Also, the number of actions required by the designers in order to run the system had to be minimised, to ensure ease of use.

The IAI IFCs were chosen as a means of delivering the data, and where appropriate, assistance was commissioned from the IAI. Help was also provided by novaSPRINT in Singapore.

The work separated into two areas for the delivery of the KBS:
1. Health and Safety Information Display.
   This concerns the display of health and safety information incorporated into a CAD system, and if feasible, as a standalone system. This area also involves adding new properties to construction elements within a CAD system, so that designers can set the values.
2. Rule Checking.
   This phase of the project involves determining the viability of taking a model from a CAD application, and carrying out checks on the values of the attributes of the construction entities to ascertain if there are any health and safety risks in the design, and alerting the designer to this.
2 INDUSTRY FOUNDATION CLASSES (IFC) USAGE

IFCs are a set of internationally standardised object definitions for use in the construction industry. The format of IFCs is designed so that it is a standard format with which all major CAD applications will be able to import and export models. They are a means to enable interoperability between different software applications. IFCs are available to all participants in the construction industry, for use globally, including use by all construction industry software vendors.

There are IFCs for all the major components within a design, such as wall, roof, roof slab, stairway, window, ramp, etc. The attributes for construction entities within CAD packages such as AutoDesk's Architectural Desktop are limited. The IFC design, in general, includes more parameters than within CAD applications, such as finish, serial number, material description, thermal conductance, cost etc. Also with IFCs, a user can create their own Property Sets, which will include a collection of new properties which the user defines. A Property Set can be related to an IFC object so that more properties for particular entity can be added. For example, we created a Property Set for rooflights which included the type of rooflight and its fragility. These two properties are not available in CAD applications.

The structure and syntax of files created when a model is saved as an IFC model are defined using the EXPRESS language which is written according to ISO 10303 which is an international standard for the computer-interpretable representation and exchange of product data. The models can be placed in a database which has an interface defined according to ISO 10303 part 22 (Standard Data Access Interface) for creating and extracting data. A model in a database can then have queries run against it.

The above is a brief description of the IFCs considering only the relevance to this project.

We can use the IFCs to:

- create Property Sets which contain the attributes that designers should consider when regarding health and safety in construction.
- use the Property Sets to link health and safety information to construction entities in a CAD application.
- load an IFC model into a database so that queries can be run against the data to search for health and safety risks in the model.
3 HEALTH AND SAFETY INFORMATION DISPLAY

There are two main areas to describe in this section. Firstly the defining, setting up and display of Property Sets. The second is the display of health and safety information within a CAD application, and the linking of it to construction entities. Figure A1 is the architecture diagram.

One CAD application was chosen to demonstrate how the health and safety information could be displayed. We chose AutoDesk Architectural Desktop (ADT). An IFC add-in can be downloaded from the AutoDesk website for free. This add-in ensures that IFC models can be imported and exported into ADT. Other CAD applications can also export and import IFC models, for example Graphisoft's ArchiCAD, which also gives further user interface functionality for setting up Property Sets.

3.1 PROPERTY SETS

This section describes how the Property Sets were implemented, and then how they can be used by the designers when they are utilising the KBS tool.

AutoDesk Architectural Desktop already has the functionality to create Property Sets, attach them to objects and to change the property values. However, we needed a means by which most of this process is automated, cutting down the amount of work that a designer has to do.

Note the terminology:

- a Property Set Definition (PSD) is a definition of the Property Set (see Figure 8 and Section 6.4).
- a Property Set Instance is a collection of the actual values of the properties for a particular entity (see Figure 9).

XML was chosen as a means to store and display the PSDs and Property Set Instances. XML is a standard, openly available method, and can be displayed using Microsoft Internet Explorer.

The PSDs had to be created in a format so that the details can be viewed by the user easily within the CAD tool. Also, the PSDs were created so that they could be viewed standalone. The PSDs are set up in Excel. One worksheet in the workbook represents one Property Set. Property names, descriptions, data type and possible enumerated values had to be given. A VB macro (the Instantiation tool in the architectural diagram Figure A1) was written by IAI which loads the PSD from the spreadsheet and outputs it in XML format. Using an XML stylesheet the PSD can be displayed as shown in Figure 8.

Instances of Property Sets had to be created containing default values. The Excel spreadsheet for creating the PSDs was also used for creating the Property Set Instances. Figure 7 shows one of the spreadsheets with the PSD at the top, and the values at the bottom. One row gives the values for one Property Set, so multiple Property Sets can be created.

The instantiation tool macro used for creating the PSDs also creates the Property Set Instances. The Property Set Instances are also in XML, and can be viewed independently using a stylesheet. An example is shown in Figure 9.

The Property Set instances are named:
PropertySetType_PolicyName.xml
for example, Rooflight_WardStandard.xml.

As described in Section 6.4 each Property Set instance must have a 'Policy Name' to define
the reasoning behind the default values.

A ‘drag and drop’ mechanism was created by the IAI so that the designer can attach the
relevant Property Set Instances to the construction entities in their building designs in a CAD
application. The designer drags and drops a file from Windows Explorer onto a design, and a
macro running in the CAD application detects this, and displays the Property Set, and the
designer has the option to load this into the application (see Figure 10).

3.2 DISPLAY OF HEALTH AND SAFETY TEXTUAL INFORMATION

The objective of this task was to be able to save textual data about health and safety in a
format so that it could be modified and viewed easily and quickly by designers. Whilst the
designer is using the CAD tool, the textual data appropriate to the objects being worked on
should be easily found, and the designer should be aware that the information is available to
them. Another objective was to investigate whether a standalone version of the information
could be created.

It was decided that a suitable format in which to save the information was in XML. XSL
stylesheets were written to format the page display. Using XML and XSL means that
designers with Internet Explorer installed will be able to view the text. Also, if necessary, the
text can be imported into other applications. The text in XML was formatted so that it would
be easy for designers to modify and add to the text. Appendix 2 gives instructions about how
to make modifications.

The text was organised in several pages, each linked to each other. The pages relate to the
different entities and accident causes, as described in Section 6.

Many relevant health and safety documents are available electronically, generally in pdf
format, and also in Word and html. Many of the pages contain links to these documents, also
to web sites, including the HSE website, and the Property Set Definitions. The links are easy
to set up in XML.

The method by which the information has been formatted means that the information can be
viewed standalone, with no connection to a CAD application required.

In ADT, text and documentation can be attached to objects by using a hyperlink. For our
purposes we had to be able to do this automatically. The tool has been set up so that when the
Property Sets are attached to objects, the hyperlink is set up too. In the Excel spreadsheet,
where the PSDs and Property Sets are defined, appropriate hyperlinks are also defined.

3.3 TECHNICAL SET UP

The following describes the technical actions that a designer must carry out in order to use the
KBS tool with ADT. Refer to the architectural diagram, Figure A1.

- Download the ADT IFC facility from their website. Alternatively the files could be
copied from an HSE website or CD (see Section 9 on suggested improvements)
- Load the ADT IFC facility into the CAD application. This only needs to be done once.
• Load the HSE drag-and-drop macro into the application. This only needs to be done once.
• In order for the macro to run, the references as shown on Figure A1 must be set up for the ADT Visual Basic editor. These references are standard and may be there by default. The set up only needs to be done once.
• Run the drag-and-drop macro. This could be set up so that it runs automatically.

In order to view the health and safety information and Property Sets the designer should install either:
Internet Explorer Version 6.0
or
Internet Explorer prior to Version 6.0, plus the Microsoft XML Parser (MSXML) Version 3.0.

3.4 PROBLEMS ENCOUNTERED

In ADT only one hyperlink can be attached to an object. This means that when the hyperlinks are added when Property Sets are attached to the object, the last one takes precedence. However, this is not seen as a major problem because all the health and safety information pages are linked to each other, so the user can navigate to any other page.
4 RULE CHECKING

This part of the project was the investigation of the viability of utilising novaSPRINT’s current building regulation checking architecture, which is to become mandatory in Singapore, for checking designs for health and safety issues and alerting the designer.

4.1 SYSTEM DESCRIPTION

Figure A2 shows the architecture for the KBS rules checking tool. The system being implemented in Singapore is to be multi-user and available on the internet. It is a relatively large internet based client-server system, and the architecture reflects this.

In the scope of this project the prototype health and safety rule checking tool can only be run on computers set up specifically for the tool. The set up requires Oracle and EDM databases to be installed, and that the computer runs as a web server.

The following sections describe all the components of the system.

IFC model
This is a building model which has been exported from a CAD application in IFC format.

EXPRESS Data Manager (EDM) Database
The EDM database contains:
- IFC models
- rules
- IFC schema. This defines the classes in the IFCs.

Oracle Database
The Oracle database is used for administering the rules system. It contains details about:
- users
- projects
- rules
- IFC models loaded into the EDM database
- output files

Rules
The rules are written in a language called EXPRESS-X which is defined in ISO 10303-11 and ISO TC184/SC4/WG11/N002. This is the query language used in the EXPRESS Data Manager database. The IFC model is loaded into the database, and the rules are run against it.

Parameter files are also set up. These are text files which contain values of attributes which are checked in the rules. For example, if a rule checks if the weight of a block is less than 20kg, the value of 20kg is in the parameter file. This helps to ensure that values are not hard-coded into the programming language, and so can be easily viewed and changed.

A Rules Description file contains a description of a rule and gives details of the possible types of failure. It also gives references to the appropriate documentation. When a designer is using the 3D Browser (see below) the contents of this file can be viewed. An example is shown in Figure 19. The files are written in html format, and so can be viewed standalone.
The rules were classified as to whether they related to all objects, or a specific type (e.g. doors). They were then split further into the particular areas:
- general, abbreviation gen
- location, abbreviation loc
- product data, abbreviation prd
- protection, abbreviationprt
- construction, abbreviation con
- maintenance/cleaning, abbreviation mnt

These classifications were used to name the rules and the filenames of the files containing the rules. The rule naming is:

HSE_Demo_object_area_number

For example:
HSE_Demo_rooflight_con_2

The rule name has to start with HSE and Demo because these are fixed for the CORENET rule software. HSE is the organisation which has defined the rules. Demo is a dummy name because of our KBS being a prototype.

**Uploader**
The Uploader is an application run in Microsoft Internet Explorer. In the Singapore Building Regulations system this is the internet client application by which the designer submits designs to be checked. An administrator can also access the system using the Uploader.

**3D Viewer**
The 3D browser is the application by which the designer can interactively run the rule checking tool. This also runs in Internet Explorer.

The rule checking process produces debug output which gives more details about the causes of the failures.

### 4.2 PROBLEMS ENCOUNTERED

Generally, because the project in Singapore is still in development, problems were encountered getting the whole system up and running. There are some areas which are still being developed by novaSPRINT.

There are several minor bugs and inefficiencies throughout the code-checking software. They can be by-passed, but do require manual modifications and a good understanding of how the whole system works.
APPENDIX 2 - MODIFYING THE TEXTUAL INFORMATION

New pages can be added to the information quite easily by using a template file. The content of this file is shown below:

```
<?xml version="1.0" ?>
<?xml-stylesheet type="text/xsl" href="../HSETextStylesheet.xsl"?>
<!-- text inside this brackets like this will not display -->
<!-- the section heading is the title of the document -->
<!-- the name will be shown as the title -->
<section name="put chapter heading here" type="chapter">
  <!-- subheadings are referenced by the subsection tag. you may use as many as you need-->
  <section name="This is a subheading"/>
  <!-- The body of the text should be written inside <text>text here</text> tags. Returns are recognized as the end of a paragraph-->
  <text>
    This is a line of text that will be shown on screen
    This is a new paragraph
    <!-- to add a bullet point list type the text with a - as the first character of a line-->
    - this is a bullet list
    _u110 ?d this is a second entry
  </text>
  <!-- reference section need to be added to in a particular way -->
  <!-- first a reference section must be created to contain all the references, the name specifies the name of the reference section-->
  <reference-sec name="I am a reference section">
    <ref href="c:\URL_to_another_document.htm">I _u109 ? a web page with an optional link to another file</ref>
    <ref>I am a book reference without a file link</ref>
  </reference-sec><!-- this is the end of the reference section-->
  <link href="RooflightExternalDocs.xml">Websites and external documentation</link>
</section>
```

Open this file in a text editor such as Notepad and then follow the instructions enclosed in the <!-- --> comment tags in the file. The top two lines of the file must not be altered and must be included, otherwise the document will not display.

The file should be saved to a directory of your choice in the main folder.

To add a link from other electronic documents in the website so that you can view the new page, open the web page you want to link from, click with the right hand mouse button in the middle of the viewer and select view source from the menu. This will bring up the original source file. This should be edited adding the following link before the </section> tag at the bottom of the page.

```
<link href="my new file.xml">This is a link to my new file</link>
```
Figure A1: Architecture diagram for health and safety information
Figure A2 Architecture of the rule checker
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADT</td>
<td>The CAD tool Autodesk Architectural Desktop</td>
</tr>
<tr>
<td>AEC/FM</td>
<td>Architecture, Engineering and Construction/Facilities Management</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer aided design</td>
</tr>
<tr>
<td>CDM</td>
<td>Construction (Design and Management) Regulations</td>
</tr>
<tr>
<td>CORENET</td>
<td>COnstruction and Real Estate NETwork</td>
</tr>
<tr>
<td>EDM</td>
<td>Express Data Management. This technology enables product data to be effectively managed, exchanged and shared across radically different systems.</td>
</tr>
<tr>
<td>EPM</td>
<td>EPM Technology specialises in products developed to fully implement the EXPRESS data modelling language which supports most international product data technology standards</td>
</tr>
<tr>
<td>Hazard</td>
<td>Something with the potential to cause harm</td>
</tr>
<tr>
<td>IAI</td>
<td>International Alliance for Interoperability</td>
</tr>
<tr>
<td>IFC</td>
<td>Industry Foundation Class. IFCs are used for sharing and exchanging information between CAD software applications</td>
</tr>
<tr>
<td>IFC object</td>
<td>A construction entity, such as a door or window</td>
</tr>
<tr>
<td>KBS</td>
<td>Knowledge based system.</td>
</tr>
<tr>
<td>Knowledge based system</td>
<td>A system in which human expertise is structured, enabling the system to diagnose situations and provide information and recommendations without the human expert being present. It emulates the knowledge and the guidance given by health and safety experts.</td>
</tr>
<tr>
<td>novaSprint</td>
<td>The company which is developing the CORENET system</td>
</tr>
<tr>
<td>Property Set</td>
<td>A collection of properties for either a particular building object (e.g. a door) or a group of objects (e.g. all objects at height)</td>
</tr>
<tr>
<td>Property Set definition</td>
<td>A definition of the Property Set</td>
</tr>
<tr>
<td>Property Set instance</td>
<td>A collection of the actual values of the properties for a specific entity</td>
</tr>
<tr>
<td>PSD</td>
<td>Property Set Definition</td>
</tr>
<tr>
<td>PSet</td>
<td>Property Set</td>
</tr>
<tr>
<td>Risk</td>
<td>The likelihood that harm from a particular hazard will occur and the possible extent of the harm</td>
</tr>
<tr>
<td>XML</td>
<td>Extensible markup language</td>
</tr>
<tr>
<td>XSL</td>
<td>Extensible stylesheet, used for formatting XML files for display purposes</td>
</tr>
</tbody>
</table>