AN INTELLIGENT SYSTEM FOR VULNERABILITY AND REMEDIATION ASSESSMENT OF FLOODED RESIDENTIAL BUILDINGS

By

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ABSTRACT

Floods are natural phenomena which are a threat to human settlements. Flooding can result in costly repairs to buildings, loss of business and, in some cases, loss of life. The forecasts for climate change show a further increased risk of flooding in future years. Accordingly, the flooding of residential property has been observed as on the rise in the UK.

It is difficult to prevent floods from occurring, but the effects of flooding can be managed in an attempt to reduce risks and costs of repair. This can be achieved through ensuring a good understanding of the problem, and thereby establishing good management systems which are capable of dealing with all aspects of the flood.

The use of an intelligent system for assessment and remediation of buildings subjected to flooding damage can facilitate the management of this problem. Such a system can provide guidance for the assessment of vulnerability and the repair of flood damaged residential buildings; this could save time and money through the use of the advantages and benefits offered by knowledge base systems.

A prototype knowledge base system has been developed in this research. The system comprises three subsystems: degree of vulnerability assessment subsystem; remediation options subsystem; and foundation damage assessment subsystem. The vulnerability assessment subsystem is used to calculate the degree of vulnerability, which will then be used by the remediation options subsystem to select remediation options strategy. The vulnerability assessment subsystem can subsequently be used to calculate the degree to which the building is vulnerable to damage by flooding—even if it is not flooded. Remediation options subsystem recommended two strategy options: either ordinary remediation options in the case of vulnerability being low or, alternatively, resilience remediation options in the case of vulnerability being high. The foundation damage assessment subsystem is working alone and is used to assess the damage caused by flooding to the building's foundation, and to thereby recommend a repair option based on the damage caused and foundation type.

The system has been developed based on the knowledge acquired from different sources and methods, including survey questionnaires, documents, interviews, and workshops. The system is then evaluated by experts and professionals in the industry.

The developed system makes a contribution in the management and standardisation of residential building flooded damage and repair.

KEYWORDS

Flood damage, Vulnerability assessment, knowledge base system and flood, residential building and flood, flooded building, damage management. Building Vulnerability to flood, flooded building, flood repair, resilient repair.

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CHAPTER 1 INTRODUCTION

1.1 PREFACE

This chapter provides an introduction for the entire thesis. It focuses on the rationale behind the study, its aim and objectives, and details a summary of methodologies as well as research processes. This chapter also outlines the thesis and the contents of each chapter.

1.2 RATIONALE FOR THE RESEARCH

Floods are natural phenomena which pose a threat to human settlements. Floods are the most common natural disasters, representing approximately 35% of the total number of natural disasters reported around the world (O. le Polain de Waroux (2011). Flooding can result in costly repairs to buildings and affect their price, loss of business and, in some cases, loss of life (Jonkman and Vrijling, 2008; Lamond *et al.*, 2007a). The forecasts for climate change show a further increased risk of flooding in future years.

In one of their reports, the Environment agency (EA) states some figures on the risk of flood:

> 'One in six homes in England is at risk of flooding; over 2.4 million properties at risk of flooding from rivers or the sea in England, of which nearly half a million are at significant risk; One million of these are also vulnerable to surface water flooding with a further 3.8 million properties susceptible to surface water flooding alone; 55 per cent living in flood risk areas knew they were at risk and for these three out of five of them had taken some action to prepare for flooding' (EA, 2009; EA,2009a).

In Wales, one in six properties are at risk of flooding, meaning more than 220,000 properties are at risk of flooding from rivers or the sea; 64,000 of these are at high risk. In addition, 97,000 of these are vulnerable to surface water flooding. Moreover, 137,000 are vulnerable to flood-prone surface water. Furthermore, 57% live in areas prone to flooding know that they are at risk, and for these, three out of five have taken some actions in preparation for flooding (EA, 2009). 5.5 million Properties at flood risk in England and Wales (EA, 2011).

It is further noted that some 2.1 million homes in the whole of the UK are in areas at risk from river and sea flooding, with 48.5% of these properties at risk of flooding from the sea, 48% from rivers, and 3.5% from both (Office of Science and Technology, 2004). Importantly, sewer and drainage systems play a significant role in the problem of flooding in the UK; it is estimated that around 6,000 properties are flooded internally each year by sewage (ABI, 2007; National Audit Office, 2007).

Figures could rise further if climate change results in more frequent extreme weather events, as predicted (Office of Science and Technology, 2003; Evans *et al.*, 2004). In addition, there are continuous reports of more properties being constructed on flood plains. The Association of British Insurers (ABI) report that one-third of a million of new homes the government permits to be built by 2020 could end up being built on flood plains, with thirteen major developments already being passed, despite the Environment's Agency advice on flood risks.

The effects of flooding can be devastating in terms of the costs of the repair and replacement of damaged property, as well as the loss of commercial activities (Lamond *et al.*, 2007b). Furthermore, they can cause loss of life and hidden costs, such as a loss in the value of property. Flood damage is categorised firstly in direct and indirect damages, and secondly in tangible and intangible damages (Parker *et al.*, 1987; Penning-Rowsell *et al.*, 2003; Messner & Meyer, 2005). Table 1.1 shows the classification of damage caused by floods, with examples.

Table 1-1: Classification of damage caused by floods, with examples (Messner et al., 2007)

		Measurement	
		Tangible	**Intangible**
Form of Damage	Direct	Physical damage to assets: - buildings - contents - infrastructure	Loss of life - health effects - Loss of ecological goods
	Indirect	- Loss of industrial production - Traffic disruption - emergency costs	- Inconvenience of post-flood recovery - Increased vulnerability of survivors

This research will deal with physical flood damage (both direct and tangible) in relation to residential buildings. Floods cause considerable damage to residential properties' elements, such as foundations, floors, walls, windows and doors, fittings, and utilities when they come into contact with floodwater (Rhodes, and Proverbs, 2008). Damage caused to a property is based on the flood characteristics, as well as the building characteristics (Proverb & Soetanto, 2004). Moreover, flood characteristics include flood depth, velocity flow, contaminant content and time duration. It is clear that flood depth is the key factor controlling the damage caused by a flood (Nicholas, Proverbs, and Holt, 2001). In actual fact, the effect of the other factors is not clear since it is difficult to measure these, and there is also a lack of clear data showing the influence of such factors.

The processes of remediation of buildings subjected to flood damage are different to ordinary construction projects. Some features that make the reinstatement of flooded buildings different include:

I. There are several stakeholders involved in the assessment and remediation (Samwinga, and Proverbs,2003):
   - The insurance company or insurer;
   - An assistance company is often engaged by the insurer to help a policy holder in mitigating and reducing damage;
   - A loss adjuster investigates claims, and accordingly determines the validity and value of individual claims;
   - A damage management company assists insurers and policy holders in establishing what needs to be done to rectify damage, and to liaise with policyholders and the contractors that repair the damage;
   - A contractor undertakes work to repair the property. It may delegate work to specialist subcontractors.

II. Involves a number of procedures, such as cleaning, decontamination, drying, etc.

III. The selection of repair strategies is based on an agreement between the insurer and the home owner, and sometimes the owner may pay an extra cost in the case of selection of resilience options, if insurance companies follow reinstatement in a 'like-for-like' manner.

Insurance companies play an important role in reinstating the residential building subjected to flood damage, where most houses have an insurance policy. More recently, the 2007 flood resulted in approximately 180,000 claims amounting to around £3billion in insured damage (Pitt, 2008). With this in mind, Figure 1.1 illustrates the steps the insurer follows to insure or repair a building in flood-prone areas.

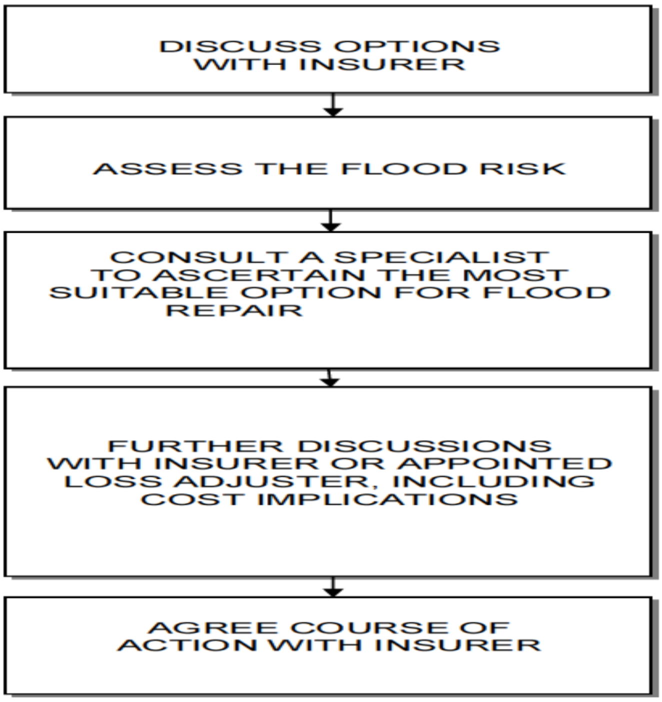


Figure 1-1: Steps to reinstate or insure a building (Association of British Insurers and the National Flood Forum, 2005)

In most insured cases, the affected homes are reinstated in a 'like-for-like' manner. The typical existing building subjected to flood damage repair contains a number of processes, as shown in Figure 1.2.

Importantly, it is difficult to prevent floods from occurring, but the effects of floods can be managed to reduce risks and the costs of repair; this can be achieved by developing a good understanding of the problem and establishing good management systems which are capable of dealing with all aspects of the flood.

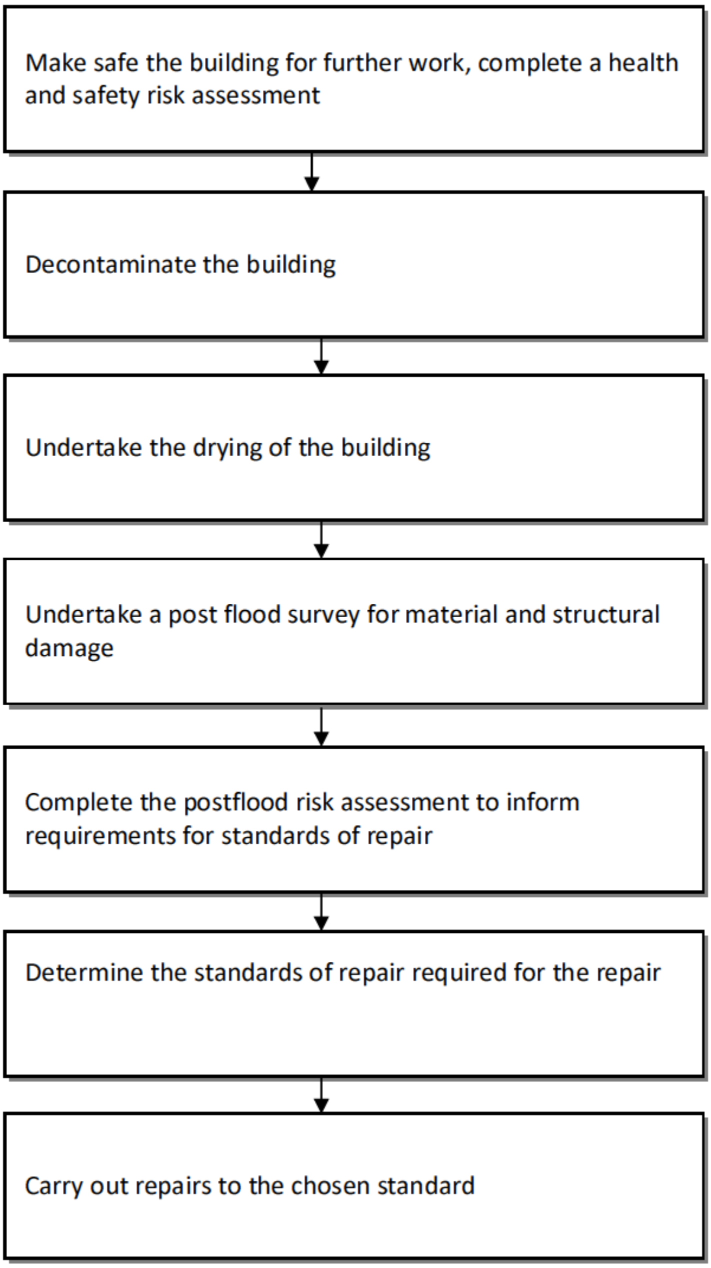


Figure 1-2: Repair process for a flooded building (CIRIA, 2005)

A number of surveys, case studies, and papers have indicated the difficulties experienced in managing flood events and their subsequent results. This highlights the need for a more coordinated approach to the problem, and also that the literature describing how to repair flood damaged properties are very general and need update (Wordsworth & Bithell, 2004; Nicholas, Holt & Proverbs, 2001; DCLG, 2010; Environment, Food and Rural Affairs Committee 2008).

A review of the literature has highlighted an increased need for professional advice for both individuals and developers on designing for floods (Wynn, 2002). In addition, definitive guidance for repairing flood damaged buildings is needed in order to minimise variations in subsequent repair and reinstatement works (Soetanto & Proverbs, 2004; DCLG, 2010; ABI, 2010).

In the Carlisle flood of 2005, Hendy (2006) mentioned the following points regarding the service provided to the homeowner by the insurer:

I. The low level of proficiency; and
II. Neighbours with similar properties and policies repair works done to their properties.

Woodhead (2008) mentioned that the level of confidence of homeowners decreases with reinstatement process time, as shown in Figure 1.3. Pitt (2008) further states that homeowners were dissatisfied with the recovery service provided by the insurance companies, simply because the repair processes took a long time.

It is clear that resilience can help to minimise the damage from floodwaters, and also greatly reduces the timescale for recovery of a property (Broadbent, 2004; ABI, 2003; DEFRA, 2008; ABI, 2006; Escarameia, Karanxha, and Tagg, 2007). A study by ABI and the Building Research Establishment (BRE) states that resistance and resilience measures can, in many cases, mean that essential services can be maintained during the flood event; flooded buildings can be re-cleaned, dried and restored within a short time and a minimum of disruption (ABI, 2002; ABI,2006).

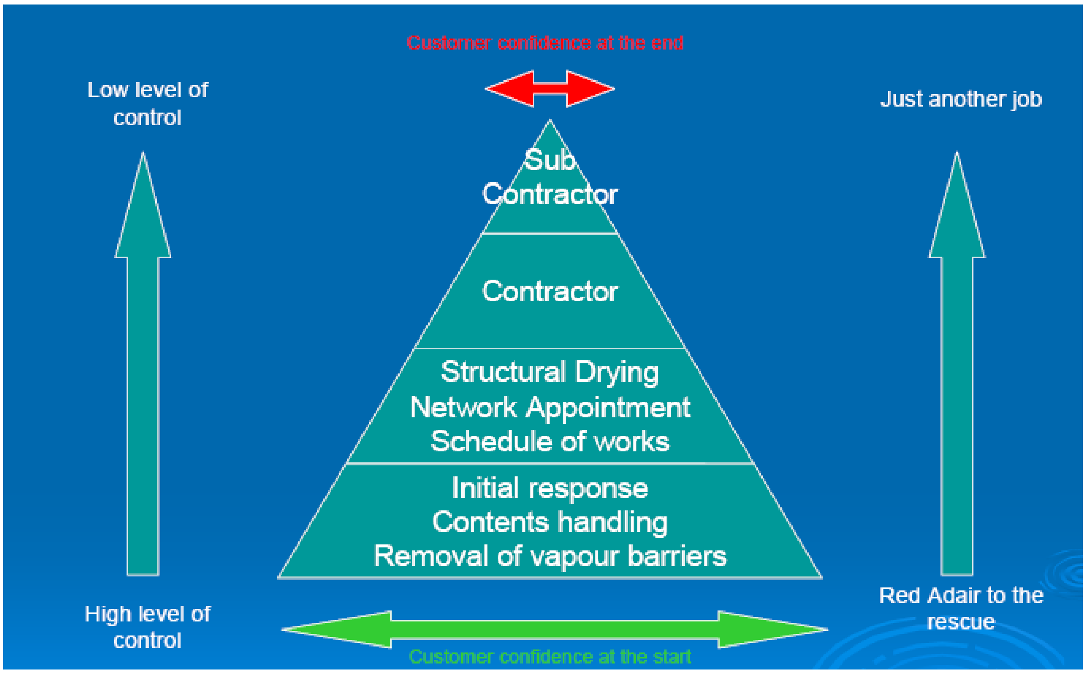


Figure 1-3: Level of homeowner satisfaction with respect to reinstatement time (Woodhead, 2008)

Pitt (2008) recommends that the Building Regulations should be revised to ensure that all new buildings or refurbished building in flood-risk areas are flood-resistant or resilient. He also adds that all local authorities should extend eligibility for home improvement grants and loans so as to include flood resistance and resilience products for properties in risk flood areas.

In July 2004, the Government launched the ‘Making Space for Water’ consultation exercise, which seeks views on a broad range of flood and coastal erosion risk management issues in an attempt to inform the development of a new strategy. Responses on flood resilience and resistance from the consultation urged the government to (OST 2004):

a) Encourage the incorporation of suitable flood resilience and resistance measures in new and existing buildings;

b) Include flood resilience measures in the new code for buildings;

c) Consider financial incentives for the adoption of flood resilience measures in the existing properties; and

d) Improve the quality of advice on flood resilience and resistance to the homeowners of properties, and to involve and train builders and surveyors to achieve this goal.

DEFRA made a £500,000 grant available for the implementation of the pilot scheme of property-level resistance and/or resilience measures. The aim was to investigate approaches and to accordingly assess the implementation and evaluation of potential take-up by property owners (Defra, July, 2008).

The comprehensive Pitt review following the severe flood in the United Kingdom in 2007—during which time 55,000 properties were affected by floods—

contained 92 recommendations, including (Pitt, 2008; EA,2011; Rhodes, and Proverbs, 2008):

a) The building regulations should be revised to ensure that all new buildings or refurbished buildings in flood-risk areas are flood-resistant or resilient; and

b) All local authorities should broaden eligibility for home improvement loans and grants so as to consider flood resistance and resilience products for properties in the high risk flood-prone areas.

1.3 RESEARCH AIMS AND OBJECTIVES

The aim of this research is to investigate the vulnerability of residential buildings to flooding damage, and to accordingly develop an intelligent system for assessing the vulnerability of residential buildings to flooding damage, and recommend remedial measures. In order to achieve the above aim, the following are the main objectives of the research:

- To review the risk exposure of residential buildings to flood damage—especially in the UK;
- To review recent research developments in the vulnerability assessment and remediation of residential buildings subjected to flooding;
- To develop a method to assess the vulnerability of residential building subjected to flood damage;
- To undertake detailed case studies with a view to establishing current industry practice, identifying opportunities for improvement, and establishing end-user requirements;

- To develop a framework and functional specification for an intelligent approach to the vulnerability assessment and remediation of residential buildings subject to flood damage; and
- To implement and evaluate a prototype system based on the functional specification developed above and using test cases from industry.

1.4 PURPOSE OF DEVELOPING THE KNOWLEDGE BASE SYSTEM

The use of an intelligent system for the assessment and remediation of buildings subjected to flooding and subsidence damage can facilitate the management of this problem. Such a system can provide guidance for the assessment of vulnerability and the repair of flood damaged residential buildings, and could also save time and money through the use of the advantage and the benefits of knowldge base systems. The management of flood damage would also gain numerous benefits and improvements through:

I. Knowledge, which can be transferred easily to the largest number of stakeholders in a short time. This will help to train younger engineers working in the field of flood damage management, and accordingly increase the level of rehabilitation;

II. Reductions in the time required for decision-making, where the information is organised, easily and rapidly accessible;

III. The ability to compare different remediation alternatives easily and in a short time;

IV. Laptop system installation, which will help to identify the problem and make decisions on-site;

V. Less expensive, thereby helping to reduce costs.

The intelligent system proposed in this research has the aim of achieving the following objectives:

- To assess and evaluate the vulnerability of buildings to flood damage, with consideration to factors contributing to building flood damage;
- To assist in the selection of repair methods and procedures to be followed when dealing with flooded buildings, as based on the degree of vulnerability to flood damage; and
- To aid in the selection of suitable flood damage reduction options by introducing resilience options as this will reduce the cost of future damage repair. The resilience remediation options are only recommended when the vulnerability of buildings to flood damage is high.

The system is expected to assess and make improvements in risk assessment by providing information and helping in the selection of remediation options at some of the stages given above, as shown in Figure 1.4 and Figure 1.5.

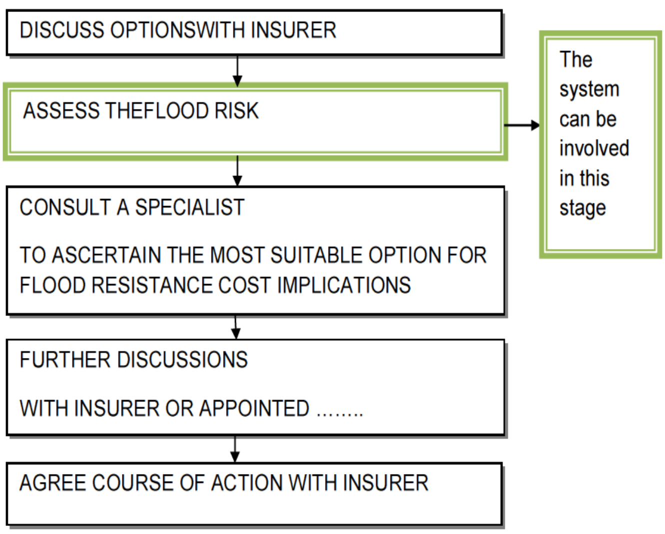


Figure 1-4: Stages at which the system can be involved during the steps to reinstate or insure a building. Adapted from Association of British Insurers (ABI) and the National Flood Forum (2005)

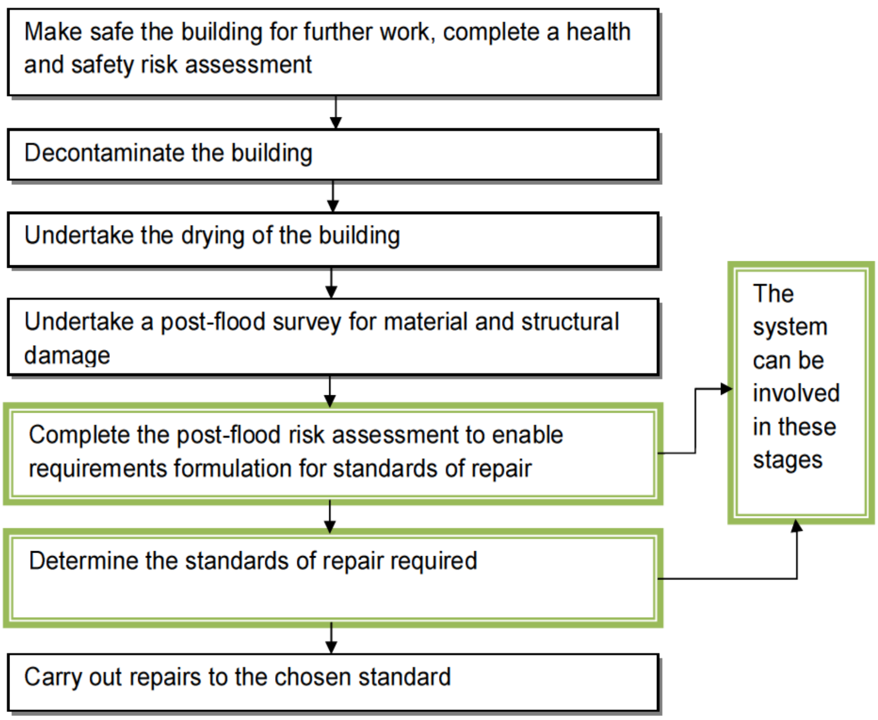


Figure 1-5: Stages at which the system can be involved during the repair process for a flooded building. Adapted from CIRIA (2005)

1.5 JUSTIFICATION FOR THE RESEARCH

Flooding is an increasingly common problem resulting in damaged homes (Manu, Phandey, and Proverbs, 2010). This requires the use of professionally qualified companies and technicians, all working to the highest standards in order to undertake building flood restoration. The knowledge relating to flood damage management is written in books and technical reports, as well as guides and journal papers, and codes of practice. This knowledge is either too general or too specialised for practical purpose, and the task of searching through many documents for information relating to a particular situation is also time-consuming (Rhodes&Proverbs 2008). Currently, there are various issues relating to the problem of flood damage management and the assessment of risk of flooded building for insurance purposes, which need to be dealt with. Mainly, insurance cover is not related to flood risk, and it is also clear that there is a need to establish repair standards. Moreover, there is a need for a system which helps to estimate the vulnerability of building to flood damage, and that also contains relevant information, which will help speed and standardised developing of repair strategies, and assessments in evaluate the risk of buildings due to flood. In addition, the knowledge acquired can be very useful, and may act as a training tool for the new people coming into the industry.

To cope with the issues mentioned above, there is the need for an organised and concise system to evaluate the vulnerability of residential buildings subjected to flood damage, which should comprise all information relating to repair methods and the procedure of remediation of buildings damaged by flood, which lead to standardised and speed flooded building repair. Notably, such a system should also help in establishing the basis for flooded residential building risk assessment and repair process.

In addition, the system should also include resilience options as one other repair option could reduce time, costs and repairs in the case of the building flooded in the future (Escarameia,Karanxha,and Tagg,2007; Department for Environment Food and Rural Affairs ,2008). In order to satisfy these needs, it is therefore essential to carry out this research.

1.6 RESEARCH METHODS

Figures 1.1 illustrates the research methods used to achieve the specific objectives of the research. A brief description of the research methods used is given in this section. The detailed research methodology is presented in Chapter 2.

1. Literature Review: The extensive literature review focused on three major subjects: first, reviewing vulnerability assessment to understand the concept of vulnerability and the methods of vulnerability assessment; second, flood damage management so as to gain an understanding of all issues relating to flood and the flood damage of residential buildings; and thirdly, review the Knowledge-Based System in general, and its applications in civil engineering in particular. Notably, the literature review on these three topics provides a theoretical background and forms the basis for continuing further into the research. Importantly, the review of literature was achieved through several sources, including publications from several professional bodies, participation at workshops, seminars to interact with other researchers and professionals in similar research areas, the use of the Loughborough University library to assess reports, theses, journals and conference papers relating to the subject, and relevant internet searches.

2. Knowledge Acquisition: The process involves capturing and transforming appropriate knowledge from experts in the related field into some manageable form in an attempt to develop a knowledge-based system which can assess the vulnerability of building subjected to flood damage and help in selection of repair options. In addition, a method to assess the

vulnerability of buildings subjected to flood damage has been developed through identifying the factors contributing to the vulnerability of buildings subjected to flood damage based on the literature available, and accordingly investigated through a questionnaire survey. Moreover, factor weighting (rating) was then used to develop a simple model to determine the vulnerability (refer to Chapter 3 and Chapter 4 of this thesis for further details).

This research has utilised two postal surveys with the objective to investigate the factors that contribute to the vulnerability of buildings subjected to flood damage, and remediation options. Knowledge acquired for the prototype system using a number of different techniques and methods, including review of literature and survey questionnaire. The first questionnaire was applied to help in rating factors assigned based on the literature, and then accordingly utilised in order to develop the model so as to determine the vulnerability. The second questionnaire was used to investigate the existing repair options. In addition, other sources were also used to validate and thereby gain a deeper understanding of the knowledge acquired each time, including documents, interviews and discussion with experts during the workshops and seminars.

In addition The Document Processing knowledge acquisition method were used which is considered as the most important and reliable approach (Castellanos, Albiter, Hernandez, and Barrera (2011).

3. Prototype Development: The development of the proposed knowledge-based system was based on the results captured from the knowledge acquisition process. Rapid prototyping methodology was used in the prototype development.

4. Evaluation: The completed prototype was evaluated following the development process in order to assess functionality and usability. The evaluators were drawn from flood damage repair industry experts, researcher and academic. The prototype was demonstrated to the evaluators, who were then asked to use the system. At the end of each evaluation process, the evaluators were asked to complete a questionnaire which assessed the prototype from various perspectives.

A flowchart summarising the research process and methods adopted is presented in Figure 1.6, with further information concerning the methodological issues presented in subsequent chapters.

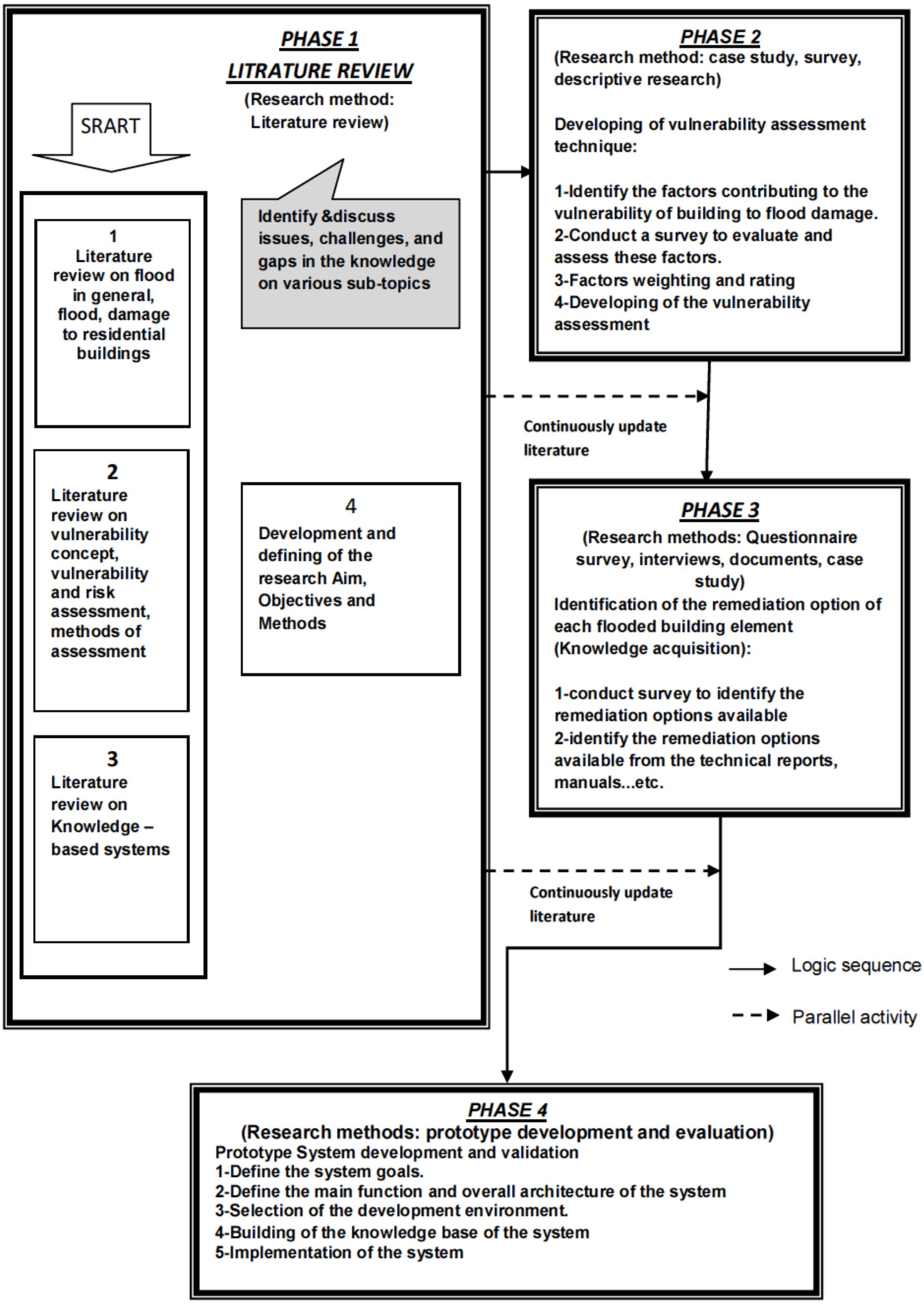


Figure 1-6: A flowchart of the research process and methodology

CHAPTER 2 RESEARCH METHODOLOGY

2.1 INTRODUCTION

Research methodology can be described as the activities carried out by researchers in the investigation of various matters, dealing specifically with the methods of data collection, analysis and interpretation. This chapter will describe different research methodologies, and subsequently focus on the research methodology used in this research.

2.2 REVIEW OF RESEARCH METHODS

Research methods can be classified in a number of ways. One of the most common methods of classification is into quantitative and qualitative research and a combination of the two (Breach, 2009):

I. Quantitative methods of research: this method of research deals with the investigation of problems that can be represented in terms of numbers. Examples of quantitative methods applied in engineering and science normally involve some or all of the following:
   - creating mathematical models to investigate theories and hypotheses
   - designing instruments
   - developing methods of measurement
   - collecting numerical data
   - experiments with controls
   - changing variables and appraising the results.

II. Qualitative research methods: these methods deal with ideas, opinions, meanings and perceptions. The methods of qualitative research are direct observation by the researcher, questionnaires, and interviews, as well as documentary review.

III. Combined (qualitative and quantitative): simply a combination of qualitative and quantitative methods, where both are used at the same time.

2.2.1 QUANTITATIVE RESEARCH

Quantitative research can be defined as 'an inquiry into a social or human problem, based on testing a hypothesis or theory composed of variables, measured with numbers, and analysed with statistical procedures to determine whether the hypothesis or theory holds true' (Creswell, 2009). There are two main types of quantitative research method: experiments and surveys. A brief note on each of these two methods is presented in the next sections. Table 2.1 describes both the advantages and disadvantages of using these methods.

Table 2-1: The advantages and disadvantages of quantitative methods (McQueen & Knussen, 2002)

The quantitative method	Advantages	Disadvantages
Surveys	Very good for factual information gathering. Cost of execution is low. Increased geographical reach, especially when e-mails are used.	Responses can be subjective. Questions can be unclear. Not effective in cases of complex and sensitive data.
Experimental	Enables the researcher to control variables. Enables the researcher to measure the extent of change. The researcher can evaluate the cause and effect of relationships.	Difficult to use when studying people-related issues. Often time-consuming. Often done in a controlled environment without external factors.

2.2.1.1 Experimental Research

Experimental research suits issues in which the variables involved are known. The experiments are usually conducted in laboratories in order to examine the relationships between variables previously identified (Fellows & Liu, 2003). An experiment is a highly precise tool that should only be applied when there is a large amount of information concerning the phenomenon being studied. Without such information, it is very difficult to determine exactly which variables are to be studied and how they should be measured. Moreover, experiments and their findings are highly valued, and provide complete and precise answers to specific research questions (Robson, 2007).

2.2.1.2 Survey Research

Surveys represent one of the most common types of quantitative social science research method. In the research study, a researcher selects a sample of the population, and issues a standardised questionnaire to the sample. The survey can be conducted via a written document to be completed by the persons being surveyed (or it can be issued via the Internet), a face-to-face interview, or a telephone interview. Surveys make it possible to obtain information from a large or small number of people. A survey can be carried out with the aim of collecting data from a group of people and/or on a subject area by various methods including mail and interviews.

A survey typically involves obtaining answers to a number of standard questions from a carefully selected group of people (Robson, 2007). Survey methods vary from highly structured questionnaires to unstructured interviews (Fellows & Liu, 2003).

2.2.2 QUALITATIVE RESEARCH

Much like quantitative research, qualitative research involves a number of methods, including action research, case studies, and ethnographic research. Qualitative research is concerned with exploring issues, understanding phenomena, and answering questions. A brief overview of each of the three methods is presented in the next sections. Table 2.2 describes the advantages and disadvantages of applying such methods.

Table 2-2: Advantages and disadvantages of qualitative methods (McQueen & Knussen, 2002)

The qualitative method	Advantages	Disadvantages
Action research	A collaborative approach which gives an active role to participants, hence a more democratic form of research than most approaches. It is particularly suitable for practitioner–researchers, contributing to their professional and personal development. If successful, it can initiate a continuing cycle of development.	The involved collaborative stance required is difficult for a novice researcher. The shared ownership of the research processes between researchers and participants can lead to problems, particularly as regards completion of the project on time. Active co-operation by participants is essential, but is difficult to achieve as it takes place in the work setting where there can be conflicting demands.
Case studies	Studying a single case (or a small number of cases) gives the opportunity to carry out a study in depth, which can capture complexities, relationships and processes. It strongly encourages the use of multiple methods of collecting data, and of multiple data sources. It can be used for a wide variety of research purposes and for widely different types of cases.	Case studies typically seek to focus on situations as they occur naturally, and hence observer effects caused by the presence of the researchers can be problematic. The flexible nature of case study design means that you have to be prepared to modify your approach, depending on the results of your involvement. It can be difficult to keep to deadlines.
Ethnographic surveys	They rely upon direct observation and do not call for other specialized data collection methods. They are particularly suitable for studies focusing on how members of a culture see events. They can be very involving and interesting.	It can be very difficult and confusing for novice researchers to come to terms with their participant observer role. The skills needed to understand what is going on in a strange situation, including decisions on the choice of informants, may need considerable experience to acquire. There are problems of generalizability of findings similar to those with case studies.

2.2.2.1 Action Research

Action research is an approach involving active participation by the researcher in a situation or practice with the aim of evaluating the problem and finding a solution or improvement. Action research can adopt a variety of data collection methods, depending on the type of research question the researcher seeks to answer. A great deal of emphasis is directed to the quality of the research data—usually in the form of words—obtained from relatively unstructured interviews or observations of participants (Fellows & Liu, 2003; Robson, 2007).

2.2.2.2 Case Studies

Case studies focus on the development and in-depth analysis of the case or a small number of cases. The cases are selected because they are important or interesting. Furthermore, case studies adopt a variety of methods of data collection, including interviews and observations. They are sometimes based purely on documentary sources. In such cases, it is advisable to have a set of documents of different types for analysis (documentary analysis) (Robson, 2007).

2.2.2.3 Ethnographic Research

Ethnography is a social science research method which can be defined as 'the art and science of describing a group or culture' (Fetterman, 1998). Ethnographic research applies three kinds of data collection method: interviews, observation and documents. The group can be a team or an organisation, and 'culture' can refer to that of the organisation. Researchers conducting ethnographic assessments of organisational culture do so through the monitoring and recording of behaviour within the organisation over an extended period of time (Somekh & Lewin, 2005). Moreover, ethnographers detail the daily routine of people in the group.

2.2.3 TRIANGULATION RESEARCH

Triangulation can be defined as a research methodology wherein multiple research methods and/or measures are utilised. Qualitative and quantitative techniques are used together to study the subject, and the method can be powerful in achieving results and supportive in making inferences and drawing conclusions (Fellows & Liu, 2008). Figure 2.1 demonstrates how triangulation can be used in assessing, making inferences and drawing conclusions.

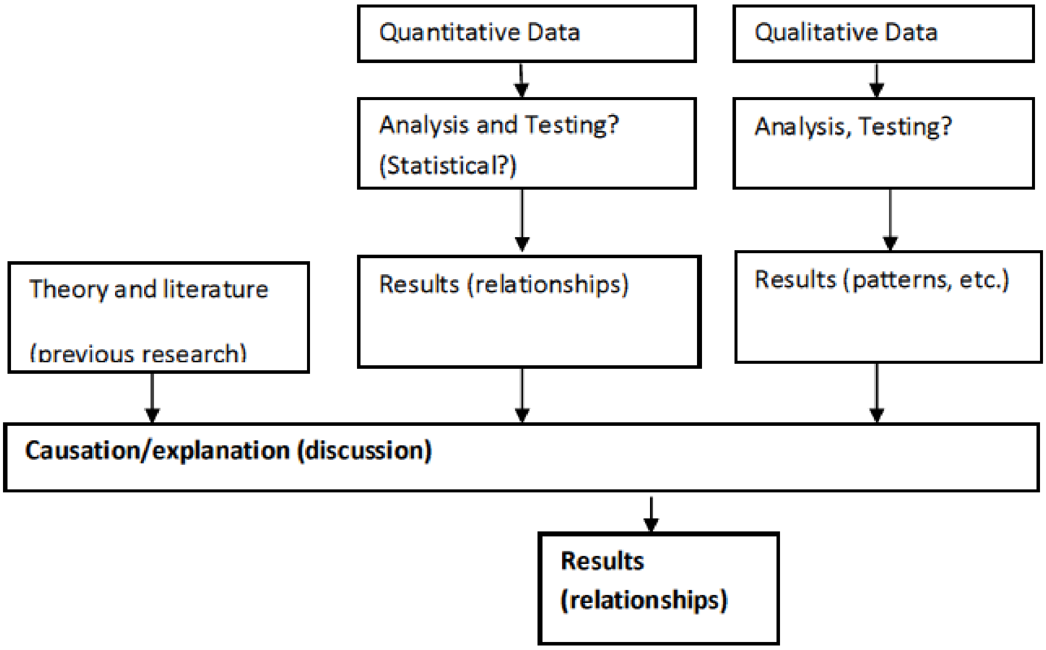


Figure 2-1: Triangulation: making inferences and drawing conclusions from both quantitative and qualitative data (Fellows & Liu, 2008).

2.3 METHODOLOGY SELECTED FOR THE RESEARCH

The decision as to which type of research strategy should be applied ultimately depends on the purpose of the research and the type and availability of information required (Naoum, 2007). In determining the most appropriate method for use, it is important that the researcher understands the type of research questions posed by the research (who? what? why? where? etc.), as well as the degree of control that the researcher will have over the process. Table 2.3 provides a useful classification for selecting the most appropriate method.

Table 2-3: Relevant situations for different research strategies (Yin, 2009)

Strategy	**Form of research question**	**Requires control over behavioural events?**	**Focuses on contemporary events?**
Experiment	How? Why?	Yes	Yes
Survey	Who? What? Where? How many? How much?	No	Yes
Archival analysis (Literature review)	Who? What? Where? How many? How much?	No	Yes/No
History	How? Why?	No	No
Case Study	How? Why?	No	Yes

2.3.1 METHODS USED

The subsections above discussed the overall research methods used for the research and the reason for using them. Table 2.4 presents the research road map. The table maps the research phases with the research objectives and task as well as the different methods selected.

Table 2-4 The research road map

Project Aim: To investigate the vulnerability of residential buildings to flood damage, to develop accordingly an intelligent system for assessing the vulnerability of residential buildings to flood damage, and to recommend remedial measures.			
Phase	**Research Objectives**	**Tasks**	**Research Methods**
Literature review	• To review the risk exposure of residential buildings to flood damage—especially in the UK. • To review recent research developments in the vulnerability assessment and remediation of residential buildings subjected to flooding.	1. Review of the topic, including: • literature review on flood in general, and flood damage to residential buildings • literature review on vulnerability and risk assessment • literature review on knowledge-based systems.	Literature review.
Developing vulnerability assessment technique	• To develop a method to assess the vulnerability of residential buildings subjected to flood damage.	2. Review vulnerability assessment methods 3. Identify the factors contributing to the vulnerability of buildings to flood damage 4. Conduct a survey to evaluate and assess these factors 5. Assign ratings and weightings to factors 6. Develop a vulnerability assessment technique.	Archival analysis, case study, survey, interviews.
Identification of the remediation option for each flooded building element	• To undertake detailed case studies with a view to establishing current industry practice, identifying opportunities for improvement, and establishing end-user requirements.	7. Identify remediation options for different flooded building elements 8. Conduct a survey to identify the remediation options available 9. Identify the remediation options available from technical reports, manuals, etc. 10. Identify flood damage to the building foundations and remediation options available.	Archival analysis, case study, postal survey, knowledge acquisition.
Prototype development and validation	• To develop a framework and functional specification for an intelligent approach to the vulnerability assessment and remediation of residential buildings subject to flood damage. • To implement and evaluate a prototype system based on the functional specification developed above and using test cases from industry.	11. Define the system goals 12. Define the main function and overall architecture of the system 13. Select a development environment 14. Build the knowledge base of the system 15. Implement the system 16. Evaluate the system.	Prototype development (rapid prototyping) and evaluation.

2.3.2 LITERATURE REVIEW

Fink (2010) defines a literature review as 'a systematic, explicit, comprehensive, and reproducible method for identifying, evaluating and interpreting the existing body of original work produced by researchers and scholars'. Moreover, in the view of Fink (2010), high quality literature reviews should base their findings on evidence ascertained through experiments or controlled observation.

A review of the literature should be carried out widely and conclusively at all stages of the study in an attempt to establish a solid foundation for the research topic and to provide a basis for addressing the problems and achieving the objectives of the research.

The main reasons for conducting a literature review, as highlighted by Neuman & Lawrence (2003) and Fink (2010), include the following:

- to clarify and explain the background of the subject of research
- to identify gaps in the available literature and thereby indicate what will add to the topic
- to identify methods, ideas and information suitable for research
- to identify experts who could assist in the interpretation of existing literature and identify sources of unpublished information
- to review previous works by others in this area
- to identify effective research and development methods.

A literature review is the cheapest and effective method of collecting the existing literature on the subject matter. In this research, an intensive review of the literature has been carried out in order to investigate the residential building flood damage problem. This involved a detailed investigation of three topics, including:

I. Vulnerability and vulnerability assessment: definition and concepts of vulnerability, vulnerability assessment, and methods of vulnerability assessment specially related to geohazard risks, such as landslides and earthquakes.

II. Issues relating to floods and flood damage caused to residential buildings: including types and characteristics of flood, types and characteristics of buildings in the UK, flood damage, building materials, and the effects of flooding. Also reviewed were different remediation methods for buildings and building elements subjected to flood damage.

III. Knowledge-based systems: including concepts, types, and advantages, methods of development, applications, and previous systems developed in the field of civil engineering.

A number of procedures were carried out in order to conduct the literature review, including: defining the research topic, identifying the sources of information, keeping records, reading, and note-taking.

2.3.3 CASE STUDIES

A case study should involve extensive data collection as a means of providing a broad understanding of the domain being studied. This is the preferred strategy when ‘how’, ‘who’, ‘why’ or ‘what’ questions are being posed, or when the focus is on contemporary real-life phenomena. Case studies are selected in an attempt to develop knowledge concerning the key topics of the research, which in this instance are: flood damage caused to residential buildings and their vulnerability assessment, and establishing a relationship between these so that the selection of the proper way of repairing these buildings can be based on their degree of vulnerability to flood damage, thereby reducing future costs. The case study method was selected as it provides an in-depth analysis of a specific domain (Naum, 2007). In this regard, the case study method helps in terms of providing an understanding of a difficult topic or subject, and can therefore extend knowledge or add strength to what is already known from existing research (Cohen, Manion, and Morrison, 2007). In addition, Anderson et al. (2005) believe that the case study strategy can contribute appropriately at any level of knowledge development. Moreover, the case study also provides a detailed investigation of variables relevant to the subject under study (Key, 1997). A case study may combine a variety of data collection methods and research strategies (Fellows & Liu, 2008). The case study approach was used in this research to develop the vulnerability assessment model, and to establish a framework for remediation options strategies.

In this research the case study approach was used for tasks 3, 7, 9, and 10 (see Table 2.3) to gather data from many different sources, including documents, experts and companies in the field of flooded buildings damage management.

2.3.4 KNOWLEDGE ACQUISITION

Many techniques have been developed to assist in obtaining knowledge from experts. This process is referred to as the development of knowledge or knowledge acquisition (KA). Knowledge acquisition can be defined as the transfer and transformation or capturing of potential problem-solving expertise from one or more knowledge sources to a computer program (Buchanan et al., 1983; Milton, 2007).

In addition, there are several different sources of knowledge acquisition (Turban & Aronson, 2001), including:

- documented (books, manuals, technical reports, etc.)
- undocumented (from experts or professionals in the field)
- databases
- the Internet.

Moreover, there are a number of factors which should be kept in mind when running a project to acquire knowledge (Milton, 2007):

- The end product must be useful to the end-users.
- In order to be useful, the knowledge should be of high quality, correct, relevant, and stored in a structured manner.
- The project must be run in an effective way so as to use most of the available resources.

In this research, the knowledge acquisition process involved collecting as much information as possible from different sources which might be needed for the objectives of this research. The knowledge captured was mainly derived from three sources: firstly, experts working in the field of flooded buildings damage management (human experts); secondly, books, peer-reviewed journal and conference papers, manuals and technical reports (documented sources); and thirdly, a questionnaire survey. The focus was on gathering information which met the purposes of this research, and was related to the following topics:

a) Factors affecting the vulnerability of residential buildings and the different components affected by the flooding, as well as the materials used in the buildings
b) Methods of repairing buildings exposed to flooding; the relationship between the choice of methods and the vulnerability of the buildings and their different components; and the use of methods and materials to reduce the risk of flooding, and accordingly reduce the costs of repair in the future.

According to Kendal & Creen (2007), printed sources and the Internet can be very useful for acquiring knowledge. In the specific context of knowledge engineering, with particular reference to the acquisition of knowledge in a certain area, detailed technical information, case studies and textbooks demonstrate high value. With this in mind, it is important that the engineer utilises knowledge from such sources.

During the knowledge acquisition phase, the knowledge engineer utilises techniques and tools such as those mentioned above in order to gain implicit knowledge from professionals in the discipline (Milton, 2007). Turban & Aronson

(2001) classified the methods of knowledge acquisition into three categories, as shown in Figure 2.2:

- Manual methods: interviewing (structured, semi-structured, unstructured), tracking the reasoning process, and observing
- Semi-automatic methods: divided into those which help the expert and those which help the knowledge engineer
- Automatic methods: those in which the roles of both the expert and the knowledge engineer are minimal, for example the induction method.

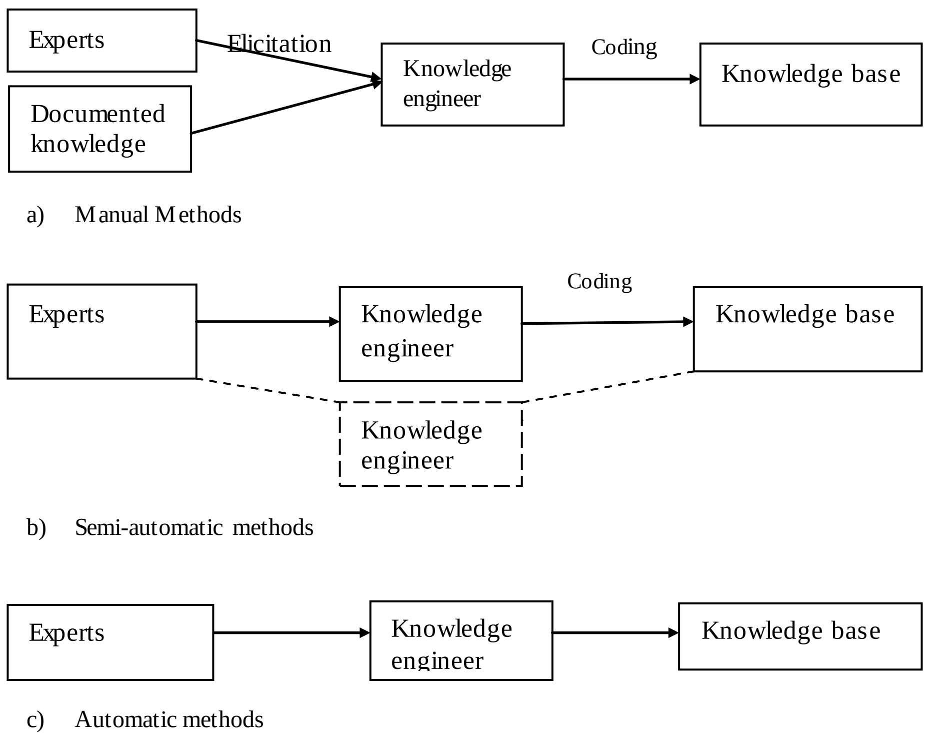


Figure 2-2: Methods of knowledge acquisition (Source: Turban & Aronson, 2001)

In this research, manual methods were selected for the knowledge acquisition, where the knowledge is acquired from experts in the field or from documents such as technical reports and manuals.

The methods developed in an attempt to assist in obtaining knowledge from an expert are referred to as knowledge elicitation or knowledge acquisition (KA) techniques. Emberey et al. (2007) compiled a matrix referring to several tools that can be used in order to acquire various types of knowledge, as shown in Figure 2.3.

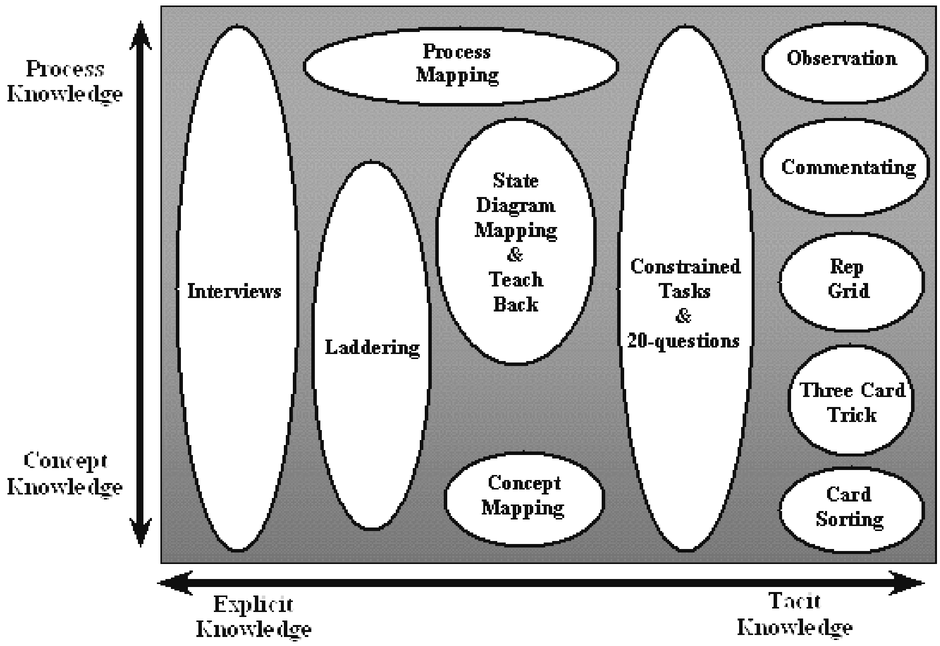


Figure 2-3: Knowledge Acquisition Matrix presents several tools used in order to acquire various types of knowledge (Emberey et al., 2007)

Welbank (1983) reviewed the appropriateness of different KA methods to different knowledge types. Table 2.4 summarises his research findings.

Table 2-4: Types of knowledge with appropriate knowledge acquisition method (Welbank, 1983)

	Facts	Conceptual structure	Casual knowledge	Procedures or process	Expert's strategy	Justification
Questionnaire survey	✔					
Interview	✔	✔	✔			✔
Case studies	✔		✔	✔		
Card Sorting		✔		✔	✔	
Laddering		✔				
Repertory grid		✔				

This research covered two topics that required knowledge acquisition: vulnerability assessment and repair of damage to flooded buildings. These two topics required the use of a number of knowledge acquisition methods to collect knowledge that was sufficient to develop the proposed knowledge base. The next section discusses the ttechniques applied for knowledge acquisition in this research.

2.3.4.1 Techniques applied for knowledge acquisition in this research

The acquisition, organisation and corresponding updating of a knowledge base—as well as the representation of the knowledge, mainly when obtained from multiple sources and methods—are difficult tasks (Richardson & Domingos, 2006). Kendal & Kreen (2007) state that there are normally three types of knowledge to be dealt with during knowledge acquisition:

- Declarative knowledge: providing facts about things.
- Procedural knowledge: is the knowledge used in the performance of some task.

- Meta-knowledge: knowledge about knowledge, which helps us to learn how experts use knowledge to make decisions.

The main sources of knowledge used in this research include:

- Expert opinion: in this research, expert opinion was ascertained in various different ways: indirectly, during workshops and seminars, when discussing or presenting ideas or problems relating to the research topic; directly, by asking a question or introducing an idea or issue, and allowing the expert to give their opinion or comments; and through using survey questionnaires.
- The library database: access to a wide range of information sources, including full-text journals, books, and electronic books, images, and statistical data related to the research area.
- Historical data: information relating to previous flood events, which was requested from the Environment Agency (EA), the Construction Industry Research and Information Association (CIRIA), and the British Insurance Association (BIA).
- Codes of Practice: used as a source of repair methods to be included in the knowledge base of the prototype system.
- Standard engineering procedures: standards relating to the methods or materials of repair, identified by their codes and numbers, given to the user for use if required. e.g. the British Standards which used in this research.
- Experimental data: results of experiments carried out by other researchers or organisations studying the effects of floodwater on different building materials or building structures, which were subsequently used in the

evaluation and rating of factors relating to building materials to identify the materials susceptible to damage by floodwater.

- Technical literature including:
  - text books
  - journals
  - manuals
  - technical reports.

  These materials were used to identify the factors adopted in vulnerability assessment, remediation options, damage caused by flood, building materials, knowledge base systems, and standards related to the research.

- The Internet: used to access information and knowledge related to the topic from different sources, including organisation websites.

The knowledge acquisition techniques used in this research for developing the prototype system comprised a combination of methods, as illustrated below.

Questionnaire survey:

A questionnaire survey is a tool of scientific research which is widely used to collect data relating to a particular topic or research problem. Two questionnaires were developed for the purpose of this research. The questionnaires were organised to obtain information relating to the following aspects of the research:

- Factors affecting vulnerability of buildings to flood damage: Following the identification of those factors believed to contribute to the vulnerability of buildings to flood damage, as based on the literature review, a survey was conducted in order to investigate these factors and to identify their relative importance in terms of their contribution to the vulnerability of buildings to flood damage; and to identify any other factors that might not have been apparent from the literature review.

- The repair of flood-damaged buildings: Data were collected from the literature review on the methods and options used for the maintenance of buildings exposed to flooding. The questionnaire was applied with the aim of identifying the various different methods of remediation. Some flood characteristics—mainly flood depth—were based on previous cases of flooding and past experience. Also of interest were any materials or other options that can be used during the repair of flood damaged buildings.

The survey questionnaire (cross-sectional) method was adopted for the collection of required information owing to its advantages in being economical and offering rapid results in data collection. Both an Internet survey via email and a postal survey were carried out because of their low cost and their effectiveness. In addition, the questionnaires were sent to a number of contractors and experts in the field of flood damage management, or otherwise handed out in person during workshops attended. The postal and email addresses of the contractors were obtained by contacting various different organisations, such as The Royal Institution of Chartered Surveyors (RICS), The Association of British Insurers (ABI) and the Environment Agency (EA), or were otherwise collected in person during the workshops.

Figure 2.4 illustrates various types of survey question. Rating questions were used to investigate the factors affecting buildings' vulnerability to flood damage. The aim was to determine the relative importance of each factor in contributing to vulnerability to flood damage (more details are given in Chapter 3). A copy of the survey is shown in Appendix A.

Partial open-ended questions (multiple-choice with other options) were used in the survey on the repair of flood-damaged buildings so as to give the participants the opportunity to add any further remediation options. A copy of the survey is shown in Appendix B.

Table 2-5: Types of survey question

Question Type	Uses	Advantages	Disadvantages
Open-ended (essay or short-answer)	• Discover relevant issues • Obtain a full range of responses • Explore respondents' views in depth	• Identifies issues most relevant to respondents • Generates new ideas about topic • Clarifies respondents' positions • Provides detail and depth	• Requires more time, thought, and communication skill to complete • Requires time-consuming data entry • May generate incomplete or irrelevant data • Complicates data summary and analysis
Closed (multiple-choice or yes/no)	• Ask many questions in a short time period • Assess learning or attitudes when issues are clear • Measure knowledge or ability	• Fast and easy to complete • Enables automated data entry • Facilitates data analysis and summary of data	• Limits response options • May omit a preferred answer • Requires moderate knowledge of the topic to write appropriate questions and responses • Lacks detail and depth
Partial open-ended (multiple-choice with 'other' option)	• Ask many questions in a short time period • Assess learning or attitudes when issues are clear and identifiable • Discover relevant issues	• Enables respondents to create their own response if choices do not represent their preferred response • Generates new ideas about topic • Fast and easy to complete	• Requires moderate knowledge of the topic to write appropriate questions and responses • Lacks detail and depth • Complicates data analysis and summary

Scaled	• Determine the degree of a response, opinion, or position	• Provides a more precise measure than yes/no or true/false items • Fast and easy to complete • Enables automated data entry	• Requires moderate knowledge of the topic to write appropriate questions
Rating	• Determine the relative importance to respondents of various options • Choose among various options	• Allows respondents to indicate the relative importance of choices • Enables automated data entry	• More difficult to answer • Limits number of response options • May omit a respondent's preferred answer

Source: Instructional Assessment Resources (IAR)
www.utexas.edu/academic/ctl/assessment/iar/teaching/plan/method/survey/survey_tables_questiontypes.pdf

Documents:

Documents can present a wide range of material (Thomas, 2009). Much of human knowledge is expressed in documents. A considerable part of the knowledge related to the research topics is available in documents. For example, technical reports and manuals contain procedures and standards for the building repairs or resilient options available. With this in mind, documents were used during this research, when available, for the purpose of obtaining information, as well as investigating and confirming the information obtained from the questionnaire, or to compensate for missing data. Table 2.5 shows examples of the documents that were used.

Table 2-6: Examples of the documents used in this research

Title of publication	Author	Type	Date of publication
Repairing flood damage: ground floors and basements	BRE	Guide 11. Part 1	1997
Repairing flood damage: foundations and walls	BRE	Guide 11. Part 2	1997
Preparing for floods: interim guidance for improving the flood resistance of domestic and small business properties	DTLR	Book	2003
Flood damaged property: a guide to repair	D.G. Proverbs & R. Soetanto	Book	2004
Standard for the repair of buildings following flooding	S. Garvin, J. Reid & M. Scott	Book. CIRIA (C637)	2005
PAS 64:2005 Professional water mitigation and initial restoration of domestic dwellings. Code of practice	British Standards Institution	Code of Practice	2005
Repairing flooded buildings: an industry guide to investigation and repair	Flood Repair Forum. BRE	Book	2006
Improving the flood performance of new buildings: flood resilient construction	DCLG	Practice and guidance, reports and summaries	2007
Improving the flood resistance of your home - advice sheets 1-7.	CIRIA	Advice sheet	2007
Developing the evidence base for flood resistance and resilience. R&D Technical Report FD2607/TR1.	DEFRA	Technical Report	2008

Workshops:

The issue of flooding is a relatively new problem that has emerged in recent years as a result of climate change, so there are few sources of information covering this topic, especially flood damage to residential buildings. As a result, several workshops have been organized in recent years covering aspects of flood damage management, or related to the issuance of new laws or regulations related to flood management. Therefore, in this research the workshops covering this topic have been used as a source of information or confirmation of gained information, because of the many specialists relevant to this subject who have attended these workshops.

Attendance and participation at a number of workshops was considered relevant throughout the period of the research, for the following purposes:

- increasing and improving the acquisition of information concerning the subject matter
- gaining views and ideas from discussions with experts
- finding sources of information on the subject of the research
- identifying the most recent developments, such as studies, technical reports, regulations and technologies developed in relation to the research problem
- establishing specialists and experts in the subject of the research.

Workshops that have been attended are given below:

1. Critical examination of developments in flood resilience. HR Wallingford, Oxfordshire, 27 March 2007.
2. Delivering flood risk management in new developments. The Arup Campus, Solihull, West Midlands, 9 April 2008.
3. The impact of flooding on property owners. Birmingham, 8 May 2008.
4. Flood Repair Network. Anderson Strathern, Edinburgh, 9 October 2008.
5. Household flood resilience and protection – DEFRA consultation workshops. DEFRA Innovation Centre, Reading, 24 October 2008.
6. Stemming the flow - managing flood risk in existing developments. The Arup Campus, Solihull, West Midlands, 15 October 2009.

In this research, the benefits gained from attendance at and participation in workshops is as follows:

1. gaining information directly from the lectures presented or from audience contributions
2. achieving a wider view and understanding of the topic
3. becoming acquainted with people and publications relating to the topic
4. gaining the opportunity to inquire about some aspects of information which need to be clarified by specialists in this area (through unstructured interviews)
5. gathering responses to the questionnaires that were distributed directly by hand
6. identifying policies and regulations that will be developed and which are related to the topic.

The unstructured interview technique was adopted during workshops in order to gain knowledge from experts attending, in addition to the information gained directly.

Various other techniques were also used, including codifying information and classifying it for use, as well as conducting interviews with professionals who attended the workshops. In addition, the database of the model was updated and developed each time new information was obtained from the workshops.

2.3.5 PROTOTYPE DEVELOPMENT

The final objective of this research was to implement and evaluate a prototype system, which is the most important element of the methodology used. A rapid prototyping methodology was applied with the objective of developing the prototype system. The prototype is a partly developed product, which allows developers to study and modify various aspects of the proposed system and thereby decide whether they are appropriate for the final product. Prototyping is widely considered to be a robust and cost-effective way of producing and developing systems with a high level of user satisfaction, quickly and at low cost (Law & Longworth, 1987; Lejk & Deeks, 2002). Sommerville (2001) mentions that the prototyping method must be used for systems where the specification cannot be developed in advance, such as AI systems and user interface systems. The prototyping process comprises a number of different steps, as shown in Figure 2.4.

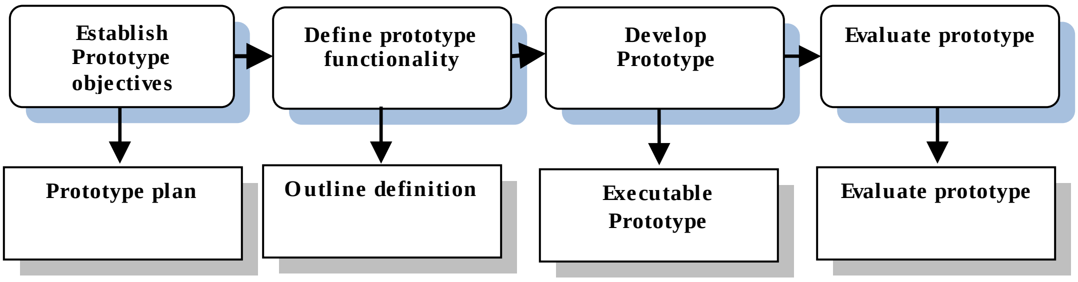


Figure 2-4: Prototyping process (Sommerville, 2001)

The prototyping methodology has a number of advantages (Sommerville, 2001; Turban et al., 2007):

- fast system delivery
- minimisation of the overall effort required to develop the software
- meeting user requirements more fully.

The process of prototyping passes through a number of stages before the final version is developed. The prototyping stages are shown in Figure 2.5.

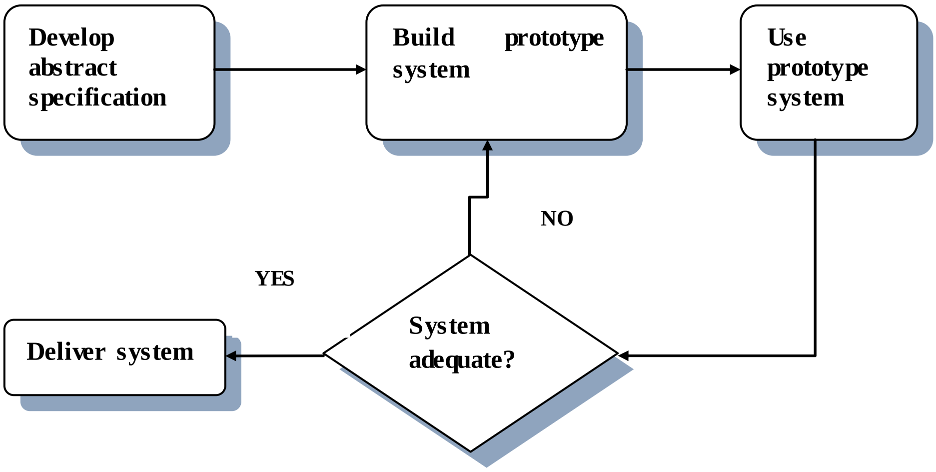


Figure 2-5: Prototyping methodology (Sommerville, 2001)

The main steps of the prototype development system based on prototyping processes are shown in Figure 2.6 below.

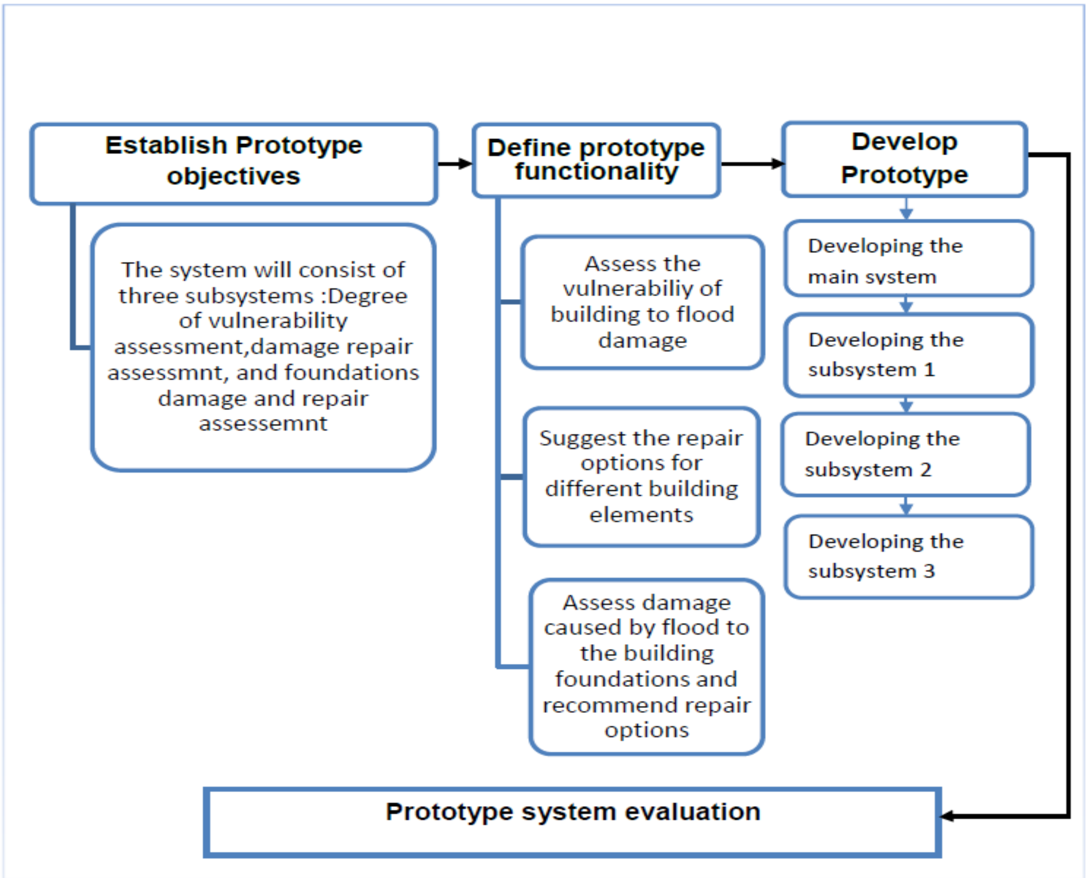


Figure 2-6: The main steps in developing the prototype system

2.3.6 EVALUATION

The aim of an evaluation process is to assess the overall value of the system. According to Kendal & Creen (2007), the evaluation of the knowledge base system is part of the overall quality control measures in building the system, and involves two terms, namely 'validation' and 'verification'. These terms can be defined as follows:

> 'Validation measures the performance of the knowledge base system. In effect, the output from the system is compared to the output that would be provided by an expert. A check is then made to ensure that the system is performing to an acceptable level of accuracy.'

(Kendal & Creen, 2007)

> 'Verification is checking that the system has been built correctly, i.e., that the rules are logical and consistent with the knowledge obtained via the knowledge acquisition process.'
>
> (Kendal & Creen, 2007)

The prototype system was evaluated in two stages: during the development stage, and following development. In the system evaluation which occurs during the development stage, also known as 'formative evaluation', the system was demonstrated to a number of experts in order to validate and verify it. The prototype subsequently went through several iterations with appropriate refinements for its improvement. In the second stage of the evaluation, which followed the development process, and which is also known as 'summative evaluation', several experts from different organisations were invited to give their views and comments on the final prototype. The comments and recommendations were noted, and various modifications were accordingly made to improve the prototype system. The prototype evaluation pricesses and purpose is described in detail in Chapter 7.

2.4 SUMMARY

In this chapter, the basic concepts and principles relating to the research methodology were reviewed, and various types of research methodologies were described. The chapter also described the methodology adopted in order to realise the aim and the objectives of the research. The research methodology adopted several approaches and such as literature review ,surveys, case study, questionnaires, prototype system developing and evaluation The next chapter describes the model that developed in order to assess the vulnerability of residential buildings to flood damage.

CHAPTER 3 VULNERABILITY ASSESSMENT

3.1 INTRODUCTION

This chapter is divided into four main sections: a definition of vulnerability, an explanation of vulnerability and hazard assessment with the provision of various examples, the method developed to calculate the vulnerability of residential buildings to flood damage, and a summary. This chapter reviews the vulnerability assessment methods used mainly in relation to natural disasters, then discusses the factors considered in the proposed model to calculate the vulnerability of buildings to flood damage. Finally illustrate the developed model to calculate the degree of vulnerability of building to flood damage.

3.2 DEFINITION OF VULNERABILITY

Vulnerability has been defined in various different ways by numerous experts on the basis of what is the desired outcome. A number of different concepts have been termed ‘vulnerability’, as given below:

- a measure, for a given population or region, of the underlying factors that influence exposure to hazardous events and predisposition to adverse consequences (Downing, 1993)
- a characteristic of individuals and groups of people who inhabit a given natural, social and economic space, within which they are differentiated according to their varying position in society into more or less vulnerable individuals and groups (Cannon, 1993)
- the potential for attributes of a system to respond adversely to the occurrence of hazardous events (Yamada et al., 1995)

- the extent to which a given hazard would impact on a property by reason of its materials or layout (Clark et al., 1998)
- the extent to which a natural or social system is susceptible to sustaining damage from climate change (IPCC, 2001)
- a function of a system's ability to cope with stress and shock (Nicholls & Klein, 2000)
- the propensity of social and ecological systems to suffer harm from external stresses and shocks (International Council for Science, 2002)
- a human condition or process resulting from physical, social, economic and environmental factors, which ultimately determine the likelihood and scale of damage from the impact of a given hazard (UNDP, 2004).
- Vulnerability is path dependent: the vulnerability of someone or something at any point of time depends upon what has previously happened to that person or thing (Green, 2004).
- The word 'vulnerability' comes from the Latin verb *vulnerare*, meaning 'to wound', and signifies exposure to physical or moral harm (Alexander, 2005).
- "the predisposition of an element or a system to be affected or susceptible to damage" (Villagran de Leon, 2006)
- The characteristics and circumstances of a community, system or asset those make it susceptible to the damaging effects of a hazard" (UNISDR, 2009).

For the purpose of this research, the term ‘vulnerability’ is defined as the expected susceptibility of a building to flood and the susceptibility of any building element to damage from a flood event.

3.3 VULNERABILITY ASSESSMENT

A risk and vulnerability assessment helps to identify people and property, as well as resources, that are considered to be at risk of injury or damage or loss resulting from hazardous incidents or natural hazards. Amongst the tangible vulnerable elements subjected to flood risk are buildings. A vulnerability assessment is the process of estimating disaster potential in terms of what is susceptible to damage (NCDEM, 1998; Kron, 2005). A building vulnerability assessment is important in the evaluation of risk from flood hazards (Chen, Yin, and Dia, 2011).

The vulnerability assessment includes an inventory and assessment of potential losses. There are two basic approaches which can be utilised in an attempt to establish the degrees of vulnerability. The first approach is based on damage data obtained from experiments or from field observations following the flood event. The second approach is based on numerical models or simplified methods, or, if no other method is available, on engineering judgments.

In the case of earthquake vulnerability assessment of buildings, which is similar to flood vulnerability assessment, Tyagunov et al. (2004) state that there are two principal approaches, namely observed vulnerability and predicted vulnerability. Observed vulnerability refers to assessment based on the statistics of past earthquake damage; predicted vulnerability refers to the assessment of performance expected of the buildings on the basis of engineering calculations and design specifications, or, if there are no other means, t based on engineering judgment. The second method is more appropriate when there are no data available regarding the observed vulnerability.

3.3.1 EXAMPLES OF VULNERABILITY AND HAZARD ASSESSMENT METHODS

One of the definitions which can be applied in the case of flood damage is that suggested by Cardona (2003): "Vulnerability: the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total loss). On the other hand, vulnerability may be understood, in general terms, as an internal risk factor, mathematically expressed in terms of the feasibility that the exposed subject or system will be affected by the phenomenon that characterizes the hazard." In layman's terms, it means the degree to which an individual, family, community, class or region is at risk from suffering a sudden and serious misfortune following an extreme natural event (Buckle et al., 2000; Fuchs, Heiss, and Hubl, 2007).

Examples of vulnerability and hazard assessment methods are provided below with consideration to several aspects of geohazard vulnerability and risk assessment:

- Fiener & Haji (1999) developed a method to calculate the landslide hazard of highway slopes, which was then used in highway slope management and maintenance. The major causative factors which are known to influence slope stability include lithology, the degree of weathering, slope condition, erosion, physical properties, land use and land cover, and slope history. Numerical ratings for different categories were determined on the basis of their estimated significance in causing instability, based on the rating scheme. A maximum value of six indicates that the factor is highly significant. The factors are subdivided into subsets, and subfactor weightings are calculated using linear extrapolation between the minimum and maximum factor weightings, or through other means. Causative factors and their ratings are provided in Table 3.1.

Table 3-1: Causative factors and their ratings (Fiener & Haji, 1999)

Causative factor	Maximum rating
Lithology	6
Degree of weathering	4
Structure	4
Slope condition	6
Hydrology	6
Erosion	4
Physical properties	4
Land use and land cover	4
Slope history	2

The total hazard value of each slope is calculated by adding together each of the values taken from the subfactor weightings. Once the total hazard value has been calculated, the slope may be classified (given a hazard rating) as follows:

HAZARD RATING	TOTAL HAZARD VALUE
Very high hazard	>32
High hazard	26-32
Moderate hazard	20-26
Low hazard	14-20
Very low hazard	<14

- Nicholas et al. (2001) developed a conceptual model for assessing flood damage to UK domestic properties. The model originates from a critique of the knowledge available at that time in the field, as well as from discussions held with practitioners responsible for surveying, and recommended strategies for the repair of such properties. The model comprises two independent factors: building characteristics and flood characteristics. The dependent variable is flood damage. The model is expressed as:

Flood damage = f (the flood characteristics + the building's characteristics) (1)

The flood characteristics are defined as:

the velocity of floodwater (m/s) in contact with a particular dwelling;

the contaminant content of the floodwater (grams/m^3);

the time duration of the flood (hours/minutes).

The building's characteristics are defined as:

the frequency of flooding of the dwelling (number of times in period x);

the materials from which the building is constructed;

drying characteristics of the materials;

the condition of the building prior to being flooded.

The mathematical relationships of the variables in equation (1) are then identified as given below:

Fcx = flood characteristics that have been in contact with property x;

Dcx = dwelling characteristics of property x;

then:

Flood damage repair index = *f (Fcx+Dcx)*

and:

$Fcx = f (Fx_{time} + Fx_{cont} + Fx_{depth} + Fx_{vel})$

where:

Fx_{time} = the time duration of flood x;

Fx_{cont} = the contaminant content of flood x;

Fx_{depth} = the depth of flood x;

Fx_{vel} = the velocity flow of flood x.

Also:

$Dxc = f (Dx_{loc}+Dx_{furnish}+Dx_{const})$

where:

Dx_{loc} = physical location of dwelling x;

$Dx_{furnish}$ = nature of furnishings of dwelling x;

Dx_{const} = construction characteristics of dwelling x.

Nicholas et al. (2001) stated that future research will determine the quantitative values for all variables.

- Papathoma & Dominey-Howes (2003) applied a tsunami vulnerability assessment method to two coastal villages in the Gulf of Corinth, Greece, using the tsunami of 7 February 1963 as a worst-case scenario. The vulnerability of each building (BV) in the inundation zone is then calculated as follows:

$$BV = (7xa)+(6xb)+(5xc)+(4xd)+(3xe)+(2xf)+(1xg)$$

where:

(a) = the standardised score that is related to the materials of the building;

(b) = the standardised score that is related to the row of the building;

(c) = the standardised score that is related to the number of floors the building has;

(d) = the standardised score that is related to the building's surroundings;

(e) = the standardised score that is related to the condition of the ground floor of the building;

(f) = the standardised score that is related to the presence of sea defences in front of the building;

(g) = the standardised score that is related to the width of the intertidal zone in front of the building.

Owing to the fact that the vulnerability factors do not all have the same effect, they then need to be ranked according to their importance. A weighting factor is then applied, as shown in Table 3.2.

Table 3-2: The criteria, their ratings and weighting factors (Nicholas et al. (2001)

Criterion	Weighting factor
Building material	7
Row	6
Surroundings	5
Condition of ground floor	4
Number of floors	3
Sea defence	2
Natural environment	1

Sur (2005) adopted the weighting and rating values given in Table 3.3 below in an attempt to assess the vulnerability of buildings subjected to earthquake damage in Dhradan City (India).

The vulnerability assessment of a building is calculated using equation 3.1:

Final weighting = [10* (building shape sub-class rank)] + [8*(building age sub-class rank)] + [6* (no. of storeys sub-class rank)] + [4* (building proximity sub-class rank)] + [2* (building maintenance sub-class rank)].

Table 3-3: Weighting and rating for building damage assessment (Sur, 2005)

No	Weighting	Parameter	Sub-classes	Rank
1	10	Building shape	Symmetrical	1
			Asymmetrical	2
2	8	Age of building	After 1975	1
			1950-1975	2
			Before 1950	3
3	6	No of storeys	1-2 storeys	1
			3-4 storeys	2
			>4 storeys	3
4	4	Proximity of other buildings	>1m	1
			0.5-1.0 m	2
			<0.5 m	3
5	2	Building maintenance	Good	1
			Moderate	2
			Poor	3

Another method has been applied in rural communities in Guatemala; this is for the evaluation of four different types of vulnerabilities associated with the housing sector at the local level, namely physical or structural, functional, social, and economic. When this particular method is applied, each type of vulnerability is measured according to factors which are directly related to the type of vulnerability in question, classifying the different types of option commonly available in these communities these variables cover three ranges: low, medium, and high. For example, in the case of volcanic eruptions, the structural vulnerability of a house is analysed according to five parameters: walls, roofing materials, roof inclination, roof support materials, doors, and windows. The classifications of low, medium and high vulnerability are introduced in terms of the construction material employed, in recognition of the fact that some materials are more vulnerable than others. Essentially, the overall vulnerability is presented in terms of arbitrary units, and accordingly classified in three ranges according to a pre-defined table, as given in Figure 3.1 below.

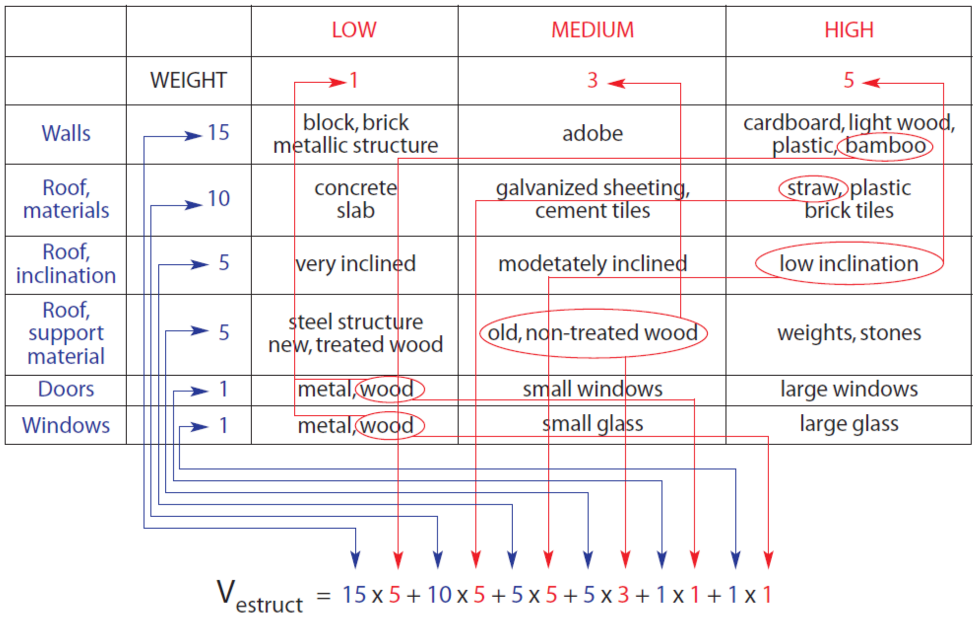


Figure 3-1: The overall vulnerability calculation (Villagran, 2006)

- Kemp (2007) established a methodology for a building's owners and managers to assess the vulnerability of its facilities. Such a process would facilitate the use of remedial measures to reduce the loss of lives and property during disasters—whether natural or man-made. The author identified nine criteria for the vulnerability assessment, in addition to a six-point classification system. The factors selected are: the level of visibility, the criticality of the site to the jurisdiction in which it is located, the impact of the site outside the jurisdiction in which it is located, access to the site, site hazards, building height, type of construction, site population capacity, and the potential for collateral mass casualties. A vulnerability rating can be accordingly estimated or determined by using these nine variables and subsequently rating the response to each potential risk category on a six-point scale, ranging from 0–5. The lower the numerical rating in each category, the lower the vulnerability or risk level of the site; conversely, the higher the rating, the greater the exposure of the site to possible attack or damage. With this in mind, the nine assessment criteria contained in this rating process—as well as the rating scale used in each category—are shown in Table 3.4 below.

Table 3-4: Vulnerability assessment form (Kemp, 2007)

Category	Rating
Level of Visibility:	0 = No visibility 1= Very low visibility 2 = Low visibility 3 = Medium visibility 4 = High visibility 5 = Very high visibility
Criticality of Site to Jurisdiction:	0 = No usefulness 1 = Minor usefulness 2 = Moderate usefulness 3 = Significant usefulness 4 = High usefulness 5 = Critical usefulness
Access to the Site:	0 = Restricted access 1 = Controlled access 2 = Limited access 3 = Moderate access 4 = Open access 5 = Unlimited access
Impact of Site Outside of Jurisdiction:	0 = No impact 1 = Very low impact 2 = Low impact 3 = Medium impact 4 = High impact 5 = Very high impact
Site Hazards:	0 = No site hazards 1 = Minimal site hazards 2 = Low site hazards 3 = Moderate site hazards 4 = High site hazards 5 = Very high site hazards
Building Height:	0 = Underground 1 = Single storey

	2 = Low rise 3 = Mid rise 4 = High rise 5 = Skyscraper
Type of Construction:	0 = Underground 1 = Hardened 2 = Reinforced concrete 3 = Structural steel/masonry 4 = Light frame 5 = Wood structure
Site Population Capacity:	0 = No population 1 = 1 to 250 population 2 = 251 to 5,000 population 3 = 5,001 to 15,000 population 4 = 15,001 to 50,000 population 5 = 50,000 plus population
Potential for Collateral Mass Casualties:	0 = 0 to 100 people 1 = 101 to 500 people 2 = 501 to 1,000 people 3 = 1,001 to 2,000 people 4 = 2,001 to 5,000 people 5 = 5,000 plus people

The potential vulnerability of a site can be assessed by rating a facility according to these factors and a numerical rating process for each category. This evaluation process leads to five categories of vulnerability, as given in Table 3.5.

Table 3-5: Categories of vulnerability (Kemp, 2007)

Total points	Rating category
0-9	Negligible
10-18	Low
19-27	Medium
28-36	High
37-45	Critical

A model to calculate the vulnerability of residential buildings to flood damage will be developed and validated on the basis of the definition of vulnerability, the ideas and examples of vulnerability assessment using the similar ideas mentioned in the previous examples. The will be discussed in next sections.

3.4 THE PROPOSED METHOD DEVELOPED TO CALCULATE THE VULNERABILITY OF RESIDENTIAL BUILDINGS TO FLOOD DAMAGE

The vulnerability of the elements at risk highlights how damaged buildings, or any other elements, may react if they experience some degree of hazard, such as floods. The loss measurement applied depends on the element at risk; therefore, the loss can be measured as a proportion of the number of dead or injured to the total population, as the cost of repair, or as the extent of physical damage measured by an appropriate scale (Gwilliam et al., 2006). Assessing the vulnerability of buildings in flood-prone areas is a key issue when evaluating the risk induced by flood events; nevertheless, a comprehensive methodology for risk assessment of buildings subject to flooding is still missing.

The model which has been developed is based on key factors—in particular, the susceptibility of the building elements to damage by floodwater, as well as the susceptibility of the entire building to flooding (e.g. as a result of its geographical location). The damage that would occur to different elements of the building is considered, as well as the building elements that would need to be repaired as a result of flood damage, leaving aside other considerations (e.g. health risks). This means that only physical damage to the building elements is considered.

On the basis of the accepted definitions of vulnerability, the vulnerability of buildings to flood damage can be represented by three controls: causes (the flood event), vulnerabilities (building elements), and results (flood damage), as shown in Figure 3.2.

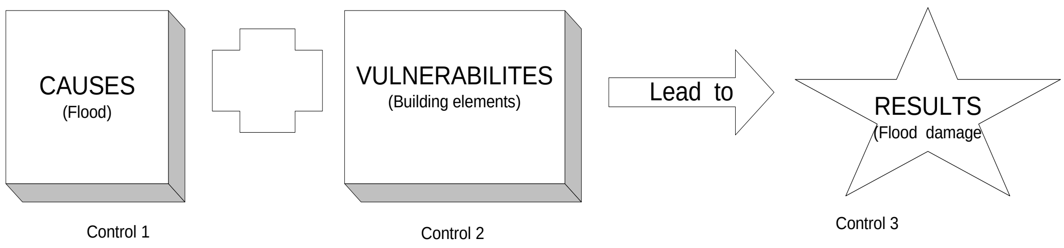


Figure 3-2: The mechanism of vulnerability of buildings to flood damage

It is clear that the three controls (Flood, Building elements, and flood damage) are controlling the mechanism of vulnerability of building elements to flood damage. Preventing the flood and making the building elements less vulnerable will notably reduce flood damage; in fact, it is not possible to prevent floods from occurring, and so the only way of reducing flood damage is to make the building elements less vulnerable. On the basis of the above figure, these points could be summarized as follows:

- Flood damage happens in all flood events.
- The damage level will be affected by the degree of vulnerability (high vulnerability leads to more damage).
- The level of damage can be reduced by reducing the vulnerability of building elements to flood damage.

- The vulnerability of buildings to flood damage can be determined according to how vulnerable they are and the other factors that put them at risk of flooding.
- Vulnerability tends to be greater when the risk of flooding is high.
- The proposed model considers the flood damage caused to different building elements.

3.4.1 THE STEPS IN THE DEVELOPMENT OF THE DEGREE OF VULNERABILITY ASSESSMENT MODEL

Itemised information relating to flood damage to building structures is not always available, and, owing to the lack of precise information or field measurements that can be used to develop the vulnerability assessment model, it has been necessary to rely on references, technical reports and research papers, as well as the questionnaire.

The model for calculating the vulnerability of buildings to flood damage has been developed on the basis of the vulnerability definitions provided at the beginning of this chapter, as well as the examples of methods detailed for the calculation of vulnerability, given in Section 3.3.1, and the discussion in Section 3.3.2.

The developed model is based on the ordinal scale relative weighting-rating technique. With this in mind, the flow chart shown in Figure 3.3 below shows the key stages involved in the vulnerability assessment adopted in this research. The description of the different steps is presented in the following sections.

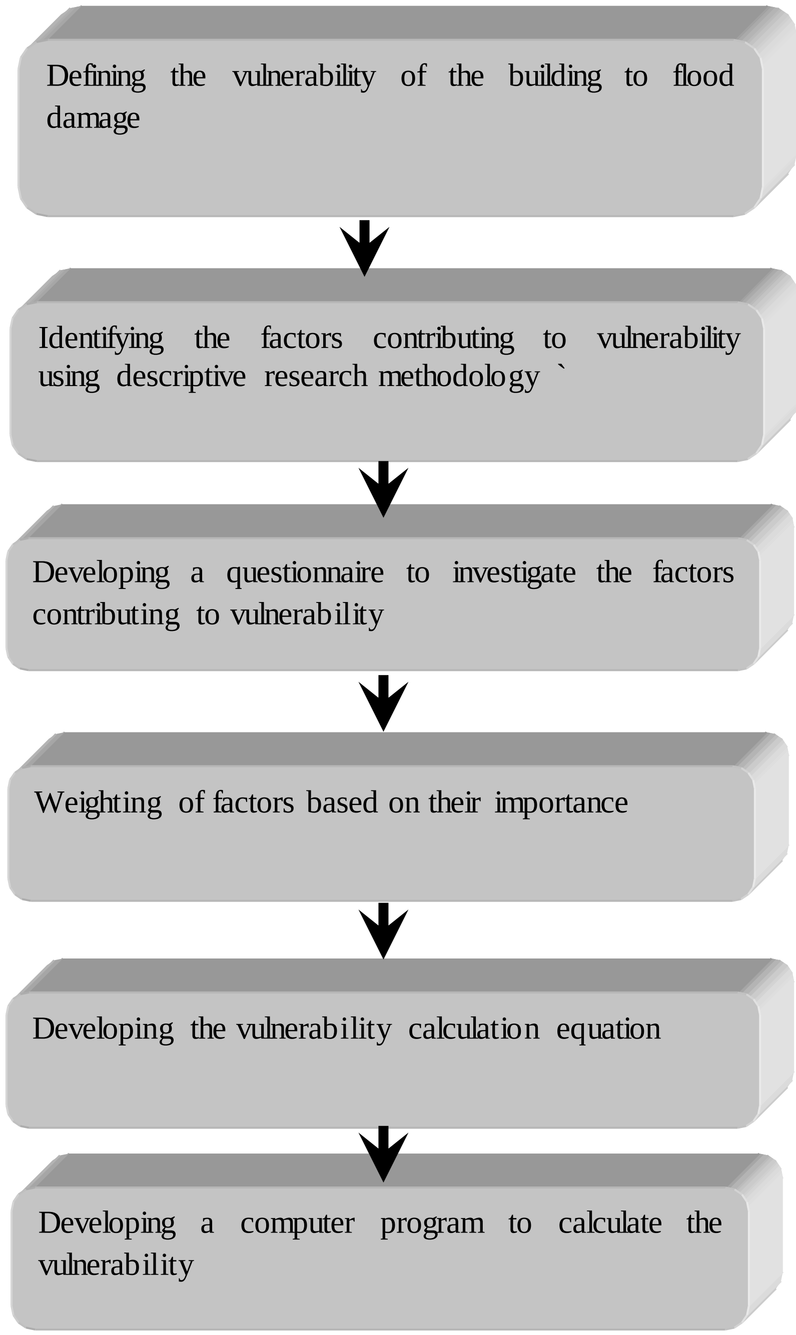


Figure 3-3: Major steps of vulnerability assessment used in this research

3.4.1.1 Identification of factors contributing to vulnerability

Brooks (2003) compares two viewpoints from which vulnerability could be viewed in the climate change literature:

i. The amount of damage caused to a system by a particular hazard (physical vulnerability)

ii. a state that exists within a system before it encounters a hazard (social vulnerability).

The first concept was considered when developing the vulnerability assessment model. The vulnerability assessed by the model and the factors considered (as given in table 6.3) aimed to calculate the physical vulnerability (damage) caused by flood to different building elements.

It can be stated that vulnerability is determined by various factors (Kunreuther et al., 2004). For the purpose of assessing the vulnerability of a building to flood damage, a number of factors have been identified, based on various sources, including the literature, previous cases, and discussions with experts in the field.

The following list of general issues can help to assess whether or not a particular property is subject to flood damage (OPDM, 2003):

- Has the property or surrounding land and gardens ever been flooded in the past?
- Has the property been issued with a flood warning?
- Is the property close to a surface water drainage ditch or stream that could overflow?
- Is the property in a hollow or a low-lying area or at the bottom of a hill?
- Is the property protected by river or coastal defences?

- Is the area at risk from groundwater flooding?

If the answer to all of these questions is negative, the vulnerability of the property to flood damage is considered small; on the other hand, if the answer to one or more of these questions is 'yes', this suggests that the vulnerability of this property to flood damage is high.

A variety of approaches use indicators for vulnerability assessment in the field of risk analysis (Cardona, 2006; Cutter et al., 2003; Dilley et al., 2005; Peduzzi, 2006). These approaches focus on assessing risk and vulnerability quantitatively by means of indicators (Birkmann, 2007; Schmidtlein, 2008).

The indicators in the vulnerability assessment can be used to evaluate adaptive strategies and measures. On this basis, factors (or indicators) have been selected which seem to be important and which make the building more vulnerable to flood damage. The selection of factors is based on:

- their contribution to vulnerability to flood damage
- susceptibility of materials to flood damage
- increased cost of repair
- the building being more at risk of damage when subjected to flooding (e.g. fair condition of the building)
- things that make the building more vulnerable to flood damage than would otherwise be the case.

The factors that are believed to contribute to the vulnerability of a building to flood damage were selected on the basis of reports in the available literature that these factors contribute in some way to building flood damage. The factors selected are listed in Table 3.6 and then discussed to show how they are important below.

Table 3-6: Factors selected to be used in the invulnerability calculation model

No.	Factor Description
1	Geographic location of the building within the flood risk zone based on the flood maps provided by the Environment Agency
2	Topography of the building site (the building is located at the bottom of a valley or foot of a hillside)
3	The building is underlain by a chalk aquifer
4	The soil is often near saturation point or is impermeable
5	Duration of previous flood was greater than 12 hours
6	Depth of the previous flood was above the building's floor
7	Issuing of flood warnings for this area in the past
8	Occurrence of sewer flooding in the past
9	The building has been flooded in the past
10	The building has cracks in the walls near floor level
11	The building contains gypsum plaster
12	The building has timber walls or frames
13	The building has mineral insulation
14	The condition of the building prior to flood
15	The building has water-resistant doors, windows and kitchen units, made from
16	Gas and electrical utilities are located above the flood level
17	Existence of any flood resistance or resilient measures
18	Previous flood damage
19	Existence of backflow device on water system
20	Building protected by flood defence.
21	The building is close to intermittent stream

1. Geographic location of the building within the flood risk zone, based on flood maps provided by the Environment Agency (EA)

Geographic location is an important factor that needs to be considered in cases of flood damage (Rhodes, and Proverbs, 2008). A flood map is intended to act as a guide only. It can be used to find the predicted risk of flooding from rivers and the sea in a certain area. A building could be at risk from other sources of flooding. The following two easy steps are offered on the Environment Agency site:

a) Search for your post code, using the search box on the right of the map page (http://www.environment-agency.gov.uk/homeandleisure/floods/default.aspx) to establish your location on the map.
b) Once you can see your location on the map, click on the point you are interested in. You will then see a guide to the chance of flooding in your area, i.e. low, moderate or significant.

There are two different kinds of area shown on the flood map. They can be described as follows:

'Dark blue ■ shows the area that could be affected by flooding, either from rivers or the sea, if there were no flood defences. This area could be flooded:

- From the sea by a flood that has a 0.5% (1 in 200) or greater chance of happening each year.
- Or from a river by a flood that has a 1% (1 in 100) or greater chance of happening each year.

- ❖ Light blue □ shows the additional extent of an extreme flood from rivers or the sea. These outlying areas are likely to be affected by a major flood, with up to a 0.1% (1 in 1000) chance of occurring each year.' (EA, 2008)

These two colours show the extent of the natural floodplain if there were no flood defences or certain other manmade structures and channel improvements.

2. <u>Topography of the building site</u>

The topography of the building site is considered to be one of the most important factors when determining the degree of vulnerability of the building to damage as a result of flooding, since a building which is located in a valley or at the bottom of a hill is at risk of flooding from water flowing from the top of the slope and gathering quickly into a large amount, thereby making the building more vulnerable to the risk of damage due to flooding.

3. <u>The building is underlain by a chalk aquifer</u>

Groundwater flooding occurs when water levels in the ground rise above surface elevations. Chalk, which is a permeable rock, forms aquifers, because the chalk stores groundwater and allows it to flow. The chalk areas show some of the largest seasonal variations at groundwater level, and are the most extensive sources of groundwater flooding. Figure 3.4 shows the extent of chalk on the UK geological map.

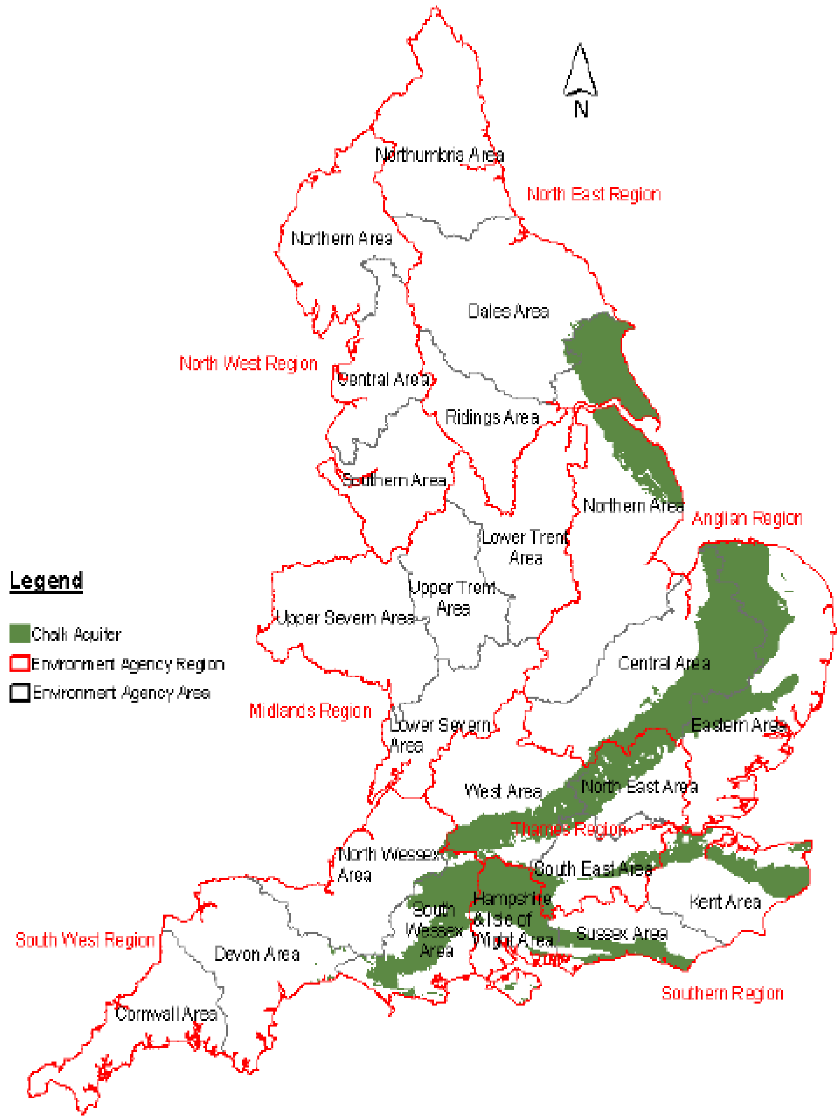


Figure 3-4: Extent of chalk on the UK geological map (EA, 2006)

Sources of groundwater flooding events within chalk aquifers can generally be divided into the following types (Cobby et al., 2009; Jacobs, 2007):

- rise of typically high groundwater levels to extreme levels in response to long-lasting extreme rainfall as shown in Figure 3.5
- increasing groundwater levels in response to reduced groundwater abstraction in an urban area

- rise of groundwater levels owing to leaking sewers, drains and water supply mains
- increases in groundwater levels and changed flow paths owing to artificial obstructions, including deep foundations and quarries, and loss of natural drainage paths
- inundation of trenches intercepting high groundwater levels.

Recent and historical records show that groundwater as the source of flooding where there are areas vulnerable to ground water flood (Cobby et al., 2009).

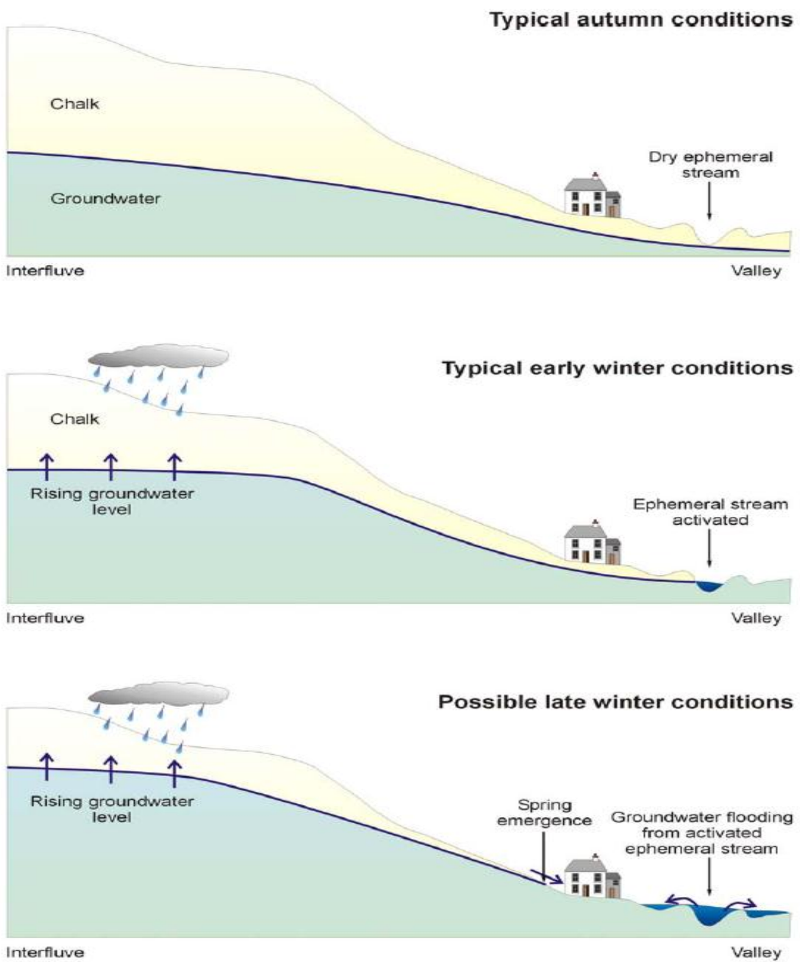


Figure 3-5: Groundwater rising during winter in chalk soil (Cobby et al., 2009)

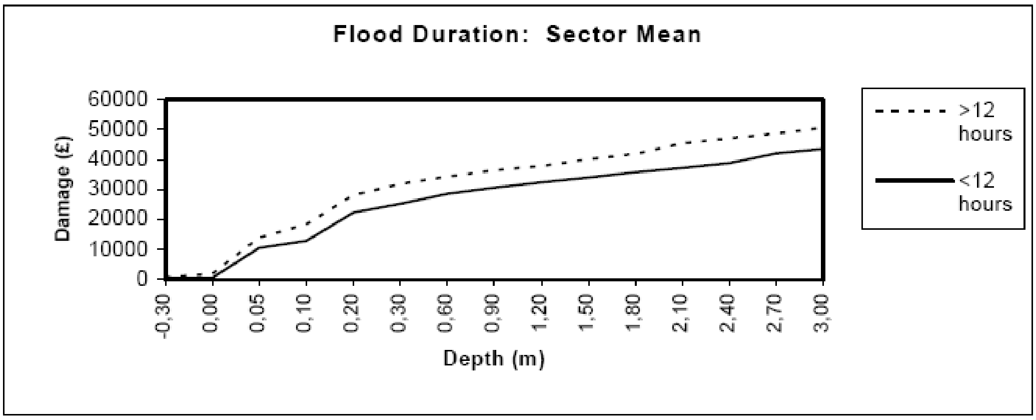
Groundwater flooding may take weeks or months to dissipate as it moves much more slowly than surface water (Macdonald et al., 2008). Flooding from groundwater is most likely to occur in areas of chalk, limestone or other aquifers. Notably, heavy rainfall in the autumn of 2000 followed the wettest 12-month period in many areas of England and Wales (AIR, 2008). These large amounts of rain led to many of the aquifers being filled earlier than usual, leading to unusually high levels of groundwater in some areas, so that surface water and springs often formed in places where people had not been aware of the presence of springs for a generation or more (Jacobs, 2007). As a result, almost one thousand homes and businesses were affected by groundwater flooding (ODPM, 2003).

4. <u>The soil is often near saturation point or is impermeable</u>

The soil becomes saturated at the point at which the soil or aquifer will not absorb any further amounts of water (Jacobs, 2007). Overland flows can be caused by heavy rains falling on saturated ground, where groundwater levels are already high, or on paved areas. Properties can be flooded by overland flows if they are located in areas where floodwater can accumulate. Paved areas, such as roads, can work as channels for overland flows. Properties can be flooded by overland flows if they are located in areas that can accumulate water (ODPM, 2003).

5. <u>Duration of previous flood was greater than 12 hours</u>

Flood duration—which is the time during which floodwaters are in contact with the building—is also a key factor in determining the level of damage. Generally, the longer the period of flooding, the more damage would be caused to the building (ODPM, 2003; Soetanto, Proverbs, and Nicholas, 2002). This is mainly because many property structures in the United Kingdom are made from porous solid materials, such as bricks, blocks and concrete. Accordingly, the longer the duration of the flood, the greater the quantity of floodwater accumulated by building materials, so the time needed for drying-out and restoration is thereby extended (Soetanto & Proverbs, 2004). If the water has been in the structure for more than a few hours, the damage and the amount of material which will need to be removed will be extensive. The relationship between flood depth and damage cost—in terms of flood duration—is shown in Figure 3.6.



Source: Penning-Rowsell et al 2003: ch. 3

Figure 3-6: Depth-damage curve differentiated by flood duration

6. Depth of the previous flood was above the building's floor

In a building prone to flooding to different depths, deeper floods occur less frequently than less deep floods. Therefore, the depth o flooding that affects a structure can be calculated by determining the height of the flood elevation above the natural surface at the site of the building.

According to Proverbs & Soetanto (2004), the main characteristics of floods which determine the degree of damage caused are the depth of the flood, the duration of the flood, and the level of pollutants in the floodwater. As the depth of floodwater or the flood duration increases, there is greater potential damage to buildings. DTLR, in their published report and guidance on preparing for floods (2002), state that the flood depth is the most important factor for damage to dwellings. Furthermore, DCLG, in their published report on *Improving the Flood Performance of New Buildings—Flood Resilient Construction* (2007), categorise a range of issues relating to flood depth, as given in Table 3.7 below.

If the water depth on the outside masonry of a building is higher than on the inside by approximately 0.6m, there is then the possibility that the structure will collapse, owing to the difference in hydrostatic pressure outside and inside the building. This difference in level is known as the 'differential head' (dH), as shown in Figure 3.7. With this in mind, flood damage curves are shown in Figure 3.8.

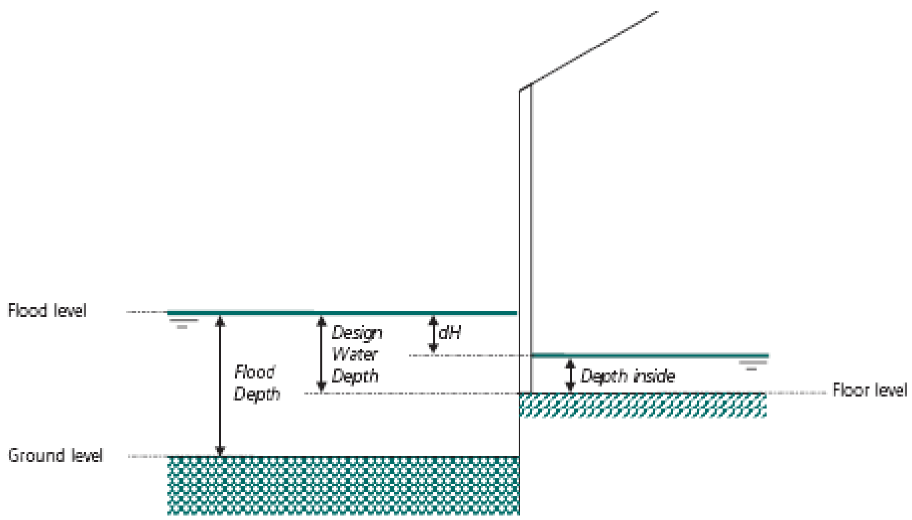


Figure 3-7: Difference in water depth dH (DCLG, 2007)

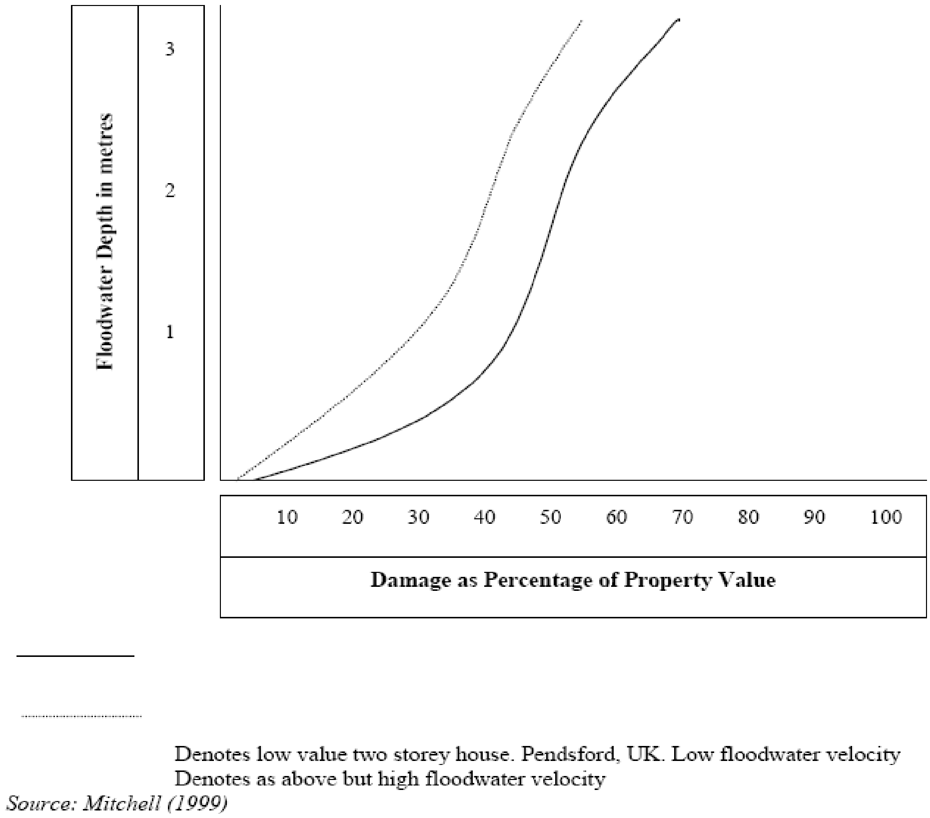


Figure 3-8: Flood damage curve (Nicholas, Holt & Proverbs, 2001)

Moreover, flood depths of more than one metre may produce a hydrostatic force which is high enough to cause structural damage or the collapse of walls. As the depth of the floodwater increases, the cost of repair works simultaneously rises (Nicholas et al., 2001). Accordingly, the damage from shallow floodwater which does not rise above the floor level is not likely to be significant for most properties (Kelman and Spence, 2004; DTLR, 2002).

Table 3-7: Likely flood damage for a typical residential property at different depths (DCLG, 2007)

Depth of Floodwater	Damage to the Building	Damage to Services and Fittings
Below ground floor level	Possible erosion beneath foundations, causing instability and settlement Possible corrosion in metal components (e.g. joist hangers) Excessive moisture absorption in timber, causing warping Cracking of ground floor due to uplift pressures Accumulation of contaminated silt Structural and material weaknesses from inappropriate drying Rot and mould	Damage to electrical sockets and other services in basements and cellars Damage to fittings in basements and cellars
Ground level to half a metre above floor level	Build-up of water and silt in cavity walls, with potential reduction in insulating properties for some materials Immersed floor insulation may tend to float and cause screeds to de-bond Damage to internal finishes, such as wall coverings and plaster linings. Floors and walls may be affected to varying degrees (e.g. by swelling) and may require cleaning and drying out Timber-based materials likely to require replacement Damage to internal and external doors and skirting boards Corrosion of metal fixings Rot and mould	Damage to water, electricity and gas meters Damage to low-level boilers and some underfloor heating systems Damage to communication wiring and services Carpets and floor coverings may need to be replaced Insulation on pipework may need replacing
Half a metre and above	Increased damage to walls (as above) Differential heads of greater than 0.6m across walls could cause structural damage, although this will vary depending on the structure of the building. Damage to windows can be caused by much smaller differential pressures. High speed flow around the building's perimeter can lead to erosion of the ground surface; there is also the potential risk of damage to the structure from large items of floating debris, e.g. tree trunks	Damage to higher units, electrical services and appliances

7. Issuing of flood warnings for this area in the past

In England and Wales, the Environment Agency (EA) operates a flood warning service in areas at risk of flooding from rivers or the sea. The EA monitors rainfall, river levels and sea conditions 24 hours a day, and utilises such data to forecast the possibility of flooding. If flooding is expected, warnings are accordingly issued using a set of four codes: Flood Watch, Flood Warning, Severe Flood Warning and All Clear. Each of the four codes indicates the level of risk associated with this warning, as given in Table 3.8. The codes are not always used in sequence; for example, in the event of heavy rains a severe flood warning may be issued immediately, without being preceded by the other warning codes.

Table 3-8: Flood warnings and their meanings (Source: EA)

Warning	Meaning and Action Required
Flood Watch	Flooding of low-lying land and roads is expected. Be aware, be prepared, and watch out.
Flood Warning	Flooding of homes and businesses is expected. Act now!
Severe Flood Warning	Severe flooding is expected. There is extreme danger to life and property. Act now!
All Clear	Flood watches or warnings are no longer in force for this area.

This service is available online via the EA web page (http://www.environment-agency.gov.uk/homeandleisure/floods/31618.aspx), which shows the current Flood Warning situation throughout England and Wales. Searching can be done by postcode, region, or river name, and previous warnings that have been issued can be found.

8. Occurrence of sewer flooding in the past

Backflow through drainage systems can cause floods when the water flows back inside buildings. In some of these cases, the floodwater might be contaminated. An overloaded or blocked roof drainage system can also cause flooding to the building. With this taken into account, sewer flooding increases flood property damage, and makes the remediation more expensive owing to the contaminated water. Some 7,650 properties were flooded internally from sewers during 2007–08, which is almost four times as many as externally (OFWAT, 2008; EA website).

9. The building has been flooded in the past

Generally speaking, all homes are at risk of being flooded, but if the building has been flooded before, it is more vulnerable to repeated flooding.

10. The building has cracks in the walls near the floor level

Seepage through cracks and joints in external walls, as well as around service pipes and cables near to floor level, is one of the ways in which floodwater can gain entry to the building, as can be seen from Figure 3.9.

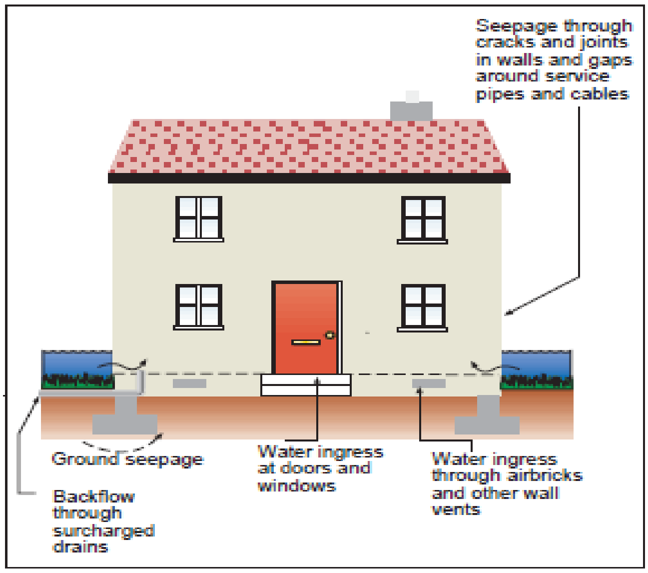


Figure 3-9: Sources of floodwater entry (ODPM, 2003)

11. The building has gypsum plaster or mineral insulation, or timber walls or frames, or a chipboard, wood, vinyl, or rubber-tiled floor.

In 2007 the Department of Communities and Local Government issued a report entitled *Improving the Flood Performance of New Buildings: Flood Resilient Construction*. This report aims to provide guidance to the developers and designers of buildings on how to improve the flood resilience of new properties in areas at risk of flooding.

The report gives guidance on flood-resilient design and construction by providing recommendations based on laboratory tests which have been carried out on different materials used in building construction. Table 3.9 shows the various components of walls classified in terms of good, medium and poor performance in respect of the characteristics which have been tested. Moreover, the water sensitivity of different materials used in building construction, based on laboratory tests, is shown in Table 3.10.

It is clear from the tables below that gypsum plaster, mineral and blown-in insulation, and timber are materials which can easily be affected by water and damaged. These materials have been classified in terms of performance characteristics as poor, and are therefore unsuitable for use as construction materials owing to their largest water sensitivity.

Table 3-9: Flood resilience characteristics of walls (based on laboratory testing) (DEFRA and EA, 2007)

Material	Resilience Characteristics*			Overall resilience performance
	Water penetration	Drying ability	Retention of pre-flood dimensions, Integrity	
External Face				
Engineering bricks (Classes A and B)	Good	Good	Good	Good
Facing bricks (wire cut, sand facing)	Medium	Medium	Good	Medium
Internal Face				
Concrete Blocks	Poor	Medium	Good	Medium
Aircrete	Medium	Poor	Good	Medium
Cavity Insulation				
Mineral fibre	Poor	Poor	Poor	Poor
Blown-in	Poor	Poor	Poor	Poor
Rigid PU foam	Medium	Medium	Good	Medium
Renders/Plaster				
Cement render—external	Good	Good	Good	Good
Cement/lime Render—external	Good	Good	Good	Good
Gypsum plasterboard	Poor	Not assessed	Poor	Poor
Lime plaster	Poor	Not assessed	Poor	Poor

Table 3-10: Water sensitivity of materials (CIRIA, 2005a).

Material	Example	Water Sensitivity
Gypsum-based materials	Plaster Plasterboard Plaster render/Wall plaster	- - -
Lime-based materials	Mortar and render Limestone	+ +
Cement-based materials	Mortar and render Concrete Concrete blocks Concrete floor	+ + + +
Fired-clay materials	Brick Clinker block Glazed ceramic tiles Unglazed earthenware	+ + + O
Timber	Joists and beams Floorboards and planks Chipboard and particleboard Cellulose insulation board Parquet flooring	- to + - - - -
Metal	Steel beams and joists Copper/zinc sheet	+ +
Plastics	Various	- to +
Bitumen materials	Gaskets Bitumen paint	+ +

{'+' good suitability (no or limited water sensitivity), 'O' moderate suitability (some water sensitivity) '-' unsuitable (strong water sensitivity)}

12. <u>The condition of the building prior to the flood</u>

The condition of the building before being flooded is also an important factor that influences flood damage (Proverbs & Soetanto, 2004). A building which is not well repaired and maintained will be more seriously affected by flooding.

13. The building has water resistant doors, windows and kitchen units, made from PVC or other water resistant materials.

"Doors, windows, skirting boards, architraves, doorframes and window frames with Fibreglass (GRP), plastic, uPVC or other similar water resistant alternatives … do not absorb water or warp and so are more readily functional after a flood" (CIRIA, 2005a).

14. Gas and electric utilities are located above the flood level

Gas meters, electricity meters and consumer units (fuse boxes) can be affected by floodwater. If they are located above the expected flood levels during refurbishment works, this will subsequently reduce the cost of replacing them if they come into contact with floodwater (CIRIA Advice sheet 7, 2003a).

15. Existence of any flood resistance or resilience measures

Resistance construction is the construction of a building in such a way as to prevent floodwater entering it and damaging its materials and structure. Resilience construction is the construction of a building in such a way that, although floodwater may enter, its impact is reduced, in that no permanent damage is caused, structural integrity is maintained, and drying and cleaning is made easy. The existence of any resistance or resilience measures will reduce the time and costs associated with repairing the property (Broadbent, 2004; Escarameia et al., 2007; Department for Environment, Food and Rural Affairs, 2008). Flood resistance or resilience measures include (Bowker, 2007):

Resistance measures

- garden or site landscaping to divert floodwaters away from property
- revised local drainage layout
- low bunds around site or properties
- periphery walls/fencing
- flood resistant gates
- periscope air vents
- outside wall renders and facings, including veneer walling
- non-return valves in waste pipes and outlets
- temporary products (free standing barriers, door boards, flood skirts, airbrick covers)
- resistant external doors.

Resilience measures

- tanking
- concrete floors
- raised electrical sockets, TV points, etc.
- horizontal replacement plasterboard
- flood resilient kitchens (plastic, stainless steel, free standing removable units)
- resilient internal walls (rendered, tiled, coated)
- plastic skirting boards
- pump and sump
- flood resilient internal doors (easily removable).

16. Building protected by flood defence

Building flood resistance can be increased by providing temporary building-level flood defence measures, such as installing flood boards on doorways or covers on service ducts (DCLG/Environment Agency, 2007).

3.4.1.2 The degree of vulnerability assessment model

It was part of the research plan to obtain detailed information concerning the factors considered by previous cases, which can be used to conduct statistical analysis in order to distinguish between these factors, as well as to exclude non-important ones. It was expected that several points would be addressed relating to this information, but this information was not available, with the exception of some general statistical data. For this reason, the weighting and rating of factors was done in a way that relies mainly on past experience and expert opinion in this area. This method has been used in previous cases, as given in examples of vulnerability assessment (Section 3.3.1). Notably, factors which are believed to cause the damage of buildings as a result of flooding were also identified on the basis of existing references, as well as a questionnaire which has been prepared for the purpose of demonstrating the importance of these factors, as well as the possibility of adding any other factors that the participants think it is important.

Based on the methods applied to assess the risk in the examples illustrated in Section 3.3.1, a method was developed in a similar way, and involves the following steps:

1. The factors which are believed to cause the collapse of buildings as a result of flooding were identified on the basis of existing literature and

expert opinions obtained during the workshops attended in relation to the topic.

2. Since, there are no data available to carry out a statistical analysis which allows the investigation of these factors. In this research, only the relative importance of these factors in contributing to flood damage is considered. Accordingly, it is important to distinguish between the degrees of importance of such factors. For this purpose, a survey has been conducted in order to investigate the value of such factors, and to give participants the opportunity to add any other factors which they believe contribute to building flood damage. A copy of this survey is shown in the appendices. The main aim of this survey is to rank these factors in two groups—either important or very important.
3. The next step is to incorporate weighting and rating, which are generally used in risk assessment, where a weighting is assigned to each risk factor. The reason for this is that the risk factors are not all equally important, and weighting should be assigned to each risk factor in order to reflect its perceived importance. For this purpose—and based on the survey results—the factors are divided into two groups: important and very important.

After the factors have been divided into the two different groups, their ratings are then converted to numerical weightings. In the case of the risk assessment, weightings can be derived for each factor by applying statistical techniques or otherwise assigned through expert judgement. In this research, the weighting is assigned by expert judgment since statistical analysis is not applicable.

The following steps are involved in the factor weighting process:

- The identified factors are divided into two groups—very important and important—on the basis of on the questionnaire survey as listed in Table 3.11 and Table 3.12.
- Weightings are then assigned to each group of factors. These weighting values can be arbitrary numerical values.
- The value of '2' is given to Group One (very important factors) whilst the value of '1' is given to Group Two (important factors).
- Finally, the vulnerability values (numbers) are converted to a vulnerability rating.

The factor weightings may be changed or updated, and more factors may be added or removed on the basis of more recent information, as and when it becomes available.

Table 3-11: Factors that are categorised as important in contributing to vulnerability, on the basis of the survey

No.	Factor Description	Weigh
1	Geographic location of the building within the flood risk zone based on	1
2	Building protected by flood defences	1
3	Topography of the building site (the building is located at the bottom	1
4	The building is close to an intermittent stream	1
5	Occurrence of sewer flooding in the past	1
6	The building has been flooded in the past	1
7	The building has cracks in the walls near the floor level	1
7	The condition of the building prior to the flood	1
8	The building has water-resistant doors, windows and kitchen units,	1
9	Gas and electric utilities are located above the flood level	1
10	Existence of flood resistance or resilience measures	1
11	Existence of backflow devices on sewer system	1
12	Previous flood damage	1

Table 3-12: Factors that are categorised as very important in contributing to vulnerability, on the basis of the survey

No.	Factor Description	Weight
1	The building is underlain by a chalk aquifer	2
2	The soil is often near saturation point or is impermeable	2
3	Duration of previous flood was greater than 12 hours	2
4	Depth of the previous flood was above the building's floor	2
5	Issuing of flood warnings for this area in the past	2
6	The building has timber walls or frames	2
7	The building contains gypsum plaster	2
8	The building has mineral insulation	2
9	The building has a chipboard, wood, vinyl, or rubber-tiled floor	2

Literature can be valuable in helping the researcher to validate findings and theories. In this regard, published studies in similar empirical domains may provide support for the findings which have emerged during the study. Validation comes in the context of empirical research that bears some similarities but which ultimately differs in some distinct way or ways, and which enables the researcher to make the comparison between the settings (Gibson & Brown, 2009).

The literature is used to develop and validate the model for assessing the degree of vulnerability. The model was developed and validated on the basis of the definition of vulnerability and the ideas and examples of vulnerability assessment available in the literature, as mentioned and discussed in Section 3.2 and Section 3.3.

Furthermore, vulnerability can be defined algebraically as a function of vulnerability indicators.

Vulnerability = function (factor1, factor 2 ……….factor n)

In this regard, it can be stated that the degree of vulnerability can be obtained by adding the vulnerability factors (indications). These factors are ranked and weighted (i.e. assigned a numerical value). A weighting is a value assigned to a factor according to the perceived importance of its contribution to the overall risk rating, i.e. the larger the value, the more important the factor.

For the development of the proposed model, the ability of buildings to avoid damage as a result of their vulnerability to flooding has been identified, based on references, technical reports and research papers, and expert opinion.

Weighting factors are estimated values indicating the relative importance or impact of each factor in a group compared with other factors in the group. Since the factors do not affect vulnerability equally, they have to be ranked according to their own importance. Essentially, the purpose of assigning weighting factors is straightforward; it will help to determine the degree of vulnerability (a numeric value) which can then be converted to descriptive terms.

The simple empirical equation given below has been developed to calculate the degree of a building’s vulnerability to flood damage:

Degree of Vulnerability (DOV) = SUM (weightings of factors in Group One) + (weightings of factors in Group Two) ....Equation 3.1

The sum of numerical weightings (values) will give the degree of building vulnerability, which will be converted into descriptive terms, as given in Table

3.13. The degree of building vulnerability provides an indication of the likely damage to be caused by flooding.

Table 3-13: Degree of vulnerability: terms

Degree of Vulnerability	Descriptive Vulnerability
<10	No or very low vulnerability
11-21	Low to medium vulnerability
>21	High vulnerability

The flow chart shown in Figure 3.10 shows the steps of vulnerability assessment, which were then incorporated into a computer software written by the author and accordingly used as a part (subsystem) of the entire developed knowledge base system. More details will be provided in Chapter 5.

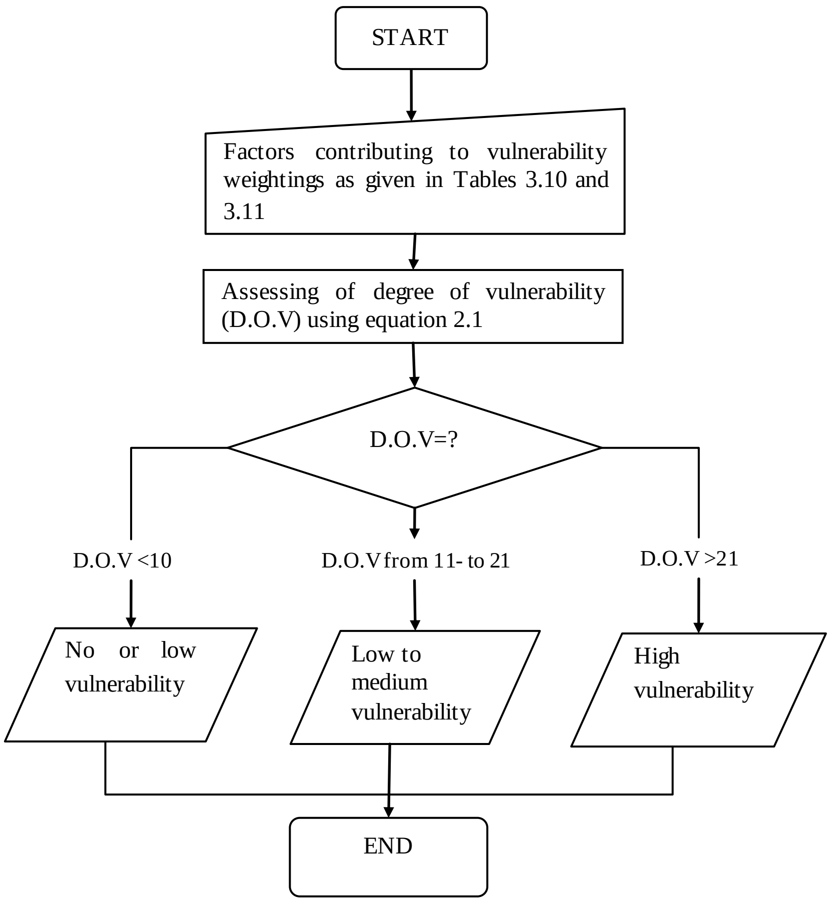


Figure 3-10: Vulnerability assessment flowchart

3.5 SUMMARY

This chapter focused on the concept and assessment of vulnerability, with examples. It also discussed the proposed model that was developed in order to calculate the degree of vulnerability of buildings to flood damage. Moreover, there are differences in vulnerability, and a variety of definitions distinguishing between different vulnerabilities. With this in mind, the proposed model has been developed on the basis of various definitions and the different vulnerability assessment methods used to calculate geohazard risks. The model is based on the weighting and rating of factors which are known to contribute to flood damage, and a simple mathematical equation has been used to calculate the degree of vulnerability.

The next chapter reviews two topics: flood damage management and knowledge-based systems.

CHAPTER 4 REVIEW OF FLOOD DAMAGE MANAGEMENT AND KNOWLEDGE BASE SYSTEMS

4.1 INTRODUCTION

This chapter comprises two parts: whilst the first part discusses a range of issues associated with floods, such as flood types, causes and sources of flooding, flood characteristics, and the damage caused by floods, specifically to residential buildings, the subsequent parts provides general and concise information concerning knowledge-based system concepts, applications, and design and development. Some examples are then provided regarding the use of knowledge-based systems in the field of civil engineering—especially geotechnical and geoenvironmental engineering.

4.2 REVIEW OF FLOOD DAMAGE MANAGEMENT

The terminology of floods or flooding is used to refer to a wide range of phenomena associated with weather extremes. The next sections will discuss a number of issues relating to floods.

4.2.1 FLOOD TYPES

Floodwater comes from the sea, lakes, rivers, canals or sewers, and can also be rainwater. Floods can be described according to the speed, geography or cause of the flooding. With this in mind, various different types of flood are discussed below.

A. Fluvial Flooding

A fluvial flood (flooding from overflowing rivers) is caused by a combination of hydrological, hydraulic and groundwater-related conditions. The most common cause of a flood is when the river catchment, i.e. the area of land that feeds water to the river, receives larger quantities of water than usual, such as through rain or melting snow. The river cannot contain this excess water—particularly when the ground is already saturated or when channels become blocked; this notably leads to a high river level and flooding taking place. Fluvial flooding is represented in Figure 4.1.

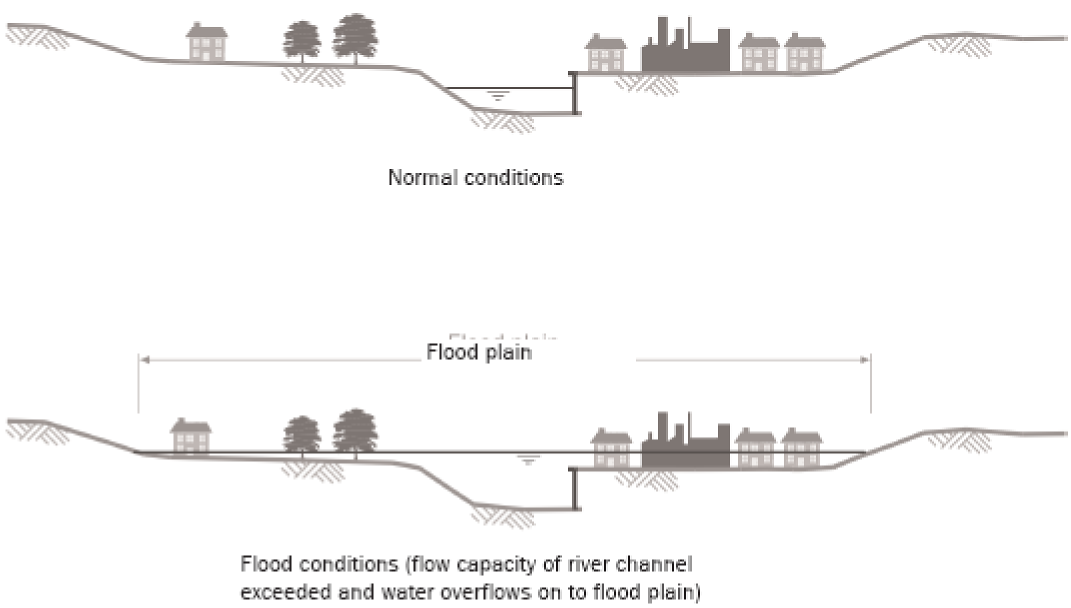


Figure 4-1: Fluvial flooding (CIRIA, 2004b)

B. Groundwater Flooding

Groundwater flooding occurs as a result of an abnormally high water table, subsequently leading to the emergence of water from amongst rocks or flowing from springs. This typically occurs after long periods of continuous, high rainfall. High rainfall means that there is more than can be infiltrated into the ground, thereby leading to a rise in water levels above normal (EA, 2009). Moreover, groundwater tends to flow from areas where the levels of the land are high towards low-level areas. It is estimated that groundwater flooding affects several hundreds of thousands of properties in the United Kingdom. Groundwater flow is illustrated in Figure 4.2.

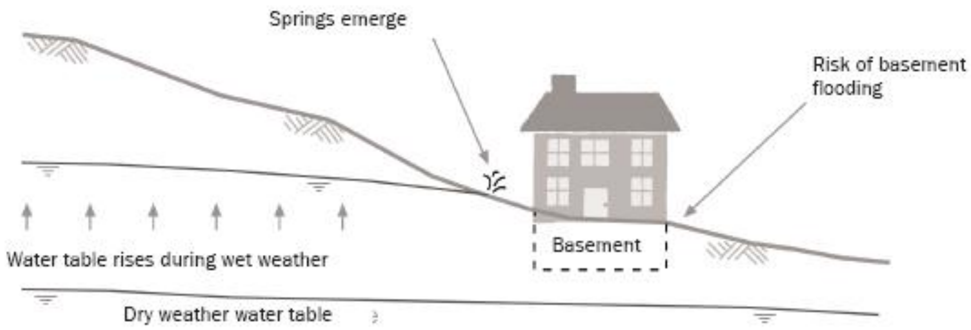


Figure 4-2: Groundwater flooding (CIRIA, 2004b)

C. Coastal Flooding

'Coastal flooding that results from a combination of high tides and stormy conditions. If low atmospheric pressure coincides with a high tide, a tidal surge may happen which can cause serious flooding' (EA, 2009). Coastal flooding can result from tidal conditions which may occur as a result of three main mechanisms, with flooding most commonly associated with a combination of two or more of these (CIRIA, 2004b):

- High astronomical tide level: cyclical variation in tide levels owing to the gravitational effects of (mainly) the sun and moon;
- Surge: an increase in water level above the astronomical tide level caused by low barometric pressure exacerbated by the wind acting on the surface of the sea; and
- Wave action: dependent on wind speed and direction, local topography and exposure.

D. Overland Flow Flooding

Overland flow is caused when rainfall intensity exceeds the infiltration capacity of the surface on which it falls, or otherwise when, during long periods of wet weather, the soil becomes so saturated that it cannot accept more water(Samwinga, Proverbs, and Homan,2004). Figure 4.3 illustrates overland flow flooding.

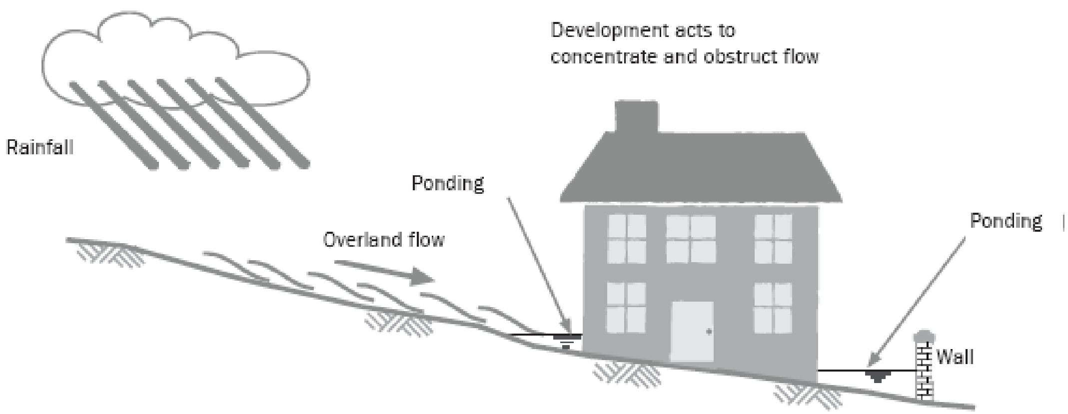


Figure 4-3: Overland flow flooding (CIRIA, 2004b)

E. Flooding from Artificial Drainage Systems

During heavy rainfall, flooding from artificial drainage systems—such as pipes, land drains, sewers and drainage channels, for example—may occur if the rainfall event exceeds the capacity of the drainage system, as shown in Figure 4.4.

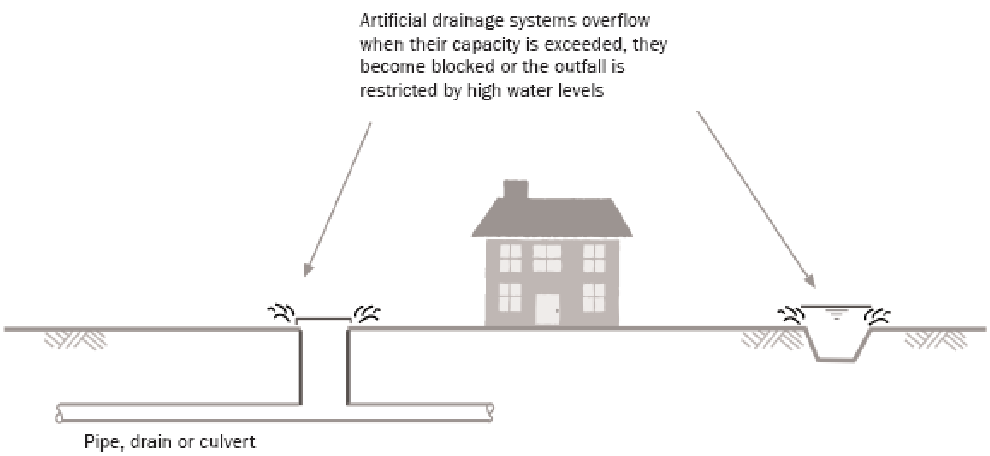


Figure 4-4: Flooding from artificial drainage systems (CIRIA, 2004b)

F. Flooding from Infrastructure Failure

Where infrastructure exists that retains, transmits or controls the flow of water, flooding may result if there is a structural, hydraulic, geotechnical, mechanical or operational failure. The risk of this mechanism of flooding is associated with three main categories of infrastructure (CIRIA, 2004b):

- Failure of infrastructure designed to store or carry water (e.g. dam break, canal leak, water mains burst);
- Failure of infrastructure designed to protect an area from flooding;
- Blockage of a pipe, bridge or culvert.

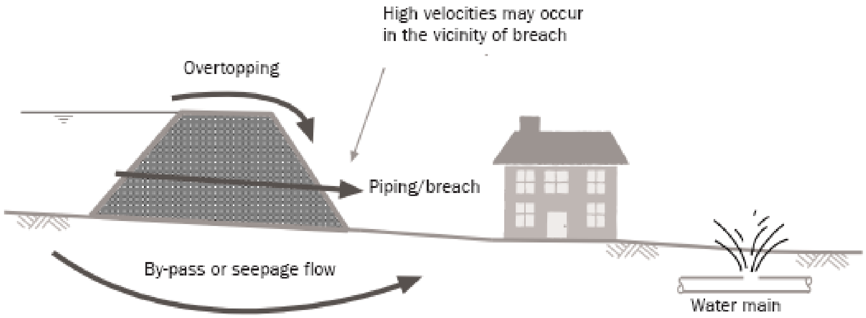


Figure 4-5: Flooding from infrastructure failure (CIRIA, 2004b).

4.2.2 CAUSES OF FLOODING

One of the most common causes of flooding is excessive rain. In this regard, floods can also be caused by rapidly melting snow: even a relatively small flow could cause severe flooding if the channel becomes blocked. Moreover, flooding can also occur in the case of a sewer system being insufficient, or if there is nowhere for local runoff to go to, or if a main river channel is already full. Different types of flooding can also occur. Severe storms with heavy rainfall could result in 'flash' floods, which can be dangerous because they often occur without warning. Less intense rains, which last for several hours or days, can also lead to serious flooding, but usually not quickly. With this taken into account, flooding can occur as a result of numerous events (DTLR, 2002):

- Coastal flood defences can be overwhelmed and broken following coastal storms, which cause storm surges and wave action;
- Ditches, drains and sewers experiencing overloading or blockages overflow into gardens, property and roads;

- Groundwater levels increase following rain soaking into the ground;
- Heavy rainfall run-off can often flow down hills and slopes;
- Property can sometimes be impacted by overloaded sewers; and
- Rainfall takes ditches, rivers and streams in excess of their flow capabilities, with floodwater subsequently overflowing onto floodplains.

Figure 4.6 shown below presents the causes of property flooding based on floods in Autumn 2000.

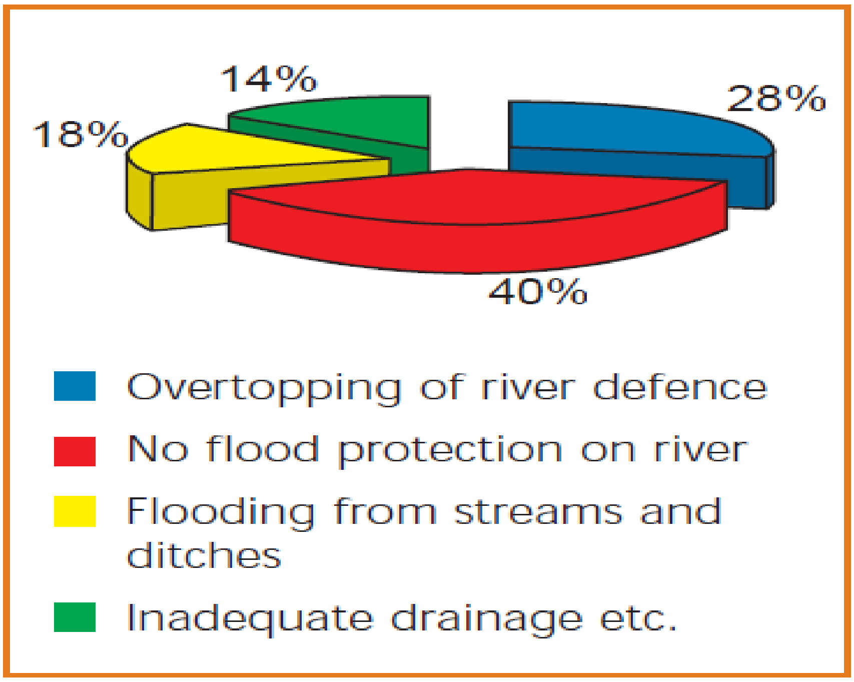


Figure 4-6: Causes of property flooding based on Autumn 2000 floods (ODPM, 2003).

4.2.3 SOURCES OF FLOODING

There are a number of sources of flooding, including (DTLR, 2002) (CIRIA, 2005):

- The sea, with flooding occurring as a result of waves, storms and high tides, which subsequently breach or overwhelm sea defences.
- Rivers and streams. Extreme rainfall, snowmelt, hail, and overtopping of defences can cause river flooding where the water exceeds the capacity level of the river. Saturation of surface soil because of wet weather can lead to an increase in run-off rates and flooding highest levels.
- Groundwater. Rising into buildings, this mainly happens in areas of chalk, limestone or other aquifers. In the autumn of 2000, heavy rainfall led to high levels of groundwater, so that approximately 1000 homes and businesses were affected by groundwater flooding.
- Blocked or overloaded drainage systems and sewers. Flash flooding can happen due to blocked or overloaded drainage and sewer systems after heavy rains.
- Infrastructure failure, such as broken water mains, which lead to flooding of buildings.
- Accidental escape or leakage from household appliances such as dishwashers, washing machines, radiators, and water tanks, etc.

Figure 4.7 illustrates how some sources of flooding affect buildings.

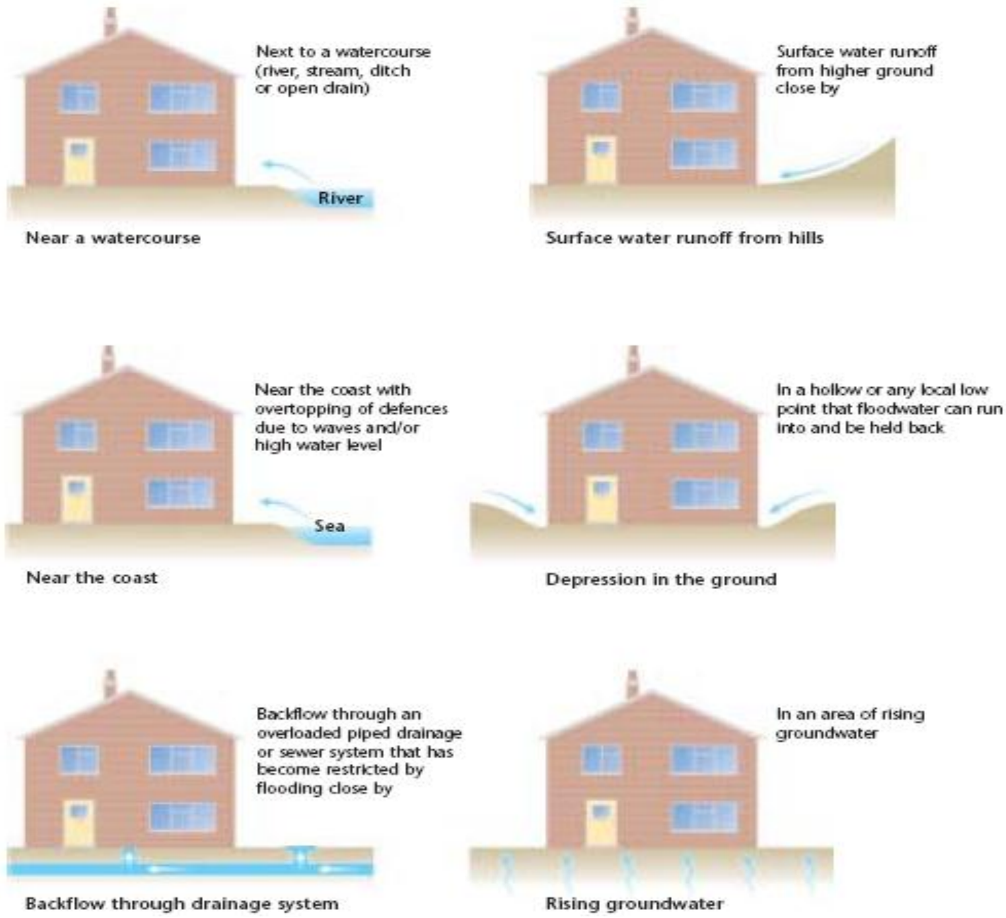


Figure 4-7: Some sources of flooding (CIRIA, 2004b)

4.3 FLOOD RISK IN THE UK

In England, more than 5% of the population lives less than 5 metres above sea level. It is also stated that approximately 7% of the country is likely to flood at least once every 100 years from rivers. In addition, almost 30% of the coasts are developed with about 1.5% of the country at risk from coastal flooding (Office of the Deputy Prime Minister, 2003).

Importantly, some 2.1 million homes in the whole of the UK are in areas which are considered to be at risk from river and sea flooding. Notably, 48.5% of these properties are at risk of flooding from the sea, 48% from rivers, and 3.5% from both (Office of Science and Technology, 2004). Sewer and drainage systems play a significant role in the problem of flooding in the UK. With this in mind, it is estimated that approximately 6,000 properties are flooded internally each year by sewage (ABI, 2007; National Audit Office, 2007).

These figures could potentially rise further if climate change results in more frequent extreme weather events, as has been predicted. In addition, there are continual reports of more properties being built on floodplains. With this in mind, the ABI has reported that a third of the millions of new homes the government plans to build by 2020 could end up being built on floodplains, adding that thirteen (13) major developments have already been passed, despite the fact that the Environment Agency has provided noteworthy advice on flood risk. With this in mind, Table 4.1 shows the extent of flood risk in the UK, with the average annual cost of damage caused by flooding. Accordingly, Table 4.2 lists major floods in England and Wales since 2000.

Table 4-1: Extent of flood risk in the UK (Office of Science and Technology, 2004)

Description	Properties at Risk	Average Annual
River and Coastal		
England and Wales	1,740,000	1,040
Scotland	180,000	32 (fluvial only)
Northern Ireland	45,000	16 (fluvial only)
Intra-urban Flooding		
All of UK	80,000	270
Total	2,045,000	1,400

Table 4-2: Major floods in England and Wales since 2000

Date	Area affected and features of the event
Autumn 2000	More than 10,000 properties were flooded in England and Wales. (ABI, 2005)
August 16, 2004 (Boscastle)	Flash floods, 100 homes and businesses were flooded. (Environment Agency)
January 8–9, 2005 (Carlisle)	1,700 homes and 300 businesses were flooded. (ABI, 2005)
Summer 2007	Claimed 14 lives. More than 49,000 homes and 7,000 businesses flooded, roads closed included M1, M4, M5, M18, M40 and M50. (ABI, 2007)
November 2009 (Cumbria)	36,000 flood and storm damage claims totalling an estimated £206 million, with 60% of the sum relating to business damage. (ABI, 2010a)

In England and Wales, the areas at risk from flooding have been mapped according to what are known as Indicative Floodplain Maps (IFM), which is available on the Environment Agency website.

Notably, flood risk has always been present for buildings near coasts, rivers or watercourses, and it has since become clear during recent years that much of the property stock in the UK has been at risk of a flood event. Markedly, the flood risk for a property can generally be defined as a combination of the possibility of a flood happening and the consequences of the flood in terms of damage caused or its impact (DTLR, 2002; ABI ,2008).

In the autumn of 2000, 11,000 homes were flooded. During the New Year period of 2003, 1,200 properties were flooded in central and southern England. More recently, during June, 2007, there were a number of flood events in various parts of Northern Ireland, North Yorkshire, the Midlands, Gloucestershire and Worcestershire. Six people died in the floods, and damage to commercial property was estimated to have reached £1 billion, with 5,000 businesses and 27,000 houses affected. Moreover, two million homes and 185,000 businesses are at risk of flooding in both England and Wales (Crichton, 2003; Environment, Food and Rural Affairs Committee, 2008).

Without question, flood danger is always present, affecting people and property near the coasts and rivers or waterways. However, during recent years, it has become clear that the risks and consequences of flood events have become a reality for more properties. With this in mind, it is noteworthy to emphasise that flood risk in the UK are likely to continue to increase, and actual floods become more frequent, widespread and costly, owing to a number of factors combined, these including (Broadbent, 2004; RMS, 2001; United Nations University, 2004; Dyer,2004):

- Development on floodplains, with plans for construction of up to three million more homes by 2016;
- Recent under-investment in the maintenance of local flood defences;
- Potential increases in risk due to climate variability which will cause heavy rains and raise sea levels, leading to an increased flood risk;
- Lack of maintenance of drainage and flood-fighting systems; and

- Coastal and river flood defences becoming less effective after a period of time.

Table 4.3 shows the number of properties within the regions of England and Wales that are potentially at risk.

Table 4-3: Number of Properties (000s) Potentially at Risk, by Region (DEFRA, 2001)

		Anglian	Midland	North East	North West	South West	Southern	Thames	Wales	Total
Fluvial	**Resid***	156	161	88	37	41	36	175	53	747
	Comm**	8	17	9	3	4	4	13	4	62
Sea/ Tidal	**Resid***	127	26	156	119	30	116	402	50	1,026
	Comm**	6	2	10	6	4	10	32	4	74
Total (Flood)	**Resid***	283	187	244	156	71	152	577	103	1,773
	Comm**	14	19	19	9	8	14	45	8	136
Coastal erosion	**Resid***	7	0	12	6	19	25	0	44	113
	Comm**	<1	<1	2	<1	1	3	0	2	9
Overall total	**Resid***	290	187	256	162	90	177	577	147	1,886
	Comm**	14	19	21	10	9	17	45	10	145

* Residential ** Commercial

During the past year (2010), at least 2.5 million properties in England and Wales were found to be at risk of flooding from rivers or the sea, with 1.1 million also at risk of flooding from surface water. In addition, there are 2.9 million properties prone to surface water flooding alone (ABI, 2010).

4.4 FLOOD DAMAGE TO BUILDINGS

Flood damage can range from minor, with small amounts of water entering the building, through to more severe cases, where extensive damage occurs. The amount of damage depends on the depth and duration of flooding (DTLR, 2002).

Importantly, flooding that causes significant damage to residential buildings essentially depends on the depth of the flood. In this regard, floodwater can enter unprotected buildings through several routes, including (EA, 2003):

- Around closed doors and windows, mainly via the joints between frames and walls;
- Through gaps around services which enter the property, e.g. pipes for gas, water and sewerage, electricity, telephone and television cables, and vents for central heating systems, washing machines, etc.;
- Directly through the walls of the property;
- Some bricks, blocks, stones and mortar used in buildings and floodwater will seep through them due to their natural permeability;
- Through cracks in the walls;
- Through party walls shared with the property next door, in the case of semi-detached or terraced houses;
- Via joints between building elements, such as expansion joints between walls, at positions where different construction materials meet or between the floor slab and wall;
- Through gaps in masonry, stonework and blockwork walls, where mortar has been omitted during the construction of the building; and

- At joints between windows, doors and their frames where the seal is missing, not fully compressed or faulty.

Moreover, groundwater can enter an unprotected building through:

- Solid ground-level floors as a result of seepage, where a water-resisting membrane is not present, or where there is a poor seal between the floor and the walls;
- Seepage underground into the void below suspended ground floors, unprotected basements and cellars through the walls or floor;
- Seepage at cracks or gaps in the below-ground building structure, e.g. foundations, basement walls and floors; or
- Backflow through a blocked or overloaded drainage or sewer system.

Flood entry routes to a house are shown in Figure 4.8 below.

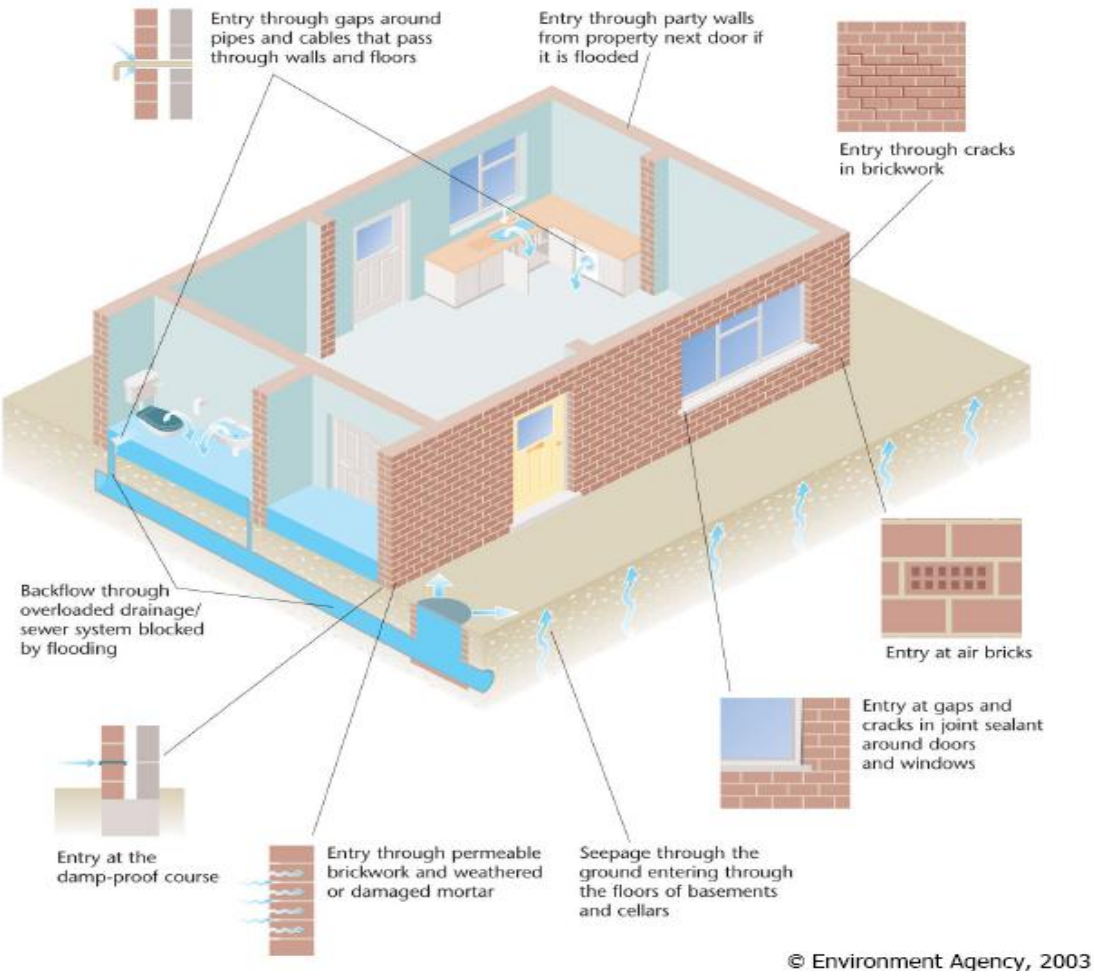


Figure 4-8: Flood entry routes into a house (Environment Agency, 2003)

Kelman & Spence (2004) identify a set of potential effects which could be experienced by houses as a result of floodwater, as follows:

- Hydrostatic actions: these include the lateral and uplift pressure forces owing to surrounding floodwater and saturated ground. Increased depth of flooding leads to increased hydrostatic pressure.
- Hydrodynamic actions: these are the effects on a building of hydrodynamic forces owing to the flowing and movement of floodwater around the building. These forces increase as the depth and velocity of flooding increase.

- Erosion actions: erosion can be caused by water flowing around the building or by the actions of waves lapping at a building.
- Buoyancy actions: buildings or components may exhibit buoyancy in floodwater. These include oil and gas tanks and all elements that rely on self-weight to ensure stability.
- Debris actions: action from any debris contained in the floodwater. Can be a static force, such as in the case of a building up of silt, or it could be a dynamic effect from an object being propelled against the building.
- Non-physical actions: building materials can be influenced by the chemical composition of water. The floodwater may be saline or contain contaminants such as sewage or chemicals.
- Direct water contact: building materials can be affected by direct contact with floodwater. For example, they may swell, crack or dissolve from exposure to water.

4.4.1 FACTORS AFFECTING BUILDING FLOOD DAMAGE

Damage caused to a property is dependent on the characteristics of the flood, as well as of the building itself. Flood characteristics include flood depth, velocity flow, contaminant content and flood duration (Robby and Proverbs, 2004). Notably, it is clear that the flood depth is the key factor controlling the damage caused by the flood. In actual fact, the effect of the other factors remains unclear since it is difficult to measure these, and there is also no clear data highlighting the effect of such factors.

4.4.1.1 Flood characteristics

a) Flood Depth

Although buildings may be prone to flooding to different depths, deeper floods occur less frequently than shallower ones. The flood depth at the building structure can be calculated by determining the height of the flood elevation above the ground level at the site of the building.

It is clear that floodwater depth is the key factor affecting the extent of the damage caused by flooding. Very shallow flooding—such as where the water does not rise above the ground level—is unlikely to be significant for most properties; however, it should be remembered that, even in the incidence of shallow flooding, water can still enter cellars, basements and spaces under decks, and can also cause problems of moisture in the walls. Moreover, serious damage can occur when the floodwater depth rises above the level of the floor, and also comes into contact with inner surfaces, electrical sockets, equipment, kitchen cupboards, carpets, furniture and personal belongings. Moreover, it is recognised that flood depths greater than one metre above the floor level are more likely to result in structural damage to the building (ODPM (2003).

According to Proverb & Soetanto (2004), the main characteristics of floods which determine the degree of damage caused are the depth of the flood, the duration of the flood, and the level of pollutants or other contaminants in the floodwater. As the depth of the flood or its duration increases, there is then greater potential damage to buildings (Figure 4.9). In their published report providing guidance on preparing for floods (2002), the DTLR state that flood depth is the most important factor for damage to dwellings. Moreover, also in their published report, Improving the Flood Performance of New Buildings—Floor Resilience Construction (2007), the DCLG categorise a range of issues relating to flood depth, as given in Table 4.4 below.

If the water depth outside a building's masonry is greater than on the inside by approximately 0.6m, there is the possibility that the structure will collapse owing to the difference in hydrostatic pressure outside and within the building. The difference in level is known as the 'differential head' (dH), as shown in Figure 4.9. Moreover, flood damage curves are shown in Figure 4.10.

Table 4-4: Likely flood damage for a typical residential property at different depths (DCLG, 2007)

Depth of Floodwater	Damage to the Building	Damage to Services and Fittings
Below ground floor level	Possible erosion beneath foundations, causing instability and settlement Possible corrosion in metal components (e.g. joist hangers) Excessive moisture absorption in timber, causing warping Cracking of ground floor due to uplift pressures Accumulation of contaminated silt Structural and material weaknesses from inappropriate drying Rot and mould	Damage to electrical sockets and other services in basements and cellars Damage to fittings in basements and cellars

Ground level to half a metre above floor level	Build-up of water and silt in cavity walls, with potential reduction in insulating properties, for some materials Immersed floor insulation may tend to float and cause screeds to debond Damage to internal finishes, such as wall coverings and plaster linings Floors and walls may be affected to varying degrees (e.g. swelling) and may require cleaning and drying out Timber-based materials likely to require replacement Damage to internal and external doors and skirting boards Corrosion of metal fixings Rot and mould	Damage to water, electricity and gas meters Damage to low-level boilers and some underfloor heating systems Damage to communication wiring and services Carpets and floor coverings may need to be replaced Insulation on pipework may need replacing
Half a metre and above	Increased damage to walls (as above) Differential heads of greater than 0.6m across walls could cause structural damage, although this will vary depending on the structure of the building Damage to windows can be caused by much smaller differential pressures High speed flow around the building's perimeter can lead to erosion of the ground surface; there is also the potential risk of damage to the structure from large items of floating debris, e.g. tree trunks	Damage to higher units, electrical services and appliances

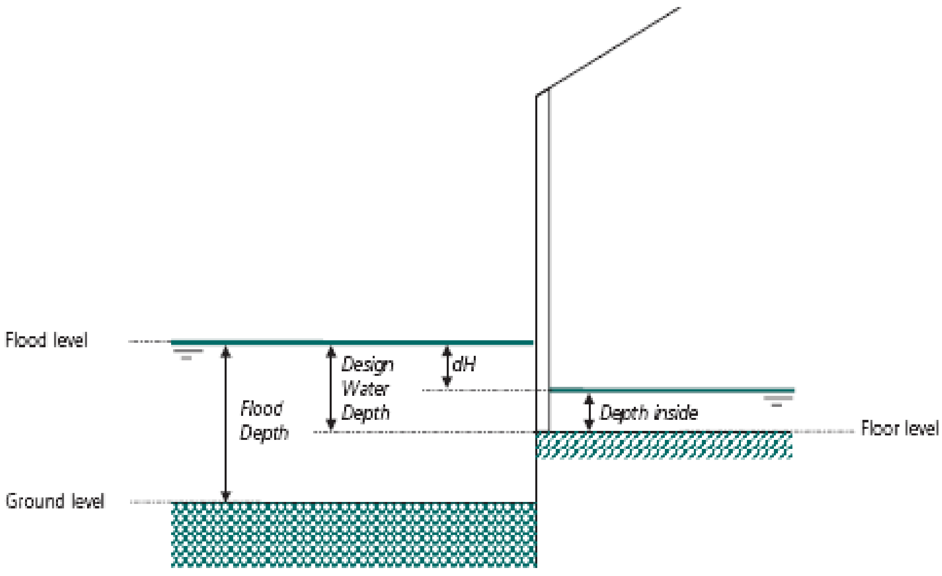


Figure 4-9: Difference in water depth (dH) (DCLG and EA, 2007)

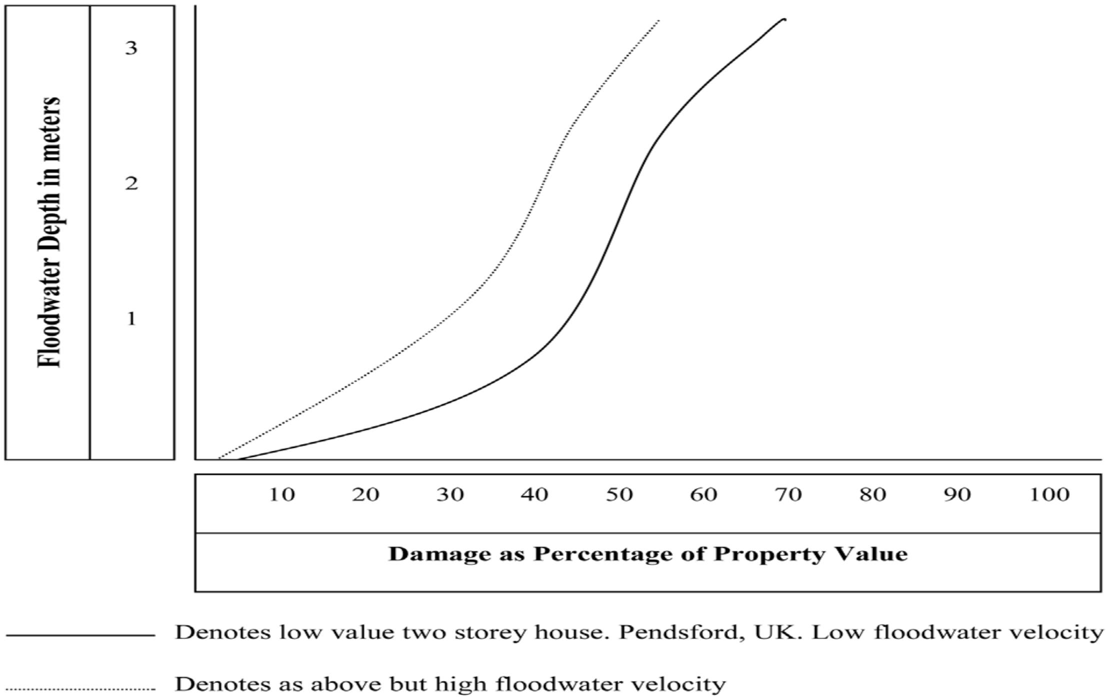
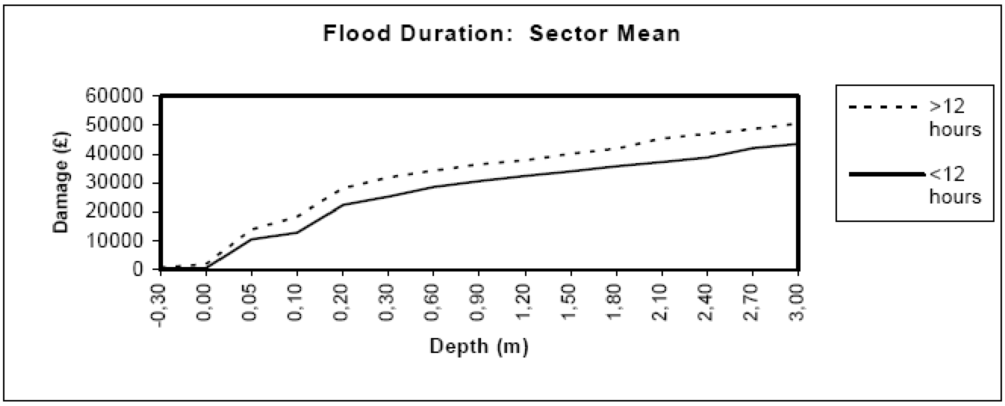


Figure 4-10: Flood damage curve (Nicholas, Holt & Proverbs, 2001)

b) Flood Duration

Flood duration—which is defined as the length of time during which floodwaters are in contact with the building—is also known to be a key factor in determining the level of damage. Generally, the longer the period of flooding, the more damage is caused to the building (Soetanto & Proverbs, 2004); this is mainly owing to the fact that many property structures in the United Kingdom are made from porous solid materials, such as bricks, blocks and concrete. Accordingly, the longer the floods, the greater the quantity of floodwater accommodated by building materials, thereby extending the time needed for drying-out and restoration (Soetanto & Proverbs, 2004). In this regard, if the water has been in the structure for more than a few hours, the damage will be extensive.

The relationship between flood depth and damage cost, in terms of flood duration, is shown in Figure 4.11. Flood duration depends on flood source; some flood types, such as groundwater flooding, might take months to dissipate. Figure 4.12 illustrates flood duration with respect to flood source.



Source: Penning-Rowsell et al 2003: ch. 3

Figure 4-11: Depth-damage curve differentiated by flood duration

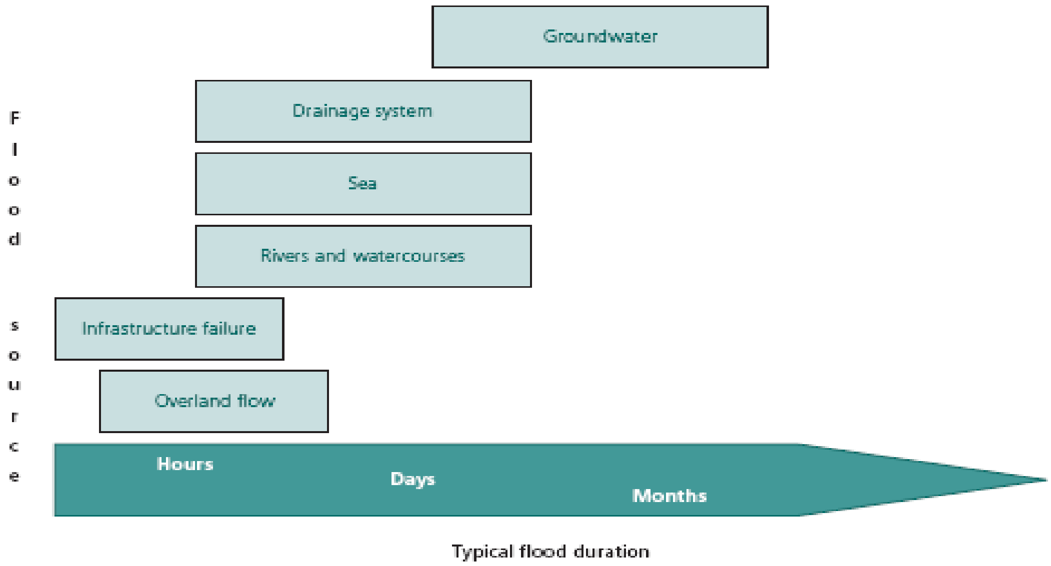


Figure 4-12: Typical duration of different types of flood (DCLG and EA, 2007)

As discussed in the previous section, there are clear indications that flood characteristics need to be considered in assessing damage to buildings due to flooding. The damage caused by flooding is increased by an increase in flood depth and duration and depends on the building materials.

4.4.1.2 Building characteristics

A building's characteristics constitute an important factor in assessing flood damage. These include building type, the materials from which the building is built, and their drying characteristics, building age, and the frequency with which the building is flooded (Nicholas *et al.*, 2001). Importantly, the majority of UK properties are constructed from porous/permeable materials, such as bricks, blocks, concrete, plaster and render. With this in mind, it is important to acknowledge how these react following exposure to floodwater (Proverbs & Soetanto, 2004).

Green & Suleman (1987) suggest that buildings which are frequently flooded seem to suffer less damage than those which are flooded infrequently, simply because the occupiers of the former will be more prepared and ready for any flood events.

In addition, the condition of a building prior to being flooded is also an important factor which is known to have a significant influence on flood damage (Proverbs & Soetanto, 2004). For instance, a building which is not well repaired and maintained will be affected more severely by flooding. With this in mind, it can therefore be seen that the damage incurred through flooding can vary from being either very minor or very severe, with the latter witnessed in the case of deep floodwater causing notable damage to not only the building itself but also that contained within.

Essentially, the degree of damage caused by a flood when it has been in contact with building elements is dependent mainly on flood depth, the material type, and other factors, as discussed previously. The building elements that might be in contact with water during a flood event are discussed in the next section.

4.4.1.3 Damage caused by flooding to building elements

Floodwater can find its way into buildings through various different ways, as mentioned in Section 4.4. The number of building elements that can be in contact with floodwater depends mainly on the floodwater depth. For example, in shallow floods, the walls might not be touched by the floodwater.

In general, the elements that might be damaged by flooding include foundations, floors, walls (internal and external), windows and doors, sanitary ware, and joinery and fittings. In addition, although it is known that flooding can damage buildings in many different ways, the most common flood damage results from:

- direct damage at the time of flooding, caused by high speed flows and waves, erosion, or debris carried by the floodwater
- damage caused to building materials due to contact with water during the flood period and sometimes after.

The building elements that might be damaged and might need repair or replacement include those detailed below. They are used as a basis for the proposed system in damage assessment and selection of the repair options. There is a subsystem that aims to assess the damage caused by flooding to the building foundations and other subsystems can be used to suggest the repair options for the other building elements. The next section presents different building elements, including types and materials, that are used in the UK's residential buildings.

a) Building Foundations

Fast flowing floodwaters can affect a building's footings by removing surrounding material, and thereby undermining the structure. In addition, it is possible that some types of soil settle after flooding and produce structural movements in the building's footings. In addition, foundation movements can occur owing to slumping of sloping sites when affected by floodwater (CIRIA, 2004).

Generally, Foundation movement indications as follow (Driscoll & Skinner, 2007; Dickinson, and Thornton, 2004; Atkinson, 2004).

- Cracks which show on both faces of a solid wall.
- Cracks which show on both faces of a cavity wall - ie on the outside of the outer leaf and the inside of the inner leaf.
- Cracks which taper - either wide at the bottom or narrow at the top or vice versa.
- Distortion in door and window openings.
- Walls out of plumb and ground floors out of level.
- Cracks which run across (i.e. above and below) the DPC.
- Broken drains or disrupted services.

There are three main types of foundations found in residential buildings (Glover , 2006):

I. Victorian and prior foundations: these can be found in older buildings built in the 19th Century and before. The technique was to dig a shallow trench and lay a brick footing on the bed of hogging approximately 500mm below the ground surface, as shown in Figure 4.13.

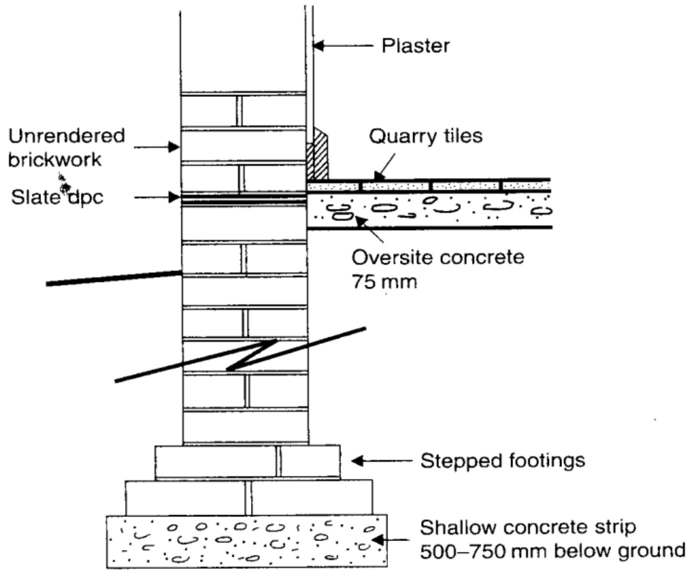


Figure 4-13: Victorian and prior foundations type (Glover, 2006)

II. 1930 domestic foundations comprises strips of concrete at a depth of more than 450mm in order to protect the foundation from frost damage. Details are given in Figure 4.14.

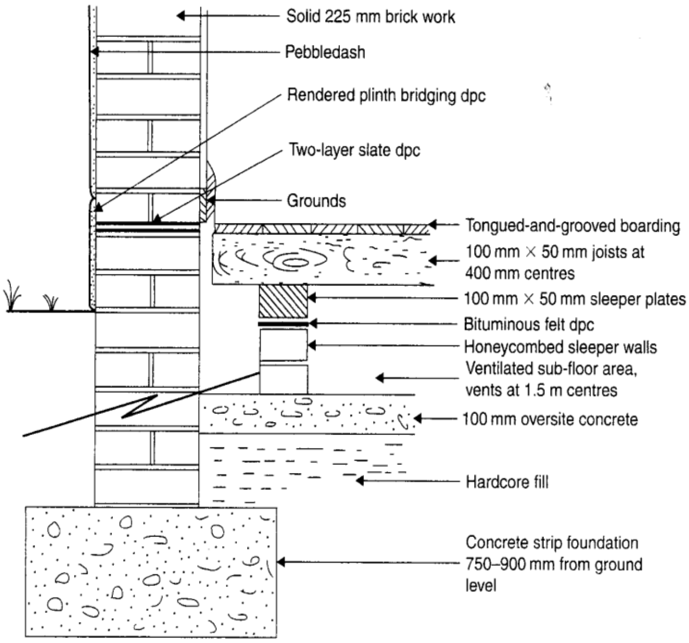


Figure 4-14: Typical 1930 domestic foundations type (Glover, 2006)

III. Modern short-bored pile foundations were founded in 1990, and comprise reinforced beam placed of concrete columns piled four meters below the surface soil on solid sub soil as given in Figure 4.15.

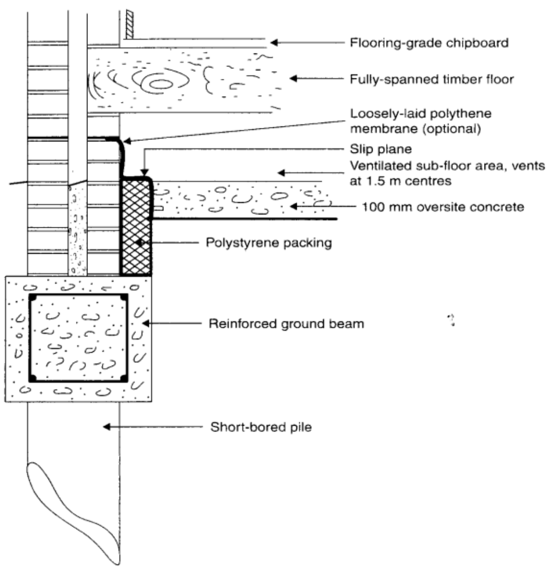


Figure 4-15: Modern short-bored pile foundations type (Glover, 2006)

b) Floors

Floors are one of the building elements that can be easily damaged as a result of floodwater, even in the case of shallow flooding. The degree of damage caused by floodwater depends on the type of floor. With this in mind, there are three recognised types of floor, which are commonly applied in UK buildings: suspended timber floors, solid concrete floors, and suspended concrete floors.

- *Suspended timber floors*

Suspended timber floors are considered to be the most common form of construction for the ground floors of existing houses in the UK, although they are only used in a small proportion of newly constructed homes (Harris, 1995). Moreover, suspended floors are usually made out of timber boards or waterproof chipboard sheets fixed on top of joists. Figure 4.16 illustrates suspended timber floor details and the issues to be considered in case of flood events.

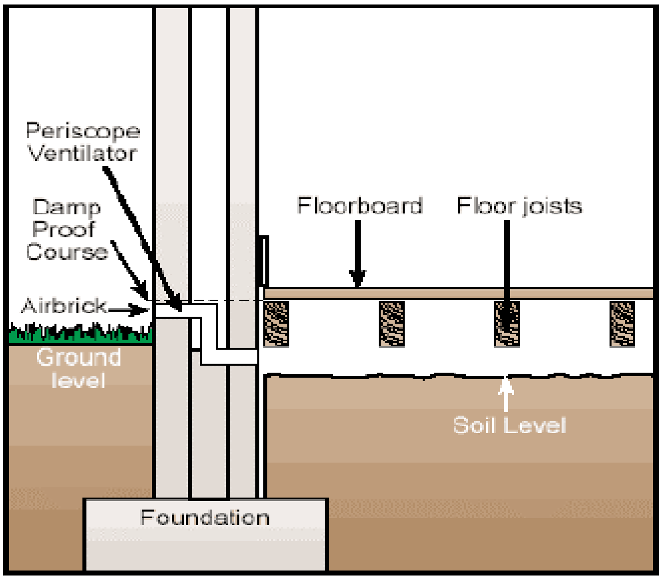
Type of Floor	Description	Issues
Suspended timber floors	• Consist of timber beams or 'joists', placed on edge and supported at the ends by the walls. • Support may consist of a wooden 'wall plate' attached to the wall, slots in the wall itself or ledges built out from the wall. Supporting walls have gaps to allow air to circulate. • Normally a vent under the floor to the outside to prevent damp building up. • Joists are boarded with tongue-in-groove or plain edged planks (floor boards), or chipboard. • In pre-1960 properties the floor will be higher off the ground and the vent channels will go straight through the wall.  	Has a cavity that will need to be cleaned and dried after flooding.

Figure 4-16: Suspended timber floor (adopted from 'Preparing for Floods') (ODPM, 2003)

- *Solid concrete floors*

Ground floor concrete slabs are laid at ground level; these are cast following the completion of foundation works. Solid concrete floors generally suffer less damage than suspended floors, and recovery exposure to floodwater is usually less expensive and quicker (ODPM, 2003). In addition, solid concrete floor details and the issues to consider in case of flooding are shown in Figure 4.17.

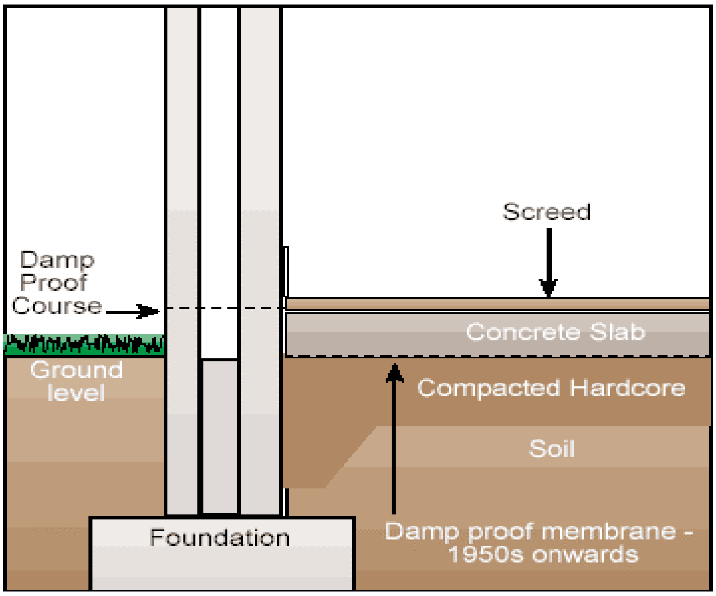
Type of Floor	Description	Issues
Solid concrete floors	▪ Composed of a concrete slab, typically 100-150mm thick, supported over its whole area by the ground. ▪ The concrete is normally placed over 'hardcore' with a thin layer of sand or concrete 'blinding'. ▪ A damp-proof membrane (DPM) of polyethylene sheet or a liquid coating of asphalt or bitumen is normally present immediately below or above the slab. ▪ The floor normally then has a layer of smooth sand and cement screed of 40-60mm thickness. 	▪ Preferable to suspended floors as they tend to reduce the rate and amount of water rising up through the floor. ▪ Generally suffer less damage than suspended floors. ▪ Less expensive and faster to restore after flooding.

Figure 4-17: Solid concrete floor (adopted from 'Preparing for Floods') (ODPM, 2003)

- *Suspended concrete floors*

There are two types of suspended concrete floor construction: pre-cast construction with or without composite screed, and cast-in-situ construction. In the case of the latter, this is more commonly encountered in older buildings (Glover, 2006). Suspended concrete floor details and the issues that arise in case of flooding are given in Figure 4.18.

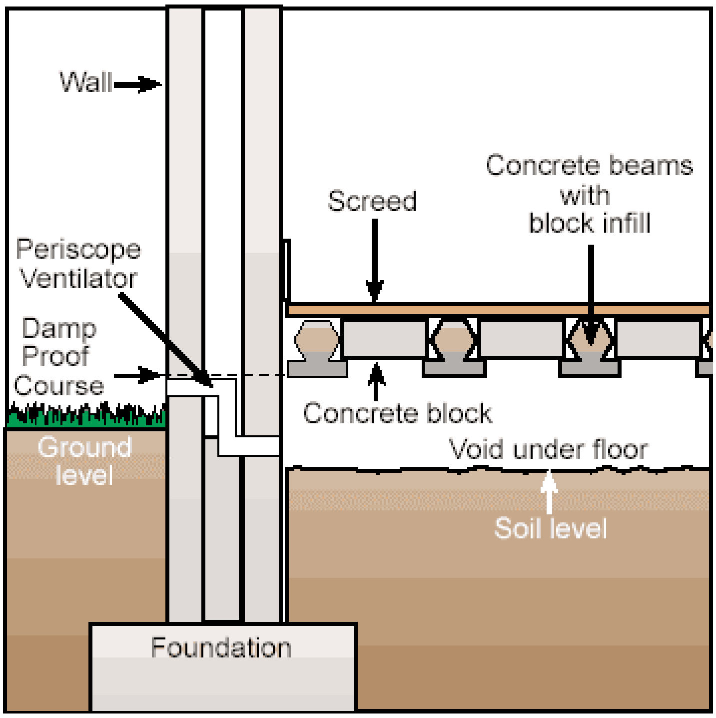
Type of Floor	Description	Issues
Suspended concrete floors	Modern floors (beam and block floors) use precast concrete beams set on sleeper walls at the damp-proof course level, infilled with concrete blocks. 	Has a cavity that will need to be cleaned and dried

Figure 4-18: Suspended concrete floor (adopted from 'Preparing for Floods' (ODPM, 2003)

c) Walls

There are three common types of wall construction in UK dwellings:

- Cavity walls with bricks and/or blocks;
- Solid brick or masonry walls; and
- Timber framed walls.

Figure 4.19 gives details of each type, and the issues that arise in case of flood events.

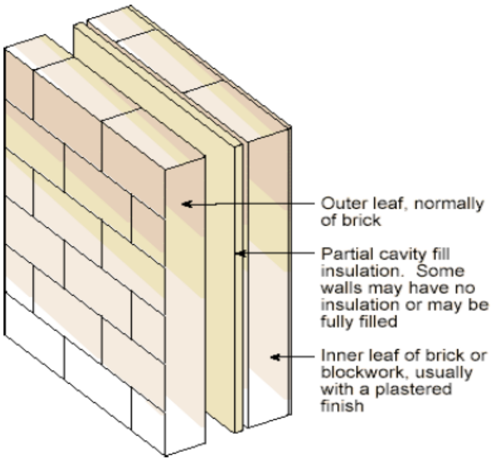
Type of wall	Description	Issues
Cavity walls	• Present in almost all modern houses, common after about 1930. • Have an air gap (typically measuring between 50 and 100mm wide) between an inner wall and an outer wall. • The walls are constructed of blocks, bricks or stone (each typically about 100mm thick) and the inner wall may be of different material to the outer.  	• Floodwater can pass through the outer leaf of the cavity wall, through cracks and gaps. • Floodwater can seep through the bricks, blocks and mortar. • Floodwater can build up in the cavity, saturate the insulation, and soak into the inner leaf. • Cavity allows water to migrate along the walls and can make it difficult to dry out.

Figure 4-19: Wall types (CIRIA, 2003b, Advice sheet 4)

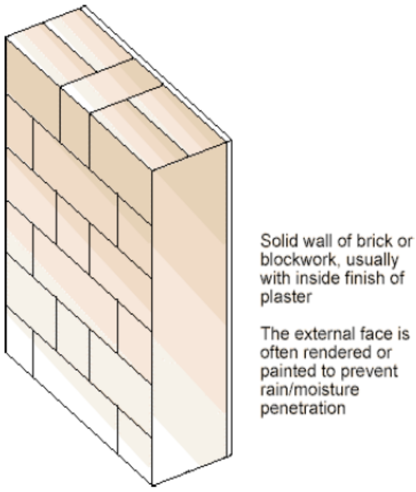
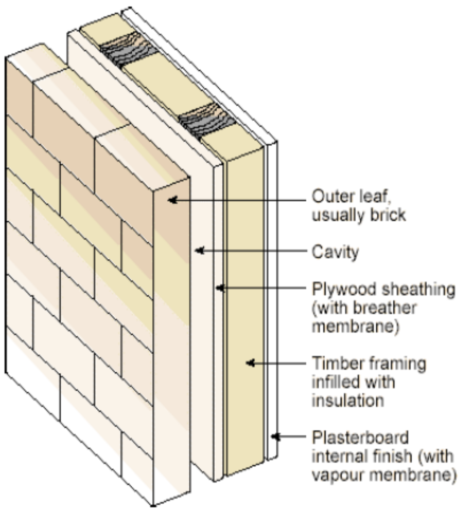
Solid walls	• No cavity. • May consist of closely spaced bricks or blocks or stone inner and outer faces with a rubble infill.  	• Floodwater can pass through the solid wall, through cracks and gaps, • Floodwater can seep through the bricks, blocks and mortar. • Will dry out from the internal and external faces, but thick solid walls may take a considerable time to dry. • Will only dry out from the internal face if the wall finishes allow. • Some solid walls have a rubber infill in the centre; this will delay drying considerably.
Timber-framed walls	• Outer face of timber-framed walls is normally made of brick or masonry • May have a render coating.  	• Floodwater can pass through the outer leaf through cracks and gaps. • Floodwater can seep through the bricks, blocks and mortar. • Water can build up in the cavity and soak into the inner timber frame construction. • Exposing the frame and the outer leaf to replace damaged boards and internal finishings can assist in drying after flooding if necessary.

Figure 4-20: Wall types (CIRIA, 2003, Advice sheet 4)

d) Fittings and building services (ODPM,2003)

- **Kitchen Cupboards:** kitchen cupboards are viewed as being highly vulnerable in the case of flooding, owing to the fact that they are made from a combination of MDF and chipboard, with plastic coverings. With this in mind, such units will need to be replaced following flooding and internal damage.

- **Kitchen Appliances:** all appliances susceptible to flooding—both gas and electric—will need to be thoroughly inspected by a professional before they are reused.

  Bathrooms: flooding commonly affects bathrooms, including hand basins and toilets. In addition, owing to their chipboard base, baths are also vulnerable to floodwater, which will therefore need to be replaced following exposure to such.

- **Doors:** both internal and external doors are made from different materials, including aluminium, PVCu and timber. Accordingly, some doors are more likely to be damaged following flooding than others: for example, more solid doors are less likely to be vulnerable whilst hollow doors are more open to damage. Moreover, fire doors, which are usually made from fire-resistant materials, can be damaged should there be exposure to floodwater.
- **Timber doors:** upon exposure to flooding, hollow timber doors commonly de-laminate, which therefore necessitates replacement.
- **Timber windows:** following floodwater exposure, wooden window frames may warp and distort, therefore necessitating replacement. Furthermore, windows made from other materials—including aluminium and PVCu—commonly have hollow section, which may therefore become filled with floodwater, and cause problems when draining.
- **Staircases:** flooding may only affect solid timber staircases to a minor extent.

- **Electricity supply:** floodwater can cause notable damage to both electric meters and fuse boxes, owing to the fact that they are within the house and located at low levels.
- **Wiring and sockets:** floodwater can affect sockets at low levels. **Gas supply:** gas systems may be affected by water and silt, which affect their overall functionality. Moreover, gas meters may also be damaged through flooding.

  Central heating systems: a professional will need to inspect and approve the use of gas and oil fire boilers, as well as all associated controls, fittings and pumps exposed to flooding. These items may need to be replaced.
- **Storage Heaters:** floodwater can also damage electrical storage heaters, therefore necessitating their replacement.
- **Water supply:** flooding generally does not affect water meters and pipes, although it is recognised that some damage may be noted in the case of pipe insulation tubes.

Importantly, time is recognised as an important element for consideration when seeking to determine the degree of damage incurred as a result of flooding. Notably, when the elements in question have been in contact with water for more than a few hours, it is recognised that damage may be significant and costly, as can be recognised when considering walls and ceilings, electrical appliances, and flooring, all of which will experience high levels of damage following exposure to water.

The flood damage scenario is based on two main factors: the characteristics of the building, and the characteristics of the flood. Different scenarios could occur that would cause damage of differing extents to the various building elements. Nicholas *et al*. (2001), for example, give a number of expected damage scenarios based on building and flood characteristics, as noted in Table 4.5. They add that scenarios two and three are more common construction types in the UK than that detailed in scenario one. Moreover, they also state that the cost of damage repair in scenario one would be greater than the cost of building a new, whilst in the case of scenario two, minor repair work would be required, whilst major repairs would be necessitated in the case of scenario three. It is clear from the table that the damage caused is dependent on a number of factors, and it is not easy to predict exactly the extent of the damage potentially caused by a flood.

Table 4-5: Three scenarios of building and flood characteristics (Nicholas et al., 2001)

Building characteristics	Flood characteristics	Flood damage
Scenario one – A timber framed self build dwelling		
Built on land that is infrequently flooded; Materials of construction are timber panelling on timber stud framework with laminated timber internal panels; and The property has a low ability to withstand floodwater pressures	Velocity of floodwater is high; Time duration of flood is three days; Depth of floodwater is two metres; Contaminant content of floodwater is great	Structural damage is caused to building by the floodwater; Repairing the dwelling would cost more than the costs of demolition and replacement of the building with a new structure
Scenario two – an architecturally designed four bedroomed detached dwelling		
Built on land that is frequently flooded; Foundations designed to withstand being saturated by floodwater; Walls are built of stone for aesthetic reasons and to resist flood damage; Floors are solid concrete and fitted with loose lay rugs for comfort; Kitchen is at a raised level to reduce the probability of floodwater damaging the kitchen units	Velocity of floodwater is low; Time duration of flood is two hours; Depth of floodwater is one metre; Contaminant content of floodwater is low	Dwelling has no structural damage and loose furnishings have been removed from being in contact with floodwater; Thorough cleaning and drying out of building required along with replacement or repainting of timber doors and frames that have been in contact with floodwater; Flood damage is essentially low in comparison to what it could have been
Scenario three – semi detached dwelling recently built		
Built on land that is infrequently flooded; Foundations not designed to withstand ground being saturated by floodwater; External walls are built of bricks and blocks with plaster internal finish; Internal walls are timber stud partitioning with plasterboard and skim finish; Floors are solid concrete and covered with fitted carpets; Kitchen is at ground floor level	Velocity of floodwater is high; Time duration of flood is three days; Depth of floodwater is two metres; Contaminant content of floodwater is great	The majority of the internal partition walls need replacement and all ground floor carpets need replacement; All kitchen units are beyond repair and need replacement; Flood damage is high as no consideration was given to flooding at building design stage

4.5 DAMAGE REPAIR OF FLOODED BUILDINGS

Association of British insurer (2009) estimate the average costs for building restoration to be approximately £25,000.

Notably, the majority of properties in flood zones in the United Kingdom are insured by private insurance companies; these agencies provide general policies under which the cost of flood damage restoration is included in the standard policy and is not costed separately in the sense that the property owner might otherwise have to pay an extra cost for reinstatement of his property. Moreover, the level of cover offered by insurance providers is different from one company to another.

4.5.1 MANAGEMENT OF DAMAGE TO FLOODED RESIDENTIAL BUILDINGS

The general steps of the repair process flow for repairing a building damaged by flooding are shown in Figure 4.20. Furthermore, it is noteworthy to recognise that, in most cases, the issues relating to flooded building damage repair are raised during the repair stage, as discussed in the next sections.

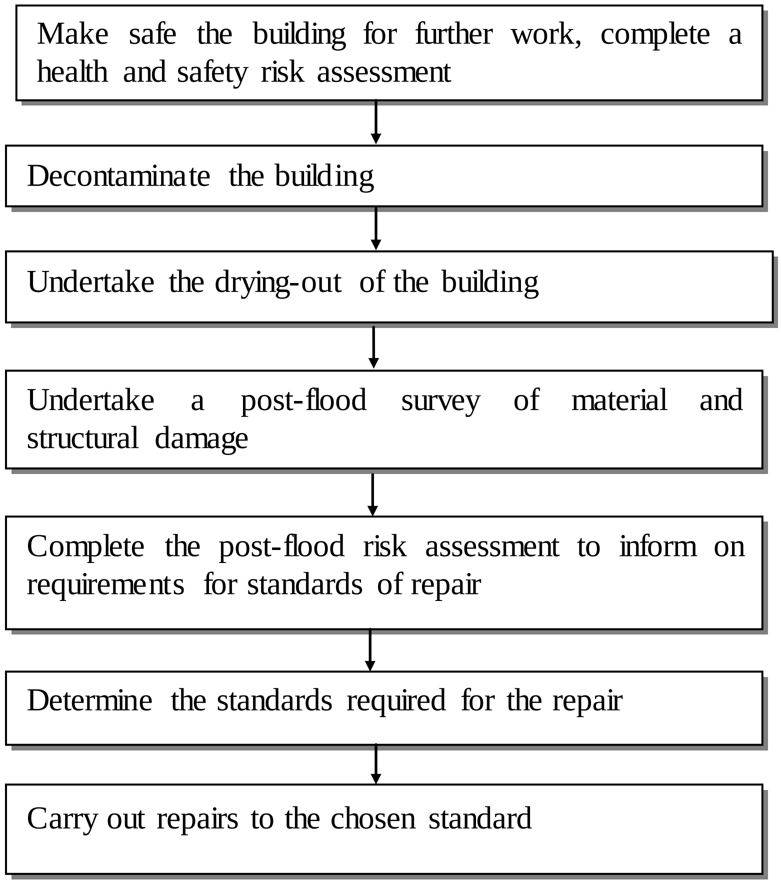


Figure 4-21: Repair process for a flooded building (CIRIA, 2005)

As mentioned in Figure 4-21 above, one of the main steps in the repair process is the selection of standards required for the repair. The existence of a knowledge base system that can help in the selection of the repair options will reduce the time and the cost required for the repair.

4.5.2 Issues in flood repair and the need to establish repair standards

4.5.2.1 Issues in flood repair

There are a number of issues which can arise during the repair stage; these can be identified as:

- The property owners are not satisfied with the performance of a particular contractor and/or insurance company. In a presentation by Paul Hendy during the Workshop on Identification and Dissemination of Good Practice in Flood Repair, held on Wednesday, March 15, 2006 at Wolverhampton University, reference was made to a survey relating to the experience of victims of the Carlisle flood event in 2005. Notably, it was highlighted that, on a scale where the worst contractors were scored at 3% and below, the three lowest scoring contractors were all employed by one insurance company. The insurance company itself subsequently scored 8% for customer satisfaction. The highest scoring contractor (Rameses at 98%) was employed by only one insurance company, namely Lloyds TSB, which was, itself, the highest scoring insurance company at 76%. The second highest (Norwich Union) scored 37% and the third (AXA) scored 21%. He also added that neighbours with similar properties and policies had different repair works done; this means that, in practice, there is still considerable diversity between the best and the worst in terms of reinstatement.
- Lamond (2008) adds two factors based to a questionnaire survey of recently flooded insured homeowners, namely:

1. Cost of cover not related to risk; and
2. Lack of fairness, including
    - Different standards pursued by different companies;
    - Flood repairs funded by those not at risk via higher premiums.

- Importantly, there is a great deal of knowledge available concerning the impacts of floods on various construction materials, as well as relating to the best ways in which the process of restoration can be addressed. This knowledge is held by several specialised flood repair companies, although a large proportion of reinstatement work is carried out by general builders, all of whom may have a limited understanding of even the basics—such as the most effective ways of drying out a building and its contents (Lamond, 2008).
- Inclusion (or not) of resilient repair as an option is one of the more contentious issues in flood repair and building reinstatement. When resilient repair is provided as an option, it is not generally taken up unless the buildings are subject to frequent flooding (Lamond, 2008). In addition, loss adjusters often recommend the cheapest reinstatement option as an alternative to the ideal or resilient option, this being done to meet the wishes of their insurance companies (Proverbs & Soetanto, 2004).

4.5.2.2 The need to establish repair standards

It is clear that there is a need to establish repair standards—or to at least produce general guides to help building repair contractors to establish acceptable repair strategies. Flood damage assessment is, at the present time, a function of surveyors' perceptions. Owing to the fact that they do not have a standard set of guidelines for the assessment of flood damage or recommended repair options, there are therefore significant differences between their decisions (Nicholas *et al.*, 2001; EA2011).

Nevertheless, there are a few publications which cover the subject of standardisation of flooded building repairs, such as:

- Flood Damaged Property: A guide to repair (Proverbs and Soetanto, 2004).
- A Guide to the Investigation and Repair of Flood Damage to Housing and Small Businesses (Flood Repairs Forum, 2006).
- Standards for the Repair of Buildings following Flooding (CIRIA, 2005).

The aforementioned guides recommended flood-resistant repairs of different building elements. In this regard, they state that the value of having repair standards is that they:

- Help to establish reinstatement repair strategies with not too much variance;
- Increase satisfaction (Lamond, 2008);
- Allow better underwriting decisions (Lamond, 2008);
- Promote fairness (Lamond, 2008);
- Maintain property values (Lamond, 2008); and
- Potentially promote resilience (ABI, 2003).

4.5.3 FLOODED BUILDING DAMAGE REPAIR OPTIONS

Every house is different, and the selection of the most appropriate repair approach depends on many factors; these include the flood risk, frequency and depth of flooding, type of floodwater, construction and condition of the fabric of the building, and the cost of repairs compared with the potential saving in the event of subsequent floods (Broadbent, 2004). With this in mind, there are two repair options available (non-resilient and resilient), and the selection of these options differ in relation to damage in each case. Details of non-resilient and resilient repair options will be given in Chapter 5.

4.5.3.1 Resilient remediation option

In 2007, the Ministry of Communities and Local Government issued a report entitled 'Improving the Flood Performance of New Buildings: Flood resilient construction.' It aims to provide guidance to developers and designers concerning how to improve the flood resilience of new properties built in flood risk areas. The report defines resilience as 'building in such a way that, although floodwater may enter a building, its impact is reduced'.

A comprehensive review was conducted by Pitt following severe flooding in the UK in 2007, when 55,000 properties were damaged. The review included 92 recommendations, including:

- Building Regulations should be revised to ensure that all new or refurbished buildings in high flood risk areas are flood resistant or resilient;
- All local authorities should extend eligibility for home improvement grants and loans to include flood resistance and resilience products for properties in high flood risk areas; and

1. Local authorities should, when carrying out their responsibilities under the Civil Emergency Act 2004, support business continuity and encourage the take-up of property flood resistance and resilience by businesses.

There are various different resilience measures which can be implemented during the reinstatement of flood damaged buildings; examples of resilient repair measures are provided in Table 4.6.

Table 4-6: Examples of resilient repair measures (DEFRA, 2010)

Example of Resilient Repair	Advantages
Replace damaged suspended timber floors with concrete floors	No need to replace floor in event of future floods
Replace damaged carpets with tiles	Floods less likely to damage floor coverings
Use solid wood, plastic or metal kitchen units instead of MDF units.	Less likely to be damaged by future floods
Install replacement white goods on raised Plinths	White goods will be safer from future low-level flooding
Use water-protection (lime-based) plaster on Walls	Floods less likely to necessitate replastering of walls
Raise electricity supply cables and sockets above floor level	Floods less likely to necessitate rewiring

The present building regulations are not considered to constitute flood resilience or resistance—either for new or existing buildings. The government responded with the Pitt report, and is currently seeking to change the regulations for building construction and repair to include flood resistance and resilience measures. The new regulations are expected to be issued in 2012 (Defra, 2010).

The main advantages of resilient repair measures include (ABI/NFF, 2006; ABI, 2009):

1. Flood-resilient repairs reduce the amount of time owners are out of their homes or businesses whilst the damage is repaired—in some cases, halving the time they are absent; and
2. Reduced repair costs of any future damage.

Importantly, the use of resilience measures has the potential to reduce the cost of damage caused by floods by approximately half, especially when compared with the situation if no measures have been used. With this in mind, Figure 4.22 illustrates the overall damage-reduction effectiveness of different packages of measures with respect to different depths of flooding.

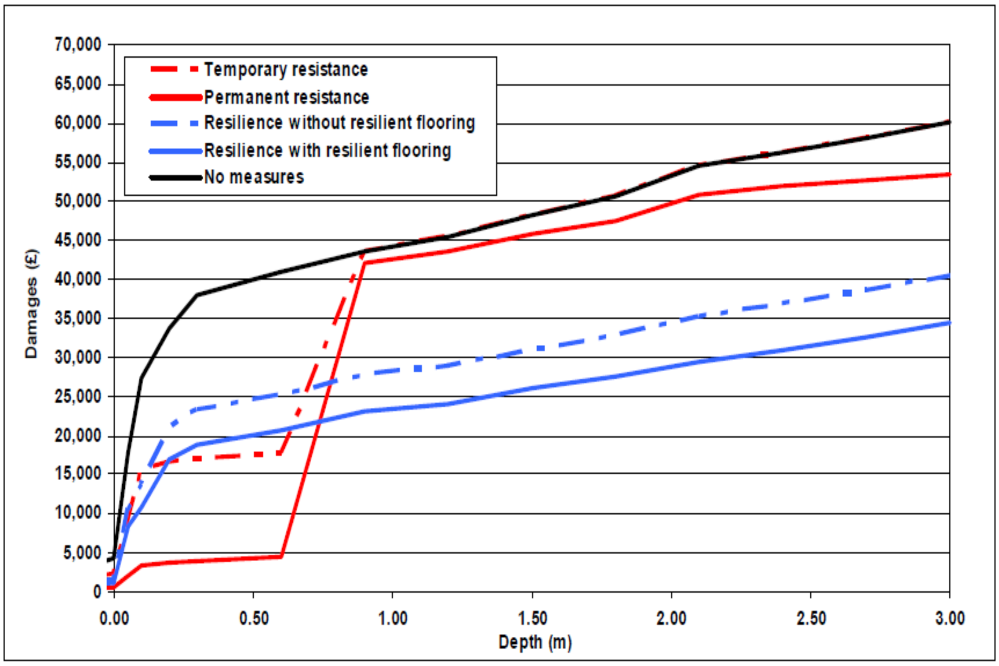


Figure 4-22 Depth/damage profiles for different flood resistance and resilience packages (DEFRA, 2008)

From the figure above it is clear that using the resilience repair option will reduce the damage caused when floodwater gets inside the property and thereby reduce the cost and time required for repair. This supports the idea of using the resilient option as one of the repair options suggested by the proposed knowledge base system in this research.

4.6 REVIEW OF KNOWLEDGE BASE SYSTEMS

The next sections will provide a general and conscience review of knowledge base system, discussion surrounding its history, types, applications and their development. Finally, examples of knowledge base systems in civil engineering will be given.

4.6.1 ARTIFICIAL INTELLIGENCE

Artificial Intelligence (AI) is a science and technology providing the scientific foundations for a number of commercial technologies. The major areas of Artificial Intelligence (AI) are (Turban & Aronson, 2001):

- Knowledge base systems (ES)
- Natural Language Processing (NLP)
- Speech Understanding
- Neural Systems
- Robotics and Sensory Systems
- Computer Vision and Scene Recognition
- Intelligent Computer-Aided Instruction
- Intelligent Software Agents
- Genetic Algorithms
- News Summarizations
- Language Translation
- Fuzzy Logic.

The term 'Intelligent Systems' covers various applications of Artificial Intelligence (AI) (Figure 4.23). Markedly, Knowledge base systems (ES) is the sub-discipline of AI which is applied and utilised more commonly than any other AI technology (Turban & Aronson, 2001).

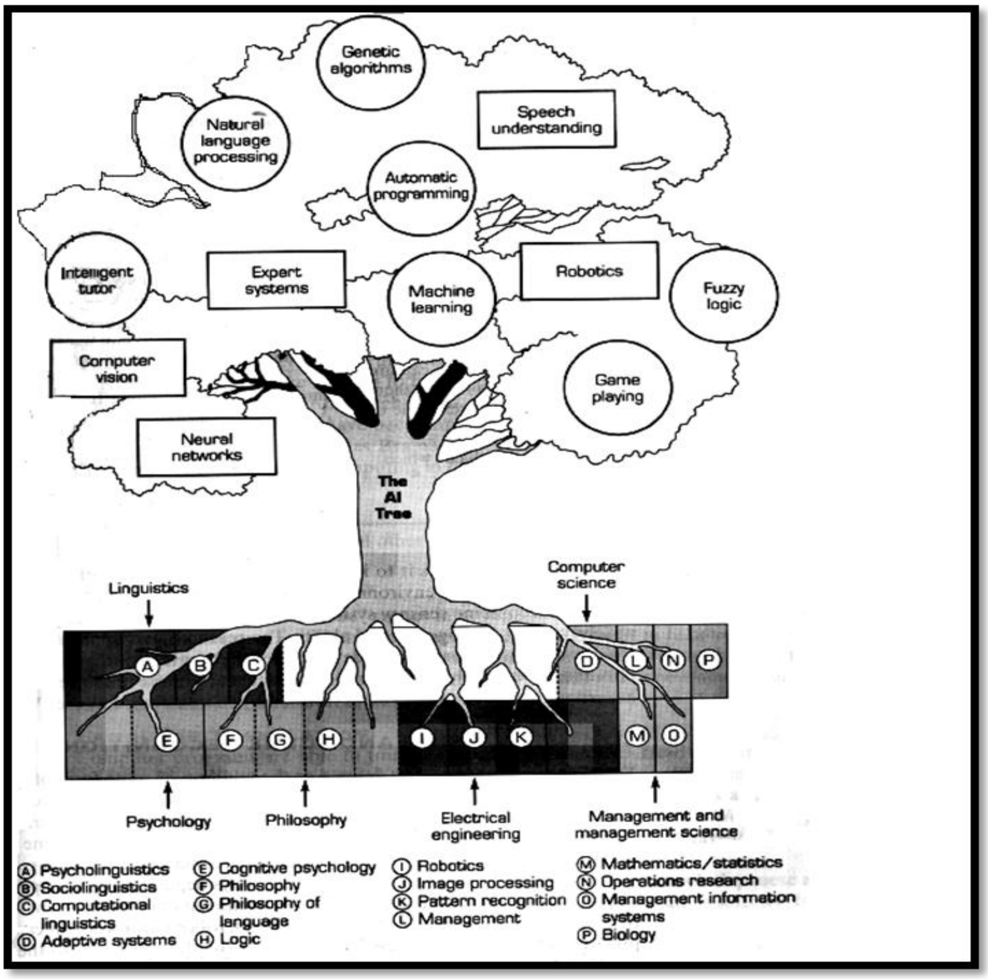


Figure 4-23: Major areas of artificial intelligence (AI) (Turban & Aronson, 2001)

4.6.1.1 Expert system definitions (ES)

Knowledge base systems are the most popular applied Artificial Intelligence (AI) technology. The terms 'knowledge base systems', 'knowledge-based systems', and 'knowledge-based knowledge base systems' are commonly applied synonymously (Giarratano & Riley, 1998). With this in mind, Turban & Aronson (2001) mention that the reference to 'knowledge base system' derived from the term 'knowledge-based knowledge base system'. In the beginning, knowledge base systems only contained expert knowledge and, although the term knowledge-based system (KBS) is more suitable, most people use knowledge base system (ES) because it is shorter. With the aforementioned in mind, knowledge base systems can therefore be defined as systems of knowledge bases (because they work on the use of knowledge or facts that are used by human experts).

Importantly, there are numerous assigned to the concept of knowledge base systems (ES). Some definitions taken from the literature and the internet are provided below:

'*A computer system capable of giving advice in a particular knowledge domain, by virtue of the fact that it contains knowledge provided by a human expert in this domain.*' (Source: http://www.mdx.ac.uk/www/ai/samples/ke/50-EXPE.HTM)

'*An expert system is a class of computer programs developed by researchers in artificial intelligence during the 1970s and applied commercially throughout the 1980s. In essence, they are programs made up of a set of rules that analyse information (usually supplied by the user of the system) about a specific class of problems, as well as provide analysis of the problem(s), and, depending upon their design, a recommended course of user action in order to implement corrections.*'

(Source: Wikipedia, the free encyclopaedia-(http://en.wikipedia.org/wiki/Expert_system)

'Is a system that uses human knowledge captured in a computer to solve problems that ordinarily require human expertise' (Turban & Aronson, 2001).

Adeli (1988) also cites three definitions of knowledge base systems, as follows:

- 'An intelligent computer program that uses knowledge and inference procedures to solve problems that is difficult enough to require significant human expertise for their solution'. (Feigenbaum, 1981).
- 'Knowledge base system or ES is a computer program that reasons with the knowledge of a specialist subject with a view to solving problems or giving advice.' (Bian, Sha and Hong 1995).
- 'An knowledge base system solves real-world, complex problems using a complex model of expert human reasoning, reaching the same conclusions that the human expert would reach if faced with a comparable problem'. (Weiss & Kulikowski, 1984).

4.6.1.2 History of knowledge base systems

Beginning in the mid-1960s, this new type of system was developed with the aim of supporting management throughout the decision-making process. The first system was designed (DENDRAL program) in 1965 in order to address the issue of chemical composition of materials. This programme contained a great deal of specialist chemical information, and the success of the program subsequently led to the development and growth of knowledge base systems, as well as the enhancement of companies specialising in the production of knowledge base systems. The main deliverables at different periods are given in Table 4.8 below (Turban & Aronson, 2001; Awad, 1996; Rodriguez-Bachiller & Glasson, 2004).

Table 4-7: Main deliverables in the area of AI and information systems at different time periods

1940s	Advancing of data-processing techniques.
1950s	Utilisation of transaction processing systems (TPS) and electronic data processing systems (EPS). First AI gathering.
1960s	AI development. Emergence of management information systems (MIS). General Problem Solver (GPS) developed by Newell, Simon & Shaw in 1957. McCarthy developed an AI programming language called LISP. Feigenbaum & Buchanan of Stanford University developed Dendral.
1970s	Development by Stanford University of the MYCIN knowledge base system for diagnosis of infectious diseases. Use of computer based information systems (CBIS) to support decision making; the study of decision support systems (DSS) becomes an essential part of CBIS. PROLOG was introduced as an knowledge base system language.
1980s	First uses of artificial intelligence-based knowledge base systems (ES) in decision making in narrow domains. DSS. Expanded commercial applications of knowledge base systems. Executive Information Systems.
1990s	Group Support Systems. Neural Computing. Integrated, hybrid computer systems. Web-based support systems.

4.6.2 CONCEPT AND COMPONENTS OF A KNOWLEDGE BASE SYSTEM (ES)

Knowledge base systems are computer programs which can help their users to solve problems or assist in making a decision. Figure 4.23 shows the basic concept of an knowledge base system whereby users, on the left-hand side, interact with the system on the right-hand side. The user enters facts and information to the system. The inference engine evaluates the rules and the knowledge base. Finally, the knowledge base system comes up with advice following conducting its reasoning, and accordingly communicates this advice back to the user. In this regard, knowledge-based systems can be designed to be adopted as intelligent assistants to human experts, and to thereby speed-up the solution of problems (Giarratano, 1998).

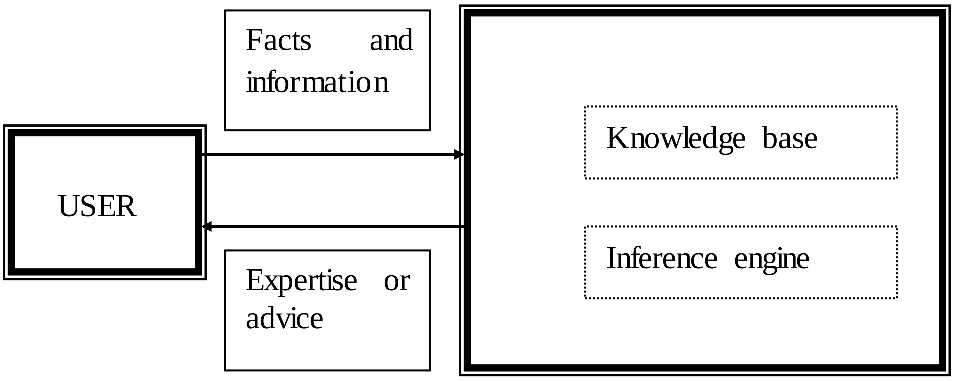


Figure 4-24: Knowledge base system concepts (Giarratano, 1998)

Knowledge base systems are generally designed to be expert in a single problem domain. The problem domain is the special problem area, such as finance, engineering, medicine, or science. A knowledge domain is an expert's knowledge concerning the solving of specific problems. With this in mind, it accordingly apples that an knowledge base system is only concerned with the knowledge domains it was programmed with, and would therefore not know anything about other knowledge domains.

Basically, the most important components of a knowledge base system (Durkin, 1994; Turban & Aronson, 2001) are:

- Knowledge base: containing all the facts, rules and relationships representing the knowledge (information and the work of experts). The knowledge base is therefore a collection of facts and rules which are placed in the form of sentences and scripts, which can be written in a programming language. Therefore, this knowledge is known as the cache memory of the expert or working memory;
- Inference engine: this aspect of the knowledge base system is concerned with the conclusion and the issuance of results from the system, where the system draws a conclusion similar to the steps followed by the expert during the treatment of the problem. The task of the inference engine is to test the facts and rules in the knowledge base system, but which also has the ability to add new facts or rules, and to thereby determine the order of the flow of conclusion and responses to the users;
- User interface or dialog system: this is one of the most important stages of the knowledge base system which links the user and the computer. The interface must enable the user to easily formulate questions and inquiries about the problem, and must thereby provide solutions and recommendations for the user in a clear and adequate manner.

The basic elements of a knowledge base system are shown in Figure 4.25. Whilst the inference engine and knowledge base are the main components of an knowledge base system, there may nevertheless be additional elements to assist or support in problem-solving or decision-making. The structure of a knowledge base system is shown in Figure 4.26.

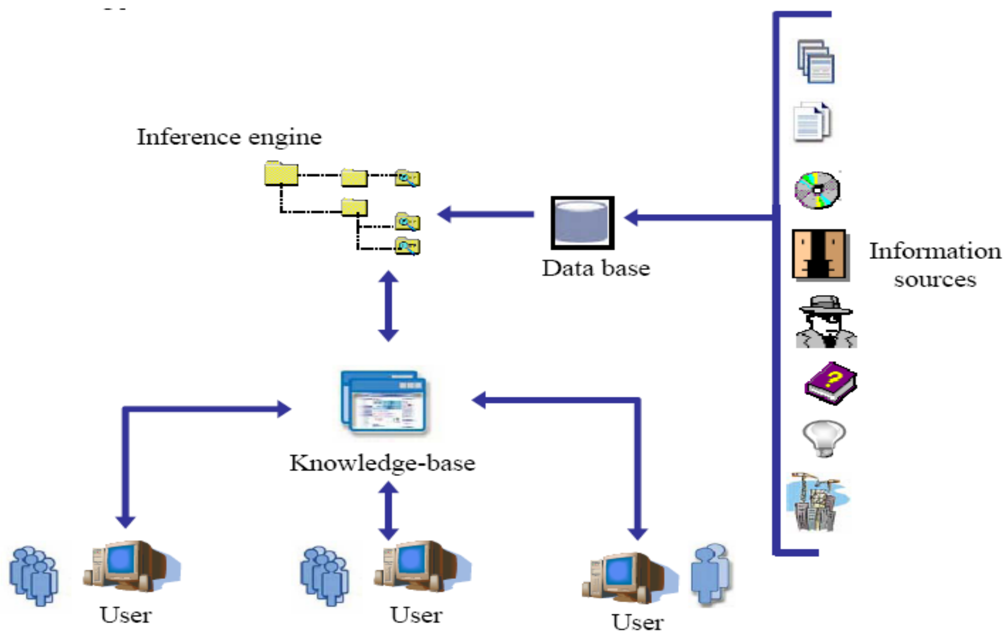


Figure 4-25: The basic elements of an ES (Arian & Pheng, 2006)

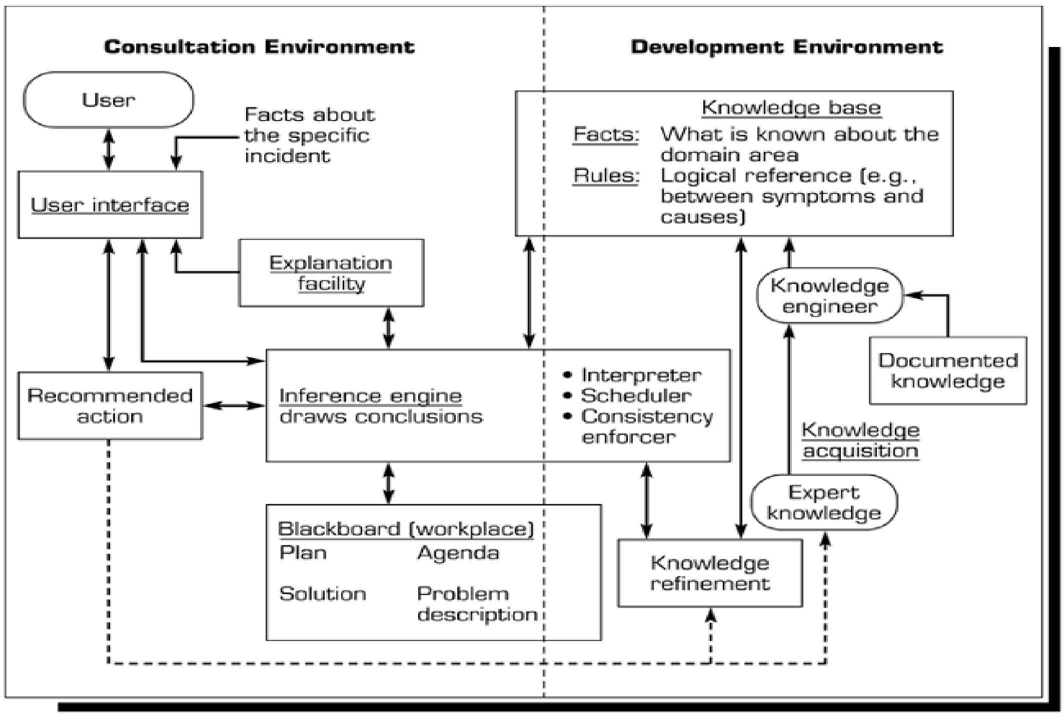


Figure 4-26: Structure of knowledge base system components (Turban & Aronson, [date?]; Liang, 2005)

4.6.3 TYPES OF KNOWLEDGE BASE SYSTEM

Knowledge base systems can range from a simple system which seeks to answer a straightforward query, to a complex system providing a solution or advice relating to a complicated problem, based on its related database. The main types of knowledge base system are (Turban & Aronson, 2001):

1. Rule-based Systems: knowledge represented by a series of rules. The rule-based approach uses an IF-THEN type rule or CONDITION-ACTION, rules and it is the method currently used;
2. Custom-made Systems: meeting the specific needs of a user;
3. Frame-based Systems: knowledge represented through frames linked together in a certain manner;
4. Hybrid Systems: several approaches are combined—commonly rules and frames;
5. Off-the-shelf Systems: ready-made packages for general use;
6. Model-based Systems: models which simulate the structure and functions of systems; and
7. Real-time Systems: strict limits set on system response times.

4.6.4 KNOWLEDGE BASE SYSTEM APPLICATIONS

One of several methods of knowledge base system classification is by the general problems they address. The general categories of knowledge base system are listed in Table 4.8.

Table 4-8 General categories of knowledge base systems (Turban & Aronson, 2001)

Category	Problem Addressed
Interpretation	Inferring situation descriptions from observations
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observations
Design	Configuring objects under constraints
Planning	Developing plans to achieve goals
Monitoring	Comparing observations to plans, flagging exceptions
Debugging	Prescribing remedies for malfunctions
Repair	Executing a plan to administer a prescribed remedy
Instruction	Diagnosing and debugging student performance
Control	Interpreting, predicting, repairing and monitoring system behaviour

Concise descriptions of these categories are provided below (Turban & Aronson, 2001; Hayes-Roth, Waterman & Lenat, 1985; Giarratano and Riley,2005)):

- Control systems effectively monitor overall system behaviour through continuously considering and describing the situation, as well as establishing the cause of issues, estimating future events, and accordingly planning, maintaining and following up application so as to ensure positive outcomes. In this regard, control systems seek to address issues in a number of arenas, namely business management, mission control and traffic control.
- Debugging systems place emphasis and dependence on two key aspects—design planning and prediction—in an attempt to create a number of

recommendations or specifications for dealing with and subsequently overcoming defined issues.

- Design systems provide configurations for those items which fulfil the restrictions posed by design issues, including budgeting, building design and layout.
- Diagnosis systems are those which create a link between noted behavioural irregularities and the causes of such. This category comprises diagnoses in the areas of electronic, mechanical, medical and software.
- Instruction systems establish and overcome student knowledge problems, and accordingly determine the most feasible solutions for overcoming such weaknesses.
- Interpretation systems seek to describe the noted information items through attributing symbolic meanings to each. Importantly, this category comprises image analysis, intelligent analysis, signal interpretation, speech understanding and surveillance.
- Monitoring systems conduct comparisons between system behaviours and characteristics considered to be valuable in regard to plan results. In this regard, a number of computer monitoring systems are in implementation, including air traffic control, factor management and nuclear power plants.
- Planning systems are concerned with planning-related issues, including automatic programming. Notably, such systems also consider a number of different areas of planning, including communications, military planning, project management and routing.
- Prediction systems apply parametric dynamic frameworks along with parameter values assigned to the particular context. In this regard,

prediction systems may comprise crop predictions, demographic predictions, military forecasting, traffic predictions and weather forecasting.

- Repair systems create and operate plans in an attempt to establish solutions to various diagnostic problems.

4.6.5 KNOWLEDGE BASE SYSTEMS STRUCTURE AND DESIGN

The process of building an knowledge base system is known as knowledge engineering. An knowledge base system development lifecycle model is illustrated in Figure 4.26. Notably, there are six main stages in the developing of an knowledge base system, which are listed below, as provided by Durkin (1994) and Negnevitsky (2005):

- Problem assessment;
- Data and knowledge acquisition;
- Development of a prototype system;
- Development of a complete system;
- Evaluation and revision of the system; and
- Integration and maintenance of the system.

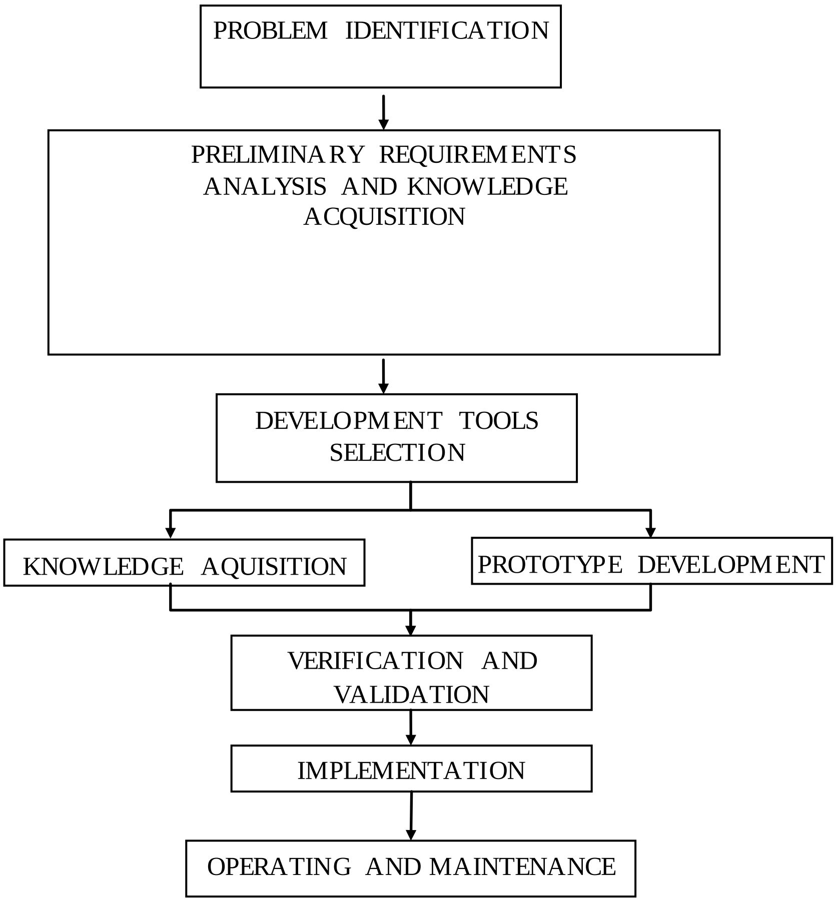


Figure 4-27: Knowledge base system lifecycle model (Awad, 1996)

a) Problem assessment

Problem selection and assessment is the first step in the knowledge base system development process. Having a good problem—in terms of suitability for solution by these means—is a major factor when determining the overall success of an knowledge base system. The problem should have the following characteristics (Badiru, 1992; Turban & Aronson, 2001):

- The problem is in an area in which experts are in short supply;
- Solving the problem will save time and money;
- There is a reliable and accessible body of knowledge to be acquired;
- The problem must be mostly qualitative in nature and not quantitative ;

- The required knowledge must be in a narrow area; and
- The user interface must be friendly for learner users.

Moreover, it is recognised that problem assessment should include a number of steps (Negnevitsky, 2005):

- Determining the problem's characteristics
- Determining the resources required for system building
- Specifying the project's objectives.

b) Data and knowledge acquisition

This task is the most difficult challenge in the development of an knowledge base system (Durkin, 1994). At this stage, the knowledge engineer gathers data from experts, textbooks, technical manuals, and research papers, etc. This acquired knowledge is subsequently converted to an electronic format for use by the computer program in question.

Kendal and Creen (2007) mention three types of knowledge which the knowledge engineer commonly deals with, namely:

- Declarative knowledge, which informs us of relevant facts;
- Meta-Knowledge: is knowledge about knowledge, which shows how the expert use the knowledge to solve specific problem; and
- Procedural knowledge, which provides other actions based on the use of facts in an attempt to gain knowledge.

According to Milton (2007) the utilisation of acquired knowledge falls into three categories:

- Information can be shared amongst individuals through special websites known as knowledge web
- Such information can be shared amongst computer systems in cases where data is coded according to 'ontology', which is a special format permitting services or systems to utilise data as and when required
- Knowledge can be utilised as one aspect of knowledge base system development in the form of a knowledge document, which is utilised by software developers during the development process. Notably, this could be an knowledge base system, a knowledge-based engineer system, or a knowledge-based system.

During the overall data-gathering process, the knowledge engineer is required to carry out four key activities (Negnevitsky, 2005):

1. The engineer needs to ensure comprehension and understanding of the key aim and objectives of the suggested knowledge base system;
2. The engineer is then required to establish working data concerning the problem domain and ensure understanding of terminology, which can be achieved through research.
3. Further in-depth knowledge should be ascertained, such as through the conduction of interviews with relevant professionals.
4. The gathered data should be analysed and evaluated in order to create a 'document knowledge base' or a group of documents for the communication of such data to the computer program.

Castellanos *et al.*, (2011) described the available knowledge for the knowledge base system as below:

1. Direct Approach: The knowledge acquired directly from the human expert, through interviews or questionnaire, obtaining an explanation of the knowledge that the expert used to solve a particular problem.
2. As a result verbal data are obtained and then interpreted by the programmer or knowledge base system designer.
3. Observational Approach: In this case, the knowledge engineer reflect the experience of the expert in him/her job and asks to explain of process step by step, while carrying out his/her job.
4. Indirect Approach: The the programmer or designer of the system experts applies a method through it is expected that the expert will reveal his information.
5. Machine Learning Approach: In this case, software with learning algorithms is used to guess the knowledge from domain examples provided by the experts.
6. Document Processing: In this case the knowledge is acquired through technical reports, books, journals, articles, etc.

c) Development of a prototype system

A prototype system is defined as a small version of the final system, which has limited ability (Durkin, 1994). The purposes of a prototype system are (Durkin, 1994):

- To validate the knowledge base system approach;

- To confirm that the choice of tools selected for building the system and the techniques for representing the acquired data and knowledge are all adequate in relation to the task; and
- To provide a vehicle for knowledge acquisition.

The development of a prototype system includes, which used in developing of the proposed system in this research:

- Selecting a tool for building an intelligent system;
- Transforming data and representing knowledge;
- Design and implementation; and
- Testing with test cases.

d) Development of a complete system

This stage includes (Negnevitsky, 2005; Turban & Aronson, 2001):

- Preparing a detailed design for a full-scale system;
- Collecting additional data and knowledge that might be needed;
- Developing the user interface; and
- Implementing the complete system.

e) Evaluation and revision of the system

At this stage, the system is revised and further evaluated against the performance criteria. Owing to the fact that intelligent systems are not like conventional computer programs in the sense that they are developed to solve problems which do not have exact solutions (right or wrong), the system should then be evaluated or validated in order to meet the user's requirements and to thereby ensure that it does what it was designed to do. A comparison between the development lifecycles of a conventional information system and an knowledge base system are shown in Figure, as provided by Awad (1996). The evaluation of the system is normally accomplished through demonstrating the results of test cases (Negnevitsky, 2005). The proposed system in this research was evaluated and validated for its performance, applicability, and general performance.

4.6.5.1 Building tools for knowledge base systems

There are a number of tools for knowledge base system development, ranging from high-level programming languages through to ready-to-use applications packages (Awad, 1996). Four levels are used to classify building tools, as detailed below and highlighted in Figure 4.28 (Awad, 1996):

- Programming languages: these may be more traditional and long-standing, such as LISP, which is the oldest programming language, or modern and relatively recent, such as in the cases of C++ and VB.
- Shells: these are reasoning systems provided without information. In this regard, it can be stated that knowledge base system shells comprise a number of key elements contained within an knowledge base system with the exception of knowledge content (Turban & Aronson, 2001). In this regard, it is further emphasised by Awad (1996) that a questionnaire concerning modern knowledge base system applications highlight that the

majority were created with the use of shells as opposed to alternative languages.

- Special knowledge base system packages: these are programs provided on a ready-to-use basis, which provide users within the arena with advice and important insight into how to deal with various issues arising in the area.
- Support tools and aids: various tools are available for the creation of a user interface, the editing of programs, the gathering of data, and the validation and verification of programs.

It is noted by Adeli (1994) that an a programming environment or expert shell considered appropriate for engineering applications must have the capacity to deal with both numerical and scientific calculations within the system. Moreover, he further states what needs to be taken into account when choosing ES shells in terms of engineering applications.

1. Availability of mathematical routines
2. Cost
3. Maximum number of rules
4. Portability
5. Program aids
6. Response time
7. The ability to interface with other programs written in the language of the shell or another language
8. The type of application
9. Type of control strategy and inference mechanism
10. Type of machine and operating system

11. User support.

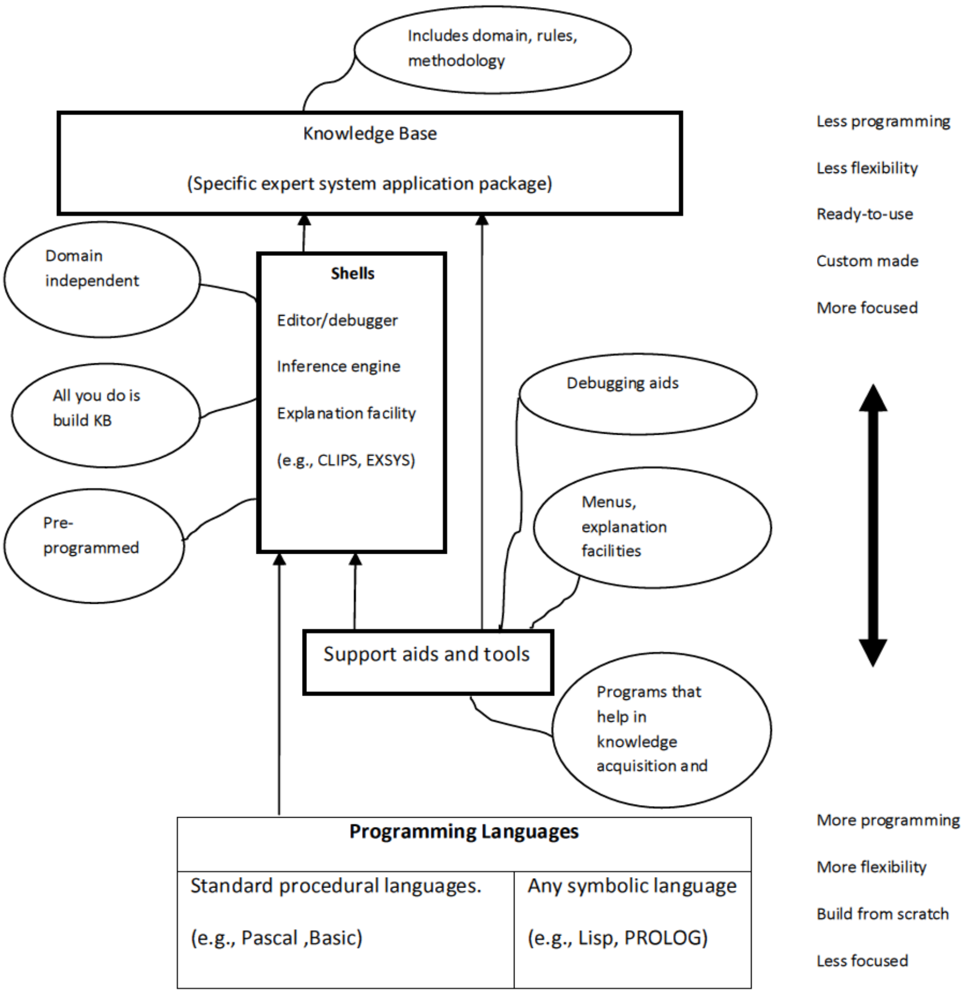


Figure 4-28: Classification of building tools (Awad, 1996)

For the development of the prototype system in this research, programming languages were used to develop the system (Visual Basic) were the system developed from scratch. The programming language was selected because of the author's previous knowledge of this language and its low cost compared with knowledge based system shells.

4.6.5.2 Benefits of knowledge base systems

Turban, Aronson and Liang (2005); Awad (1996) and Turban et al, (2008) list and discuss the benefits associated with knowledge base systems, as those given below:

1. Increased output and productivity
2. Decreased decision making time
3. Increased processes and product quality
4. Reduced downtime
5. Flexible and easy to modify compared with traditional programs
6. Elimination of expensive equipment
7. Make equipment operation easier
8. Integration of several experts' opinions
9. Deal with incomplete or uncertain information
10. Provide training by providing knowledge and information
11. Improved problem-solving and decision making
12. Improved decision making processes
13. Improved decision quality
14. Ability to solve complex problems.

4.7 APPLICATIONS OF KNOWLEDGE BASE SYSTEMS IN CIVIL ENGINEERING

Knowledge base systems have been applied as assessment tools for the purposes of design, maintenance and management in all fields of civil engineering. Some such examples of developed knowledge base systems are provided below:

A. Applications in concrete technology

- COMIX: rule- and frame-based knowledge base systems which provide advice on the design of concrete mixes. The system has been designed for use by concrete technologists, design engineers, and consultants (Kaetzel & Clifton, 1993).
- DURCON: knowledge base systems which provide suggestions concerning the choice of concrete material for the following durability areas: corrosion freeze-thaw, sulphate attack, alkali-aggregate reaction (Kaetzel & Clifton, 1993).
- HPCMIX: prototype knowledge base systems which provide proportions for trial mixing of High Performance Concrete (HPC). The system is based on knowledge from textual and human experts. HPCMIX is capable of selecting the mixing proportions of water, cement, supplementary cementation materials and aggregate, considering the air content and moisture condition of the aggregate (Zain, Islam & Basri, 2005).

B. Structural assessment applications

- A hybrid reasoning system: a knowledge-based system developed for damage assessment of structures. The system combines use of a model of the structure with a knowledge-based reasoning scheme to evaluate whether or not damage is present, as well as its overall severity and location (Mujica, Rodellar & Kolakowski, 2005).

C. Dam engineering applications

- CASTOR: a dam safety assessment system integrated with a knowledge-based system (SISAS). This system has been developed with the objective to assess engineers responsible for dam safety assessment (Farinha, Portela, Domingues & Sousa, 2005).

D. Railway tunnelling applications

- MATUF system: a knowledge-based system designed in order to assist in the making of recommendations for diagnosis and the repair of tunnels. The system integrates various different types of knowledge obtained from experts in the field of underground work. Notably, it is designed to represent the information obtained, to carry out a brief assessment of the safety conditions of the work, and to thereby classify the tunnel with reference to its safety level, accordingly making recommendations for its repair (Farinha, Portela, Domingues & Sousa, 2005).

E. Structure design applications

- A knowledge-based system for liquid retaining structures. This is a prototype knowledge-based system developed for the design of liquid retaining structures based on the blackboard architecture. The system is tailored to provide advice regarding preliminary design, loading specifications, and optimised configuration selection for this type of structure (Chau & Albermani, 2005).
- BREXS: Bridge Rail Knowledge base system is an advisory system developed to assist novice engineers with railway bridge design. The goals of this system are to incorporate a railway bridge knowledge base, a railway bridge database and analytical computer codes to aid in decision-making (Tommelein, 1997).
- CUFAD+: Compression and Uplift Foundation Analysis and Design is a knowledge-based expert advice system built for use in designing foundations for electric power transmission line structures. The goal of

this system is to provide engineers with the capacity to make better designs (Tommelein, 1997).

F. Environmental engineering

- LDEM-DSS: A decision support system for landfill design, evaluation, and monitoring. LDEM contains a number of decision support modules related to the various design and monitoring operations of sanitary landfill (Lukasheh *et al.*, 2001).
- SLEUTH: A decision support system in landfill design and waste management evaluation including transport and hydrology. SLEUTH was developed for the design and remediation of shallow landfill burial systems (Lukasheh *et al.*, 2001).

G. Construction management (maintenance and repair)

- (ESMHS) Knowledge base system for maintenance of Major Hydraulic Structures. This system is applied for the diagnosis of different types and classes of problem which may occur in various different elements of masonry barrages (de Brito, Branco & Ibañez, 1994).
- A Knowledge-based Advisory System for the Diagnosis and Repair of Subsidence Damage: This system is provided to improve the management of subsidence cases by providing engineers with intelligent advice at all stages of the management process (Anumba *et al.*, 1995).
- Knowledge base system for Maintenance and Repair of Masonry Barrages: This knowledge base system developed for diagnosis of various types and categories of problems that may occur in the various elements of Masonry

Barrages. The system helps to recognize possible causes, and propose the suitable method of remediation.

- Knowledge base system for Airport Pavement Maintenance and Rehabilitation: This knowledge base system is developed to help in identifying the problems related to airport pavements and structures, diagnosing the cause of deterioration, recommending the repair actions, and estimate the cost of repair (Ismail, Ismail & Atiq, 2009).

4.8 SUMMARY

There are different causes of flood such as sea, rivers and streams, blocked or overloaded drainage systems and sewers, and ground water. One of the most common causes of flooding is excessive rain. Some 2.1 million homes in the whole of the UK are in areas which are considered to be at risk from river and sea flooding. Flood damage can range from minor to more severe cases, where extensive damage occurs. Damage caused to a property is dependent on the characteristics of the flood, as well as of the building itself. There are a number of issues which can arise during the repair stage which emphasise clearly that there is a need to establish repair standards. Considering using resilient repair options will reduce repair costs of any future damage.

Knowledge base systems have been applied as assessment tools for the purposes of design, maintenance and management in all fields of civil engineering and could be helpful in the field of flooded building damage management.

The next chapter will discuss the Knowledge acquisition for prototype development.

CHAPTER 5 KNOWLEDGE ACQUISITION FOR PROTOTYPE DEVLOPMENT

5.1 INTRODUCTION

The chapter present the results of the survey and the knowledge elicited in the knowledge acquisition stage from various different documents reviewed, summarises the remediation options available for each building elements, and finally demonstrates the remediation options used by the prototype system.

5.2 METHODOLOGY USED

Data generation methods are a means by which empirical (field) data or evidence is produced. In this regard, data can be either quantitative or qualitative: quantitative data is a numeric data, whereas qualitative data is all other types of data.

According to Oates (2006), there are four different data-generation methods, as detailed below:

1. Interviews: a particular kind of conservation between people. One-to-one or group interview are possible;
2. Observation: watching what people actually do, rather than what they report they do.
3. Questionnaire: a predefined set of questions assembled in a pre-determined order, which provides the research with data to be analysed or interoperated;

4. Documents: documents which already exist prior to the research, such as academic literature, previous research, visual resource of data, and organisation publications. Moreover, it is often useful to study relevant documentation either as the main basis for a project or as complement to the other methods of data collection (Cornford & Smithson, 2006; *et al.*, 2011).

Following the topic having been defined and the literature identified to be reviewed, some issues related to the topic were also identified, workshops related to the topic were identified in an attempt to gain updated knowledge as well as the chance to meet experts and professionals in the arena. A number of workshops were attended during the research time period. The unstructured interview technique was used to collect preliminary information at the beginning of the research, and to thereby gain updated information during the research timescale. Moreover, an initial interview with experts were conducted in order to determine what knowledge is to be acquired, the purpose of the knowledge, and to gain some understanding of key terminology.

The information-gathering was carried out mainly through the use of questionnaire surveys, technical publications and manuals, as well as attendance at, and contributions to, flood management workshops where there has been the opportunity to meet experts in the field in order to gain knowledge or update existing knowledge. This is because of the nature of the information that needed to be collected, especially related to the maintenance of buildings, where it was difficult to elicit responses through the questionnaires alone. This applies to all cases of flooding damage repair: for example, in most cases where the flood depth has not been deep, it was found that the responses concentrated on these cases alone, therefore requiring the use of other sources, such as documents (a list of documents are given in Table 2.5). During this phase, there was the need to rely on such sources so that they would complement each other and meet shortfalls which might occur as a result of reliance on one source.

5.2.1 THE QUESTIONNAIRE SURVEYS

Two questionnaire surveys were conducted: one on vulnerability assessment, and the second on flood repair options.

5.2.1.1 Vulnerability assessment questionnaire

The survey was conducted with the aim of investigating factors that contribute to the vulnerability of residential buildings to flood damage, and to thereby identify their relative importance in contributing to the vulnerability of buildings to damage from flooding. Moreover, there was also the need to identify any other factors which might not have been apparent from the literature review, but which were suggested based on the experiences elicited by the responses.

The questionnaire was designed in four parts: a covering letter, basic information concerning the participant, the body of the questionnaire, and finally, space for additional comments. A copy of the questionnaire is shown in Appendix A.

Rating questions were used to investigate those factors affecting buildings' vulnerability to flood damage. Extra space was given in case the participants wanted to add additional factors or make any further comments.

The questionnaire was sent to a number of contractors, researchers and experts in the field of flood damage management, either by mail with an addressed and stamped, return envelope, emailed, or otherwise handed out in person during the workshops attended. The postal and email addresses of the contractors were obtained by contacting various organisations, such as the Royal Institution of Chartered Surveyors (RICS), the Association of British Insurers (ABI) and the Environment Agency (EA), or were otherwise collected in person through workshops. 50 questionnaires were sent and distributed to different participants.

- **Results**

The following sections present the results of the survey of factors contributing to the vulnerability of residential buildings to flood damage.

- **Response**

14 questionnaires were received out of a total of 50 questionnaires distributed. The response rate was 28%, which is acceptable considering that a 20–30% response rate to postal questionnaire surveys is typical in the construction industry (Akintoye *et al.*, 2000).

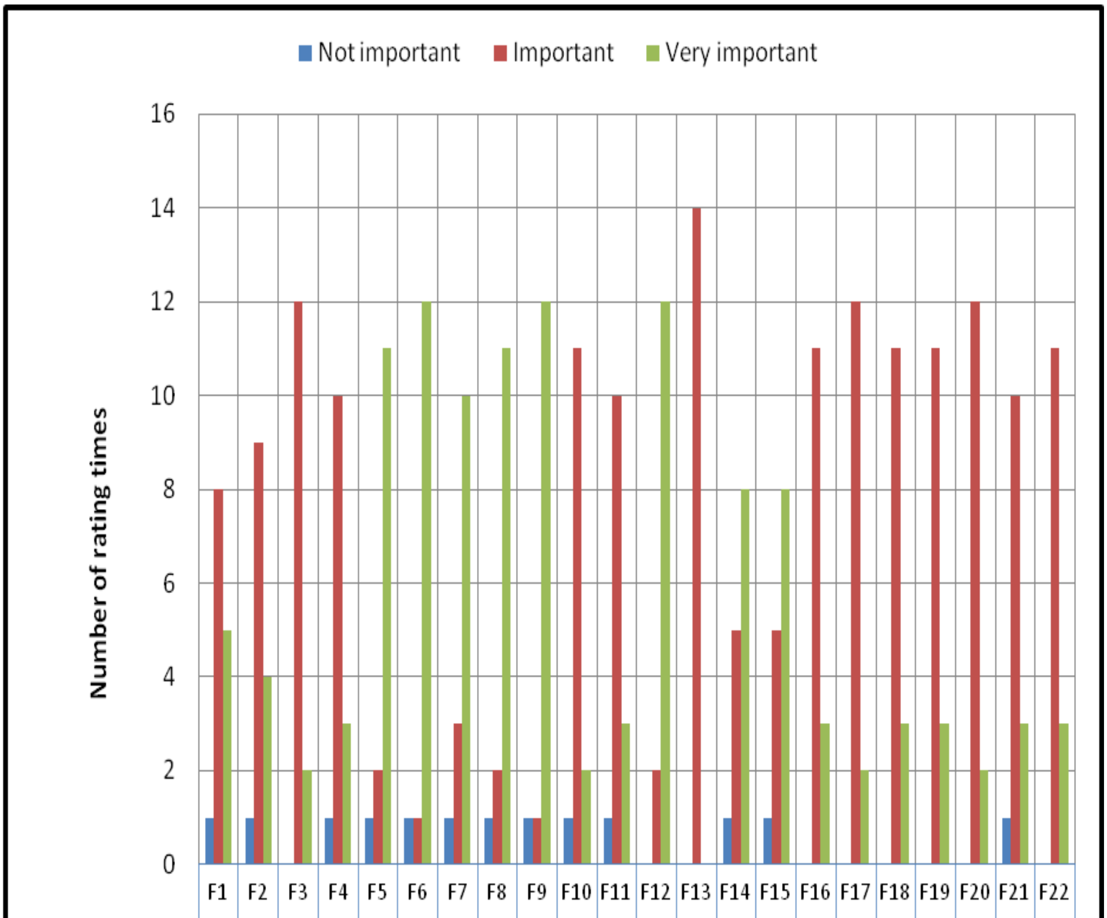
- **Factors rating**

All 14 participants ranked the factors given as being either *important* or *very important*, with the exception of one participant, who ranked some factors as *not important*. Only one extra factor was added by a participant, namely the existence of timber floors, which was ranked as *very important*. This factor has been included as factor number 12. Table 5.1 shows the number of times that each factor was deemed to be either *Not Important*, *Important* or *Very Important*. Table 5.2 is a plot of how the factors were ranked.

Table 5-1: Raw figures for factors ratings

Factor Number	Factor Description	*Number of times ranked as:* Not Important	Important	Very Important
1	Geographic location of the building is within a flood risk zone based on the flood maps provided by the Environment Agency	1	8	5
2	Building protected by flood defences.	1	9	4
3	Topography of the building site (the building is located on the floor of a valley or at the bottom of a hill)	0	12	2
4	The building is close to an intermittent stream	1	10	3
5	The building is underlain by a chalk aquifer	1	2	11
6	The soil is often near saturation point or is impermeable	1	1	12
7	Duration of previous flood was greater than 12 hours	1	3	10
8	Depth of the previous flood was above the building floor	1	2	11
9	Issuing of flood warnings for this area in the past	1	1	12
10	Occurrence of sewer flooding in the past	1	11	2
11	The building has been flooded in the past	1	10	3
12	The building has a timber floor, walls or frames	0	2	12
13	The building has cracks in the walls near the floor level	0	14	0
14	The building incorporates gypsum plaster	1	5	8
15	The building has a mineral insulation	1	5	8
16	The condition of the building prior to the flood	0	11	3
17	The building has a chipboard, wood, vinyl, or rubber tiled floor	0	12	2
18	The building has water resistant doors and windows, and the kitchen has PVC or other water resistant material	0	11	3
19	Gas and electrical utilities are located above the flood level	0	11	3
20	Existence of any flood resistance or resilience measures	0	12	2
21	Existence of backflow devices on sewer system	1	10	3
22	Previous flood damage	0	11	3

Table 5-2: Plot of Factors ratings



	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22
Not important	1	1	0	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0	0	0	1	0
Important	8	9	12	10	2	1	3	2	1	11	10	2	14	5	5	11	12	11	11	12	10	11
Very important	5	4	2	3	11	12	10	11	12	2	3	12	0	8	8	3	2	3	3	2	3	3

Importantly, these results have been used as the basis for calculating the degree of vulnerability, as discussed in Section 3.3.2.2.

5.2.1.2 Flood repair options questionnaire

The survey was conducted with the objective to investigate and identify options and alternatives in existent, and is followed in the maintenance of buildings hit by flooding, and also in relation to certain flood properties, such as flood depth, speed and duration. The survey addressed several issues, including damaged building elements and the time taken to reinstate flooded buildings.

The questionnaire was designed in five parts: the covering letter, basic information and flood characteristics, building characteristics and damage, damaged components and remediation options, and finally space for additional comments. Moreover, partially open-ended questions (multiple choices between various options) were used in the survey on the repair of flood damaged buildings so as to provide participants with the opportunity to add any other remediation options they considered to be important. In addition, extra space was given for the participants in case they wanted to add any comments. A copy of the survey is shown in Appendix B.

The questionnaire was revised more than once, and several modifications were made, with some questions being rephrased for clarity and the survey being shortened from thirteen pages to eight pages. Accordingly, the questionnaire was then sent to a number of contractors and experts in the field of flood damage management, either by mail with an addressed and stamped, return envelope, emailed, or otherwise handed out in person during the workshops that were attended. The postal and email addresses of the contractors were obtained by contacting various organisations such as THE Royal Institution of Chartered Surveyors (RICS), THE Association of British Insurers (ABI) AND THE Environment Agency (EA), or were collected in person during the workshops. 100 questionnaires were sent and distributed to different participants.

- **Results**

The following sections present the results of the survey into the options available for repairing flood damaged buildings. Example of questionnaire survey reply is given in Appendix B.

- **Response**

16 questionnaires were returned out of 100 questionnaires that were delivered, but only 12 were usable. The response rate was 12%, which is low considering that a 20–30% response rate for postal questionnaire surveys is typical in the construction industry (Akintoye *et al*., 2000).

Moreover, owing to the diversity and the large amount of information needed to be obtained from the questionnaire, as well as the overall lack of response, the information that was gathered was not sufficient to cover all scenarios of flood damage. For example, all the responses focused on cases where the flood depth was very shallow, and so there was no possibility of obtaining information on damage to walls, for example. Furthermore, most of the responses did not address the use of resilience options as an alternative for the maintenance of flooded buildings. Because of these reasons and the points mentioned in sections 4.5.2.1 and 4.5.2.2 in relation to those issues concerning flooded building maintenance and management, it was deemed necessary to use publications and information obtained through participation and attendance at relevant workshops in order to complete the gathering of the information which was required for developing strategies for the maintenance of buildings, and to thereby validate the information obtained from the survey. Another reason was the need to consider other alternatives, such as resilience repair. The use of documents will be clarified extensively in the following paragraphs. The reply from this survey questionnaire is covered only some flood damage scenarios and used were useful.

5.2.2 REVIEW OF TECHNICAL PUBLICATIONS AND MANUALS

A number of documents have been used for this research (refer to Table 2.5). Some of these documents are based on surveys investigating the selection of different repair options, whilst others investigate the damage caused by water to different building elements, based on laboratory tests and simulations of different flood scenarios. Furthermore, there are a number of documents which offer repair strategies, including resilience options (such as BRE, 2006). Documents including PAS 64 (2005) offer repair standards and specifications. With this in mind, the following sections set out the repair options for different elements of residential buildings (ordinary or resilience) as elicited from these documents. This information is then used in the knowledge base of the developed prototype.

5.2.2.1 Flood damaged building elements

The building elements that are subjected to flood damage will include:

- **Flood damaged foundations:**

1- Ground erosion surrounding foundations;

2- Foundation subsidence and settlement;

3- Loosening of mortar;

4- Foundation cracks or partial damage.

- **Flood damaged floors:**

1- Vinyl floor tiles submerged by floodwater;

2- Vinyl sheet floors submerged by floodwater;

3- Quarry tiled floors submerged by floodwater;
4- Solid concrete floors submerged by floodwater;
5- Suspended timber (chipboard) floors submerged by floodwater;
6- Suspended timber (chipboard) floors with tongue and groove floorboards;
7- When the floorboards are removed, it is discovered that the sleeper walls are constructed directly on the ground;
8- Concrete floors which have been covered by solid oak blocks.

- **Flood damaged walls:**

1- External wall of brickwork with cement mortar joints;
2- External wall has a rendered finish;
3- External wall has a pebbledash finish;
4- Internal wall constructed of brickwork with a paint finish applied directly to it;
5- Internal wall covered with ceramic tiles;
6- Internal wall covered with a wood veneer on a timber base;
7- Internal wall decorated with wallpaper;
8- Internal wall has evidence of a rising damp problem;
9- Internal block wall has a gypsum plaster finish;
10- Internal block wall has a cement/sand mix undercoat and a 1mm plaster skim applied to it;
11- Internal block wall has a lime/ox-hair mix and lime putty finish;
12- Internal timber partition wall;
13- Internal metal-framed partition wall.

- **Flood damaged doors and windows:**

1- Softwood front door;

2- Double-glazed hardwood patio doors;

3- Hollow cellular type infill wooden doors;

4- PVC external door;

5- Wooden window frames.

- **Flood damaged utilities:**

1- Steel panel radiators;

2- Gas fired heater;

3- Gas meter which has been in contact with floodwater;

4- Wall-hung gas fire which has been in contact with floodwater;

5- Electric circuit containing sockets which have been partially submerged by floodwater;

6- Wall-hung electrical heater which has been submerged by floodwater;

7- Timber skirting boards;

8- Staircase constructed from timber;

9- Built-in wall cupboards ;

10- Fitted kitchen that has been partially submerged above the plinths by floodwater.

5.2.2.2 Flood damage and water depth

The degree of damage that can be caused by floodwater depends mainly on the floodwater depth at which the building elements become in contact with water.

Figure 5.2 below illustrates the building elements which are subject to flood damage with respect to flood depth.

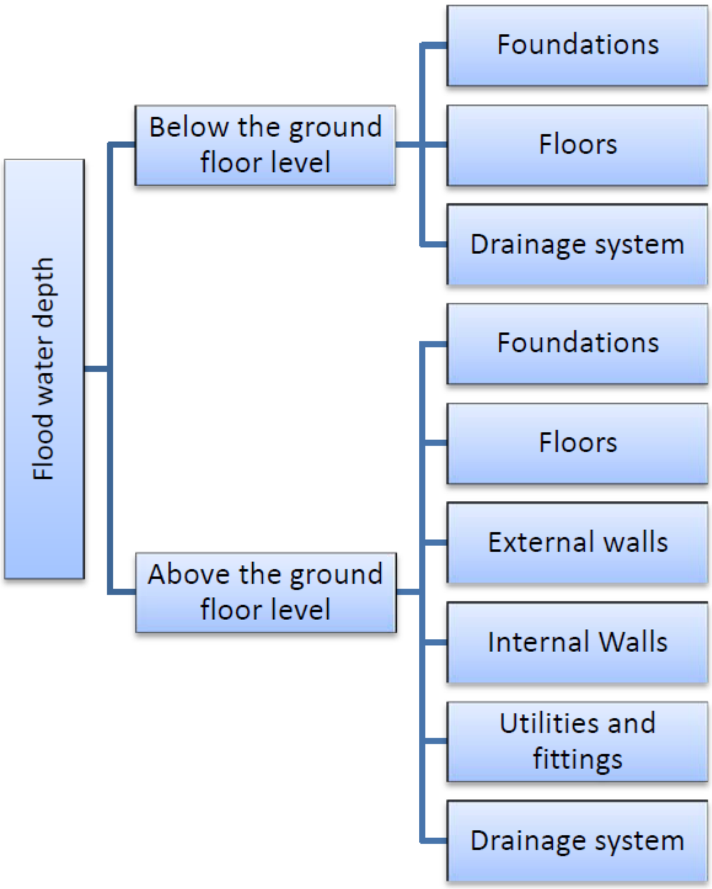


Figure 5-1: Building elements that are subject to flood damage with respect to flood depth

Figures 5.3 through to 5.10 categorise the different building elements according to type and materials used.

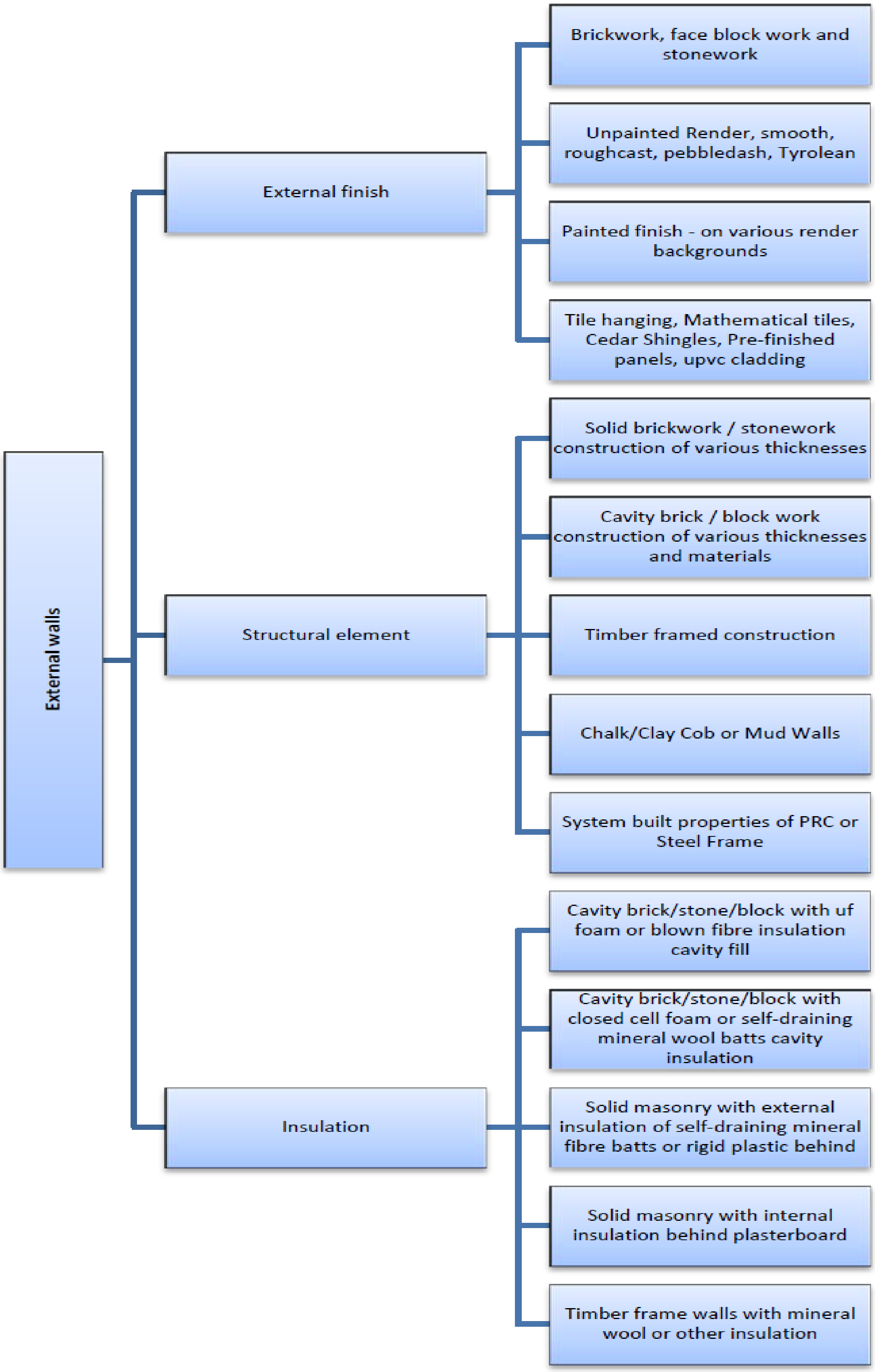


Figure 5-2: Categorised building elements (external walls)

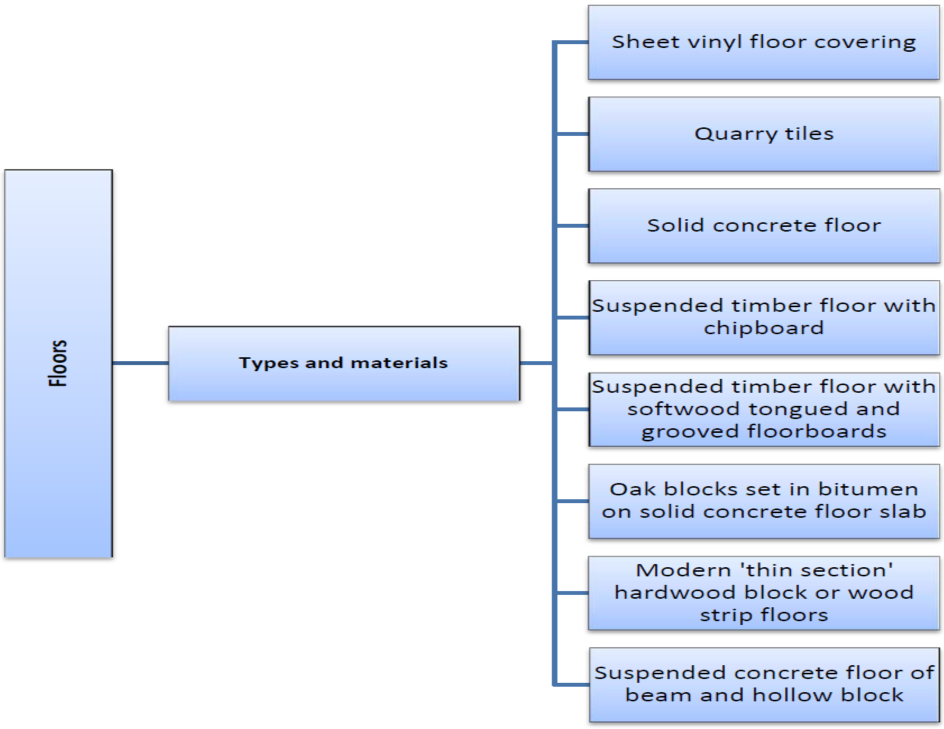


Figure 5-3: Categorised building elements (floors)

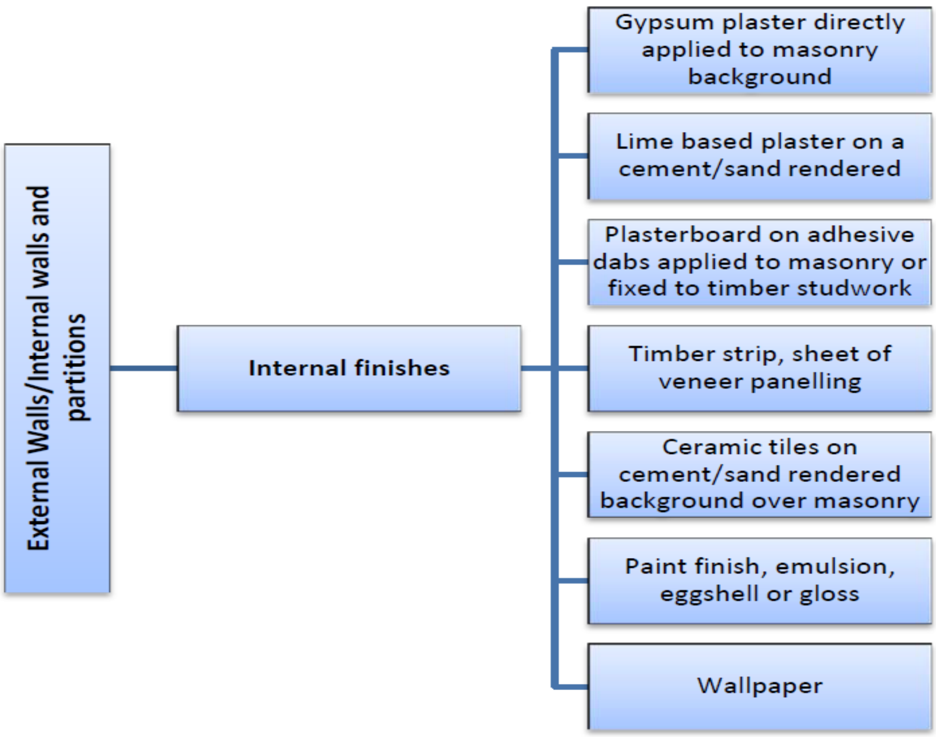


Figure 5-4: Categorised building elements (external walls/internal walls and partitions)

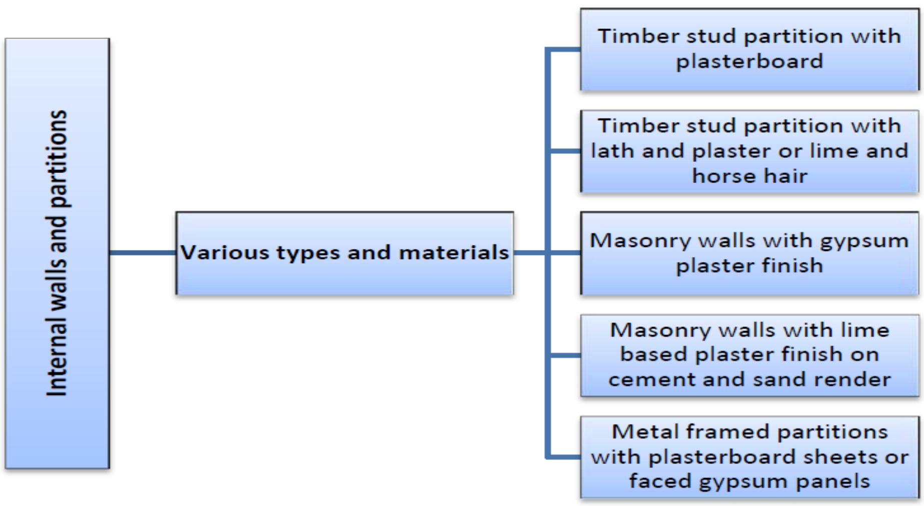


Figure 5-5: Categorised building elements (internal walls and partitions)

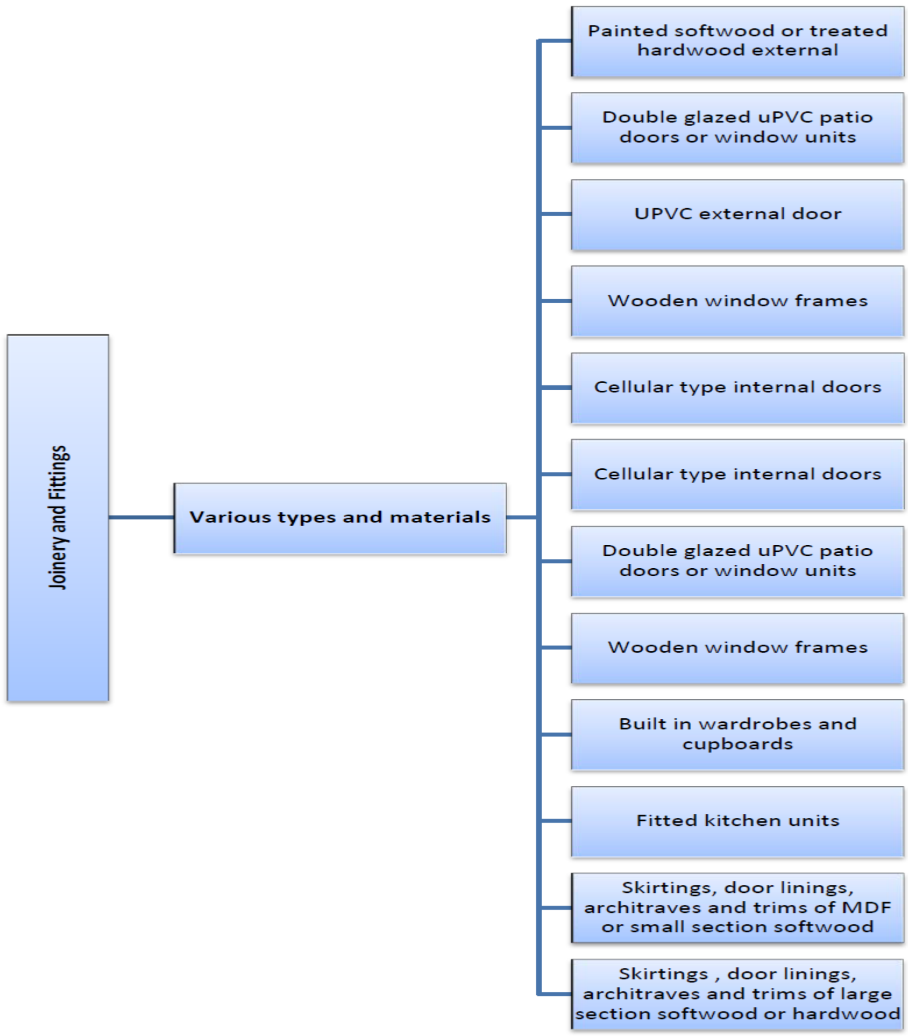


Figure 5-6: Categorised building elements (joinery and fittings)

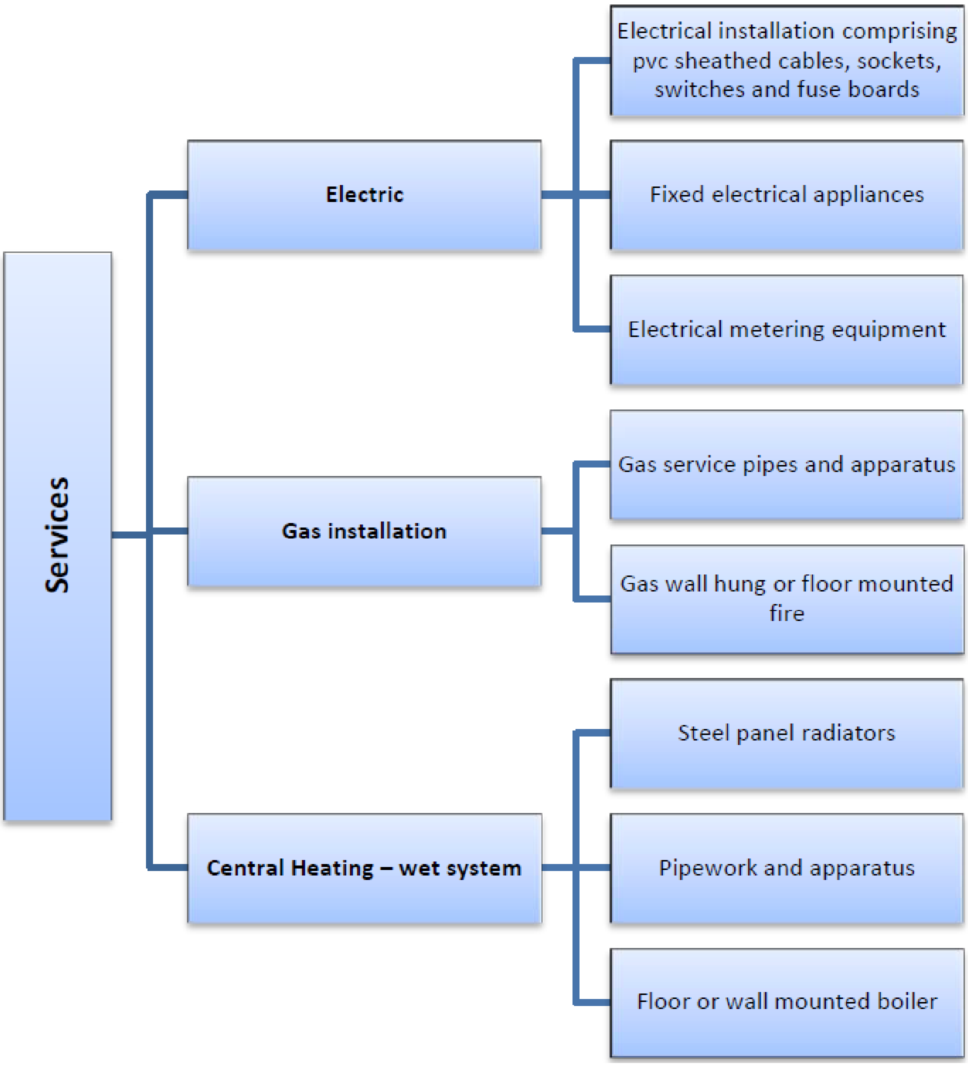


Figure 5-7: Categorised building elements (services)

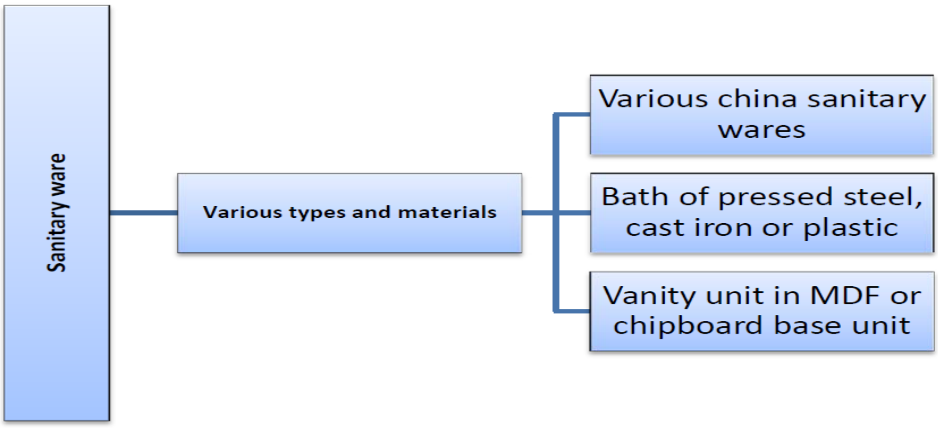


Figure 5-8: Categorised building elements (sanitary ware)

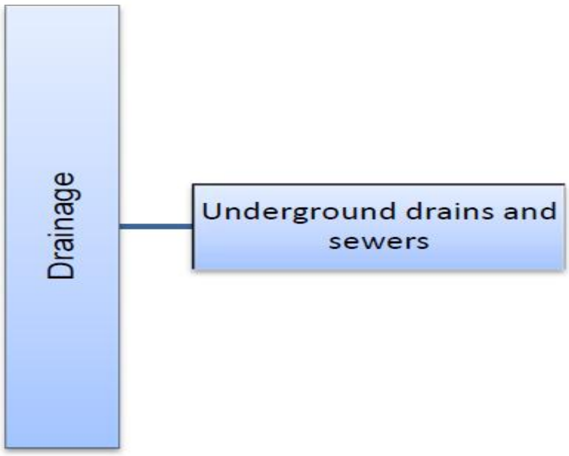


Figure 5-9: Categorised building elements (drainage)

5.3 FLOOD DAMAGE REPAIR OPTIONS

The damage caused by flooding is always the same, whether it's caused by natural disasters or owing to man-made issues. In general, two main options are available when dealing with repairing a property that has been flooded: the ordinary flood damage repair option (or standard), whereby traditional building materials are used; and secondly, the resilience option, where flood resilient materials or methods are used. The use of resilient materials and techniques is emphasised owing to the fact that it minimises the damage and disruption that can be caused by a flood in the future. The ordinary and resilience options are discussed below, and then the summaries used in the knowledge base system are detailed in the form of tables.

5.3.1 FLOOD DAMAGE REPAIR OPTIONS

Some examples of repair strategies provided by the publications listed in Chapter 2 are shown in the subsequent tables. Proverbs & Soetanto (2004) present the current benchmark strategies for reinstatement of a range of different flood damage conditions which are common in domestic properties, as based on various different flood damage scenarios. These benchmark repair strategies are based on the literature review and various consultations with damage management experts, insurers and loss adjusters, as well as questions to insurers and loss adjuster. These strategies are summarised in tables 5.2 through to 5.5 below.

Soetanto, Proverbs, Lamond & Samwinga (2008) illustrate the ideal and resilient repair strategies of different building components as shown in tables, as given below.

Table 5-3: Ideal and resilient repair strategies for flooded damaged floors (adapted from Soetanto, Proverbs, Lamond & Samwinga, 2008)

Elements Damaged and Type of Damage	Ideal Repair Strategy	Resilient Strategy
The dwelling has vinyl floor tiles installed that have been submerged by floodwater	Recommend replacement of all floor tiles	Vinyl is generally water resistant, but the substrata should be dry before the tiles are put in place
The dwelling has a quarry tiled floor which has been submerged by floodwater	Recommend the replacement of floor tiles	Use a full bedding of tile adhesive (and water resistant grout) to fix the tiles to the (dry) substrate
The dwelling has a solid concrete floor which has been submerged by floodwater	Recommend that the floor screed be removed, the floor allowed to dry and then the screed replaced.	Replace screed using cement-rich screed for flood resilience, although drying could take a long time.
The dwelling has a suspended timber (chipboard) floor which has been submerged by floodwater.	Recommend replacement of all timber components	Replace all chipboard and damage timber components (with preservative-treated timber joists and floorboards) or Replace suspended floor with solid floors
The dwelling has a concrete floor which has been covered with solid oak blocks	Replace all floor covering (i.e. the oak blocks)	Replacement with more resilient material (such as tiles)

Table 5-4: Ideal and resilient repair strategies for flooded damaged walls (adapted from Soetanto, Proverbs, Lamond & Samwinga, 2008)

Elements Damaged and Type of Damage	Ideal Repair Strategy Options	Resilient Strategy
The external wall of the property is brickwork with cement mortar joints	The walls be sandblasted to remove any flood debris	Render the external wall, or apply water-resistant paints and coatings (or tanking), or alternatively use flood protection products, such as flood protection skirt.
The external wall of the property has a rendered finish	All the render be removed and replaced	Apply a propriety render finish (e.g. polymer-modified system) to reduce water penetration
The external wall of the property has a pebbledash finish	All the pebbledash render be removed and replaced	Apply impermeable render mix
An internal wall of the flood damaged property is constructed of brickwork with a paint finish applied directly to it	Recommend the wall be cleaned plastered and decorated	Apply lime-based plaster or tiles
An internal wall of the flood damaged property is covered with ceramic tiles	Replace all tiles	Use waterproof tile adhesive on the wall and use water resistant grout
An internal wall of the flood damaged property has been covered with a wood veneer on a timber base	Replace the wood veneer	Replace damaged veneer with treated timber. Consider using more resilient material such as cement or lime based plaster or even tiles
Floodwater has been in contact with an internal block wall that has a gypsum plaster finish	Replace the wall's plaster	Use resilient plaster, such as cement or lime based, or consider using tiles
Floodwater has been in contact with an internal brick wall which has a lime/ox-hair mix and lime putty finish	Replace the wall's plaster	Replace of damaged plaster with same or even better mix or tiles.
Floodwater has been in contact with an internal timber partition wall	Replace the timber components and the plasterboard	Replace damaged timber with treated timber; mineral wool insulation with closed cell type insulation

Table 5-5: Ideal and resilient repair strategies for flooded damaged doors and windows (adapted from Soetanto, Proverbs, Lamond & Samwinga, 2008)

Elements Damaged and Type of Damage	Ideal Repair Strategy Options	Resilient Strategy
A flood damaged property has a softwood front door that has been in contact with floodwater	Replace the door	Replace the door with hard wood; consider use sealed PVC door and/or demountable flood protection
A flood damaged property has double glazed hardwood patio doors that have been in contact with floodwater	Replace the door	Assess the timber components, seal: door frame into building, door into its frame Consider use of sealed PVC door and/or demountable flood protection
A flood damaged property has a hollow cellular type infill wooden door that has been in contact with floodwater	Replace the door	Replace the door with resistant type, e.g. solid timber doors
A flood damaged property has wooden window in contact with floodwater	Replace the windows	Consider replace damaged or corroded hardware with non-corrosive components. Consider use of sealed PVC windows

Table 5-6: Ideal and resilient repair strategies for flooded damaged utilities (adapted from Soetanto, Proverbs, Lamond & Samwinga, 2008)

Elements Damaged and Type of Damage	Ideal Repair Strategy Options	Resilient Strategy
A flood damaged property has steel panel radiators that have been in contact with floodwater	Replace the radiator and valves	Qualified engineers to inspect the valves and radiators before re-used.
A flood damaged property has a gas fired heater that has been in contact with floodwater	Replace the heater	Qualified engineers to inspect the heater before re-used.
A flood damaged property has a gas meter that has been in contact with floodwater	Replace the meter	Qualified engineers to inspect the gas meter before re-used. move the gas meter to at least 1m above the floor level or expected flood level
A flood damaged property has a wall-hung gas fire that has been in contact with floodwater	The fire be placed	Qualified engineers to inspect the fire before re-used.
The property has an electric circuit containing sockets that have been partially submerged by floodwater	Completely replace this installation	replace this installation and move to a higher level in the structure so that cables drop from first-floor level down to sockets
The dwelling has a wall-hung electric heater that has been submerged by floodwater	The heater be replaced	Qualified engineers to inspect the heater before re-used. Move at least 1m above floor level, depending on the predicted flood depth.
The dwelling has timber skirting boards	Replace all skirting boards	Replace skirting boards with more resilient materials such as ceramic tiles and PVC
The property has a staircase constructed from timber	Complete replacement of the stair caser	Use timber stair cases of solid timber construction.
The dwelling has built-in wall cupboards	Completely replace the cupboards	Consider repositioning cupboards above predicted future flood level. Use more resilient materials such as PVC.
The dwelling has a fitted kitchen that has been partially	Completely replace the kitchen	Replace kitchen with water resistant alternatives (PVC) or consider moving kitchen to first floor

5.4 REPAIR OPTIONS USED IN THE PROPOSED SYSTEM

The repair options used for the proposed system were identified based on the documents as the examples given in Table 2.5, and other sources used in the knowledge acquisition stage. The selected repair options are given below in the form of tables.

5.4.1 STANDARD REPAIR OPTIONS

The table below shows standard repair options used in, and recommended by, the system as standard repair options when the degree of vulnerability assessed is low to medium.

Table 5-7: Standard repair options for basement

Flood Damaged Element	Repair Strategies	Additional Information
Walls	1- replastering walls; do not use gypsum plasters 2- repairing floor screeds using dense cement/sand materials 3- positioning services in protected conduits, preferably at high level 4- replacing all damaged white goods and fittings	Refer to: BS 8102:1990 and BS 8000-4:1989

Table 5-8: Standard repair options for external walls (external finishes)

Flood Damaged Element	Repair Strategies	Additional Information
External finish: brickwork, facing blockwork and stonework	Pressure clean and make good pointing if required. **Issue to consider:** Pre-flooding condition of the materials and the pointing	**1- REPOINTING:** The main steps are as follows: • Rake out mortar joints to at least 20 mm depth into the wall and not less than twice the thickness of the joint. Any wide joints should be raked out to at least 38–50 mm, while preserving the stability of the masonry units above • clear dust and loose material from joints by air or clean water • thoroughly clean and wet joints before placing new mortar • Achieve maximum penetration of repair mortar so as to bond to the original bed - the finish to the pointing should match the original and the mortar should not extend beyond the face of the masonry. Refer to BS 8221-1:2000 and -2:2000 and Good Building Guide 24 (BRE, 1997b) for good practice guidance **2- MORTAR MIX:** Suitable mortar mixes include the following: • cement/sand-based (with additives such as plasticisers and retarders) • polymer-modified cement • hydrated lime: cement/sand-based • hydraulic lime: sand-based.

Continued: Table 5.8……………external walls (external finishes)

External finish: unpainted render, smooth, roughcast, pebbledash, Tyrolean	Pressure clean and make good pointing if required. The areas of the render that have become unbonded from the wall substrate should be replaced. **Issue to consider:** Pre-flooding condition of the render.	Refer to: 1- BS EN 13914-1:2005 Design, preparation and application of external rendering and internal plastering. For external rendering. 2- GBG18 Choosing external rendering (BRE, 1994). For render selection. 3- Digest 410 Cementitious renders for external walls (BRE, 1995). For application of renders. 4- GBG23 Assessing external renders for repair or replacement (BRE, 1997a) and GBG24 Repairing external render (BRE, 1997b). Identifying damage and deterioration of existing render finishes. 5- External rendering appearance matters (BCA, 1999).
External finish: painted finish - on various render backgrounds	Pressure clean- repaint if required. **Issues to consider:** 1. Aesthetics 2. Entrapped moisture beneath impervious coatings 3. Bonding	Refer to: 1. BS 6150:1991 Code of practice for painting of buildings; 2. BS EN 13914-1:2005 Design, preparation and application of external rendering and internal plastering. External rendering. 3. Report 352 (1998) BRE building elements: walls, windows and doors - performance, diagnosis, maintenance, repair and the avoidance of defects.
External finish: hanging tiles, mathematical tiles, cedar shingles, pre-finished panels, upvc cladding	Clean manually with low pressure hose and brush **Issues to consider:** 1. Substrate 2. Corrosion of fixings 3. Entrapped moisture	BS 5385-2:2006 Wall and floor tiling. Code of practice for the design and installation of external ceramic wall tiling and mosaics (including terracotta and faience tiles). 1. BS EN 13888:2009 Grout for tiles. Requirements, evaluation of conformity, classification and designation. 2. BS 6150:1991 Code of practice for painting of buildings.

Table 5-9: Standard repair options for external wall (structural elements)

Flood Damaged Element	Repair Strategies	Additional Information
Structural element: solid brickwork/stonework construction of various thicknesses	Controlled and monitored drying **Issue to consider:** Solid walls may suffer from pre-flood dampness and never achieve 'dry condition'	Where structural damage has occurred, for the reconstruction of the masonry in general use a mortar that is no stronger than designation (iii) according to BS 5628-3:2005, but check this against the strength required to maintain the structural integrity of the building. Fill the mortar joints (both horizontal and vertical) in accordance with the good practice guidelines set out in Report BR352 (BRE, 1998). Concrete blocks with a minimum strength of 7 N/mm² should be used for repair of blockwork. Refer to : BS 5628-3:2005 Code of practice for the use of masonry. Materials and components, design and workmanship
Structural element: cavity brick/blockwork construction of various thicknesses and materials	Controlled and monitored drying. **Issues to consider:** 1. Type of insulation within cavity. 2. Silt entry to cavity through airbricks	Refer to: 1. BS 5628-3:2005 Code of practice for the use of masonry. Materials and components, design and workmanship
Structural element: timber framed construction	Strip out internal finishes and insulation to facilitate controlled and monitored drying.	Achieve timber moisture content of less than 20% (to avoid dry rot) before replacing wall finishing; ensure readings are taken from depth, not the surfaces. Repair damaged cladding to prevent water ingress from driving rain.
Chalk/clay cob or mud walls	Allow to dry with natural ventilation **Issue to consider:** Submersion in floodwater can result in significant loss in strength or collapse	N/A

Continued: Table 5.9……………Standard repair options for external wall (structural elements)

Flood Damaged Element	Repair Strategies	Additional Information
Structural element: system built properties of PRC or steel frame construction	Use good quality treated timber to replace damaged structural timber components. Replace any damaged steel-frame components. **Issues to consider:** 1. Corrosion of metal components and fixings 2. Deterioration of insulation.	Refer to: BS 5268-2:2002 Structural use of timber. Code of practice for permissible stress design, materials and workmanship.

Table 5-10: Standard repair options for external walls (insulation)

Flood Damaged Element	Repair Strategies	Additional Information
Cavity brick/stone/block with uf foam or blown fibre insulation cavity filling Cavity brick/stone/block with closed cell foam or self-draining mineral wool batts cavity insulation Solid masonry with external insulation of self-draining mineral fibre batts or rigid plastic behind cladding	The three kinds of insulation must be treated differently: 1- Styrofoam might only need to be hosed off. 2- Fibreglass batts should be thrown out if muddy but may be reused if dried thoroughly. 3- Loose or blown-in cellulose should be replaced since it holds water for a long time and can lose its antifungal and fire retardant abilities. **Issue to consider:** Corrosion of wall ties and insulation fixings	BS 6232:Part 2:1982 Thermal insulation of cavity walls by filling with blown man-made mineral fibre. Code of practice for installation of blown man-made mineral fibre in cavity walls with masonry and/or concrete leaves. BS EN 13162:2008 Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification BS 6676:Part 1:1986 Thermal insulation of cavity walls using man-made mineral fibre batts (slabs). Specification for man-made mineral fibre batts (slabs).

Continued: Table 5.10 ……………………. Standard repair options for external walls (insulation)

Flood Damaged Element	Repair Strategies	Additional Information
Solid masonry with internal insulation behind plasterboard linings	Strip out plasterboard and remove insulation if of a water absorbent type. **Issues to consider:** 1. Corrosion of fixings 2. Existence of embedded timber grounded in masonry	BS EN 13162:2008 Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification BS 6676:Part 1:1986 Thermal insulation of cavity walls using man-made mineral fibre batts (slabs). Specification for man-made mineral fibre batts (slabs).
Timber frame walls with mineral wool or other insulation	Remove internal linings and insulation to facilitate controlled and monitored drying of timber frame. **Issues to consider:** 1. Corrosion of fixings 2. Existence of embedded timber grounded in masonry	BS EN 13162:2008 Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification

Table 5-11: Standard repair options for internal walls and partitions

Flood Damaged Element	Repair Strategies	Additional Information
Gypsum plaster applied directly to masonry background	Remove plaster to 500mm above flood line **Issues to consider:** 1. Visible joint between new and old plaster 2. Bonding of old plaster.	**Specification**. The following standards apply to plasterwork: • PD CEN/TR 15123:2005 Design, preparation and application of internal polymer plastering systems. • Report BR352 (BRE, 1998) can be used for general advice on internal walls. • Bonding coats or stipple-coats may be required on dense concrete or concrete blocks. • Some suction (by masonry units on the fresh plaster) is required to achieve a good bond, but this should not be excessive otherwise too much water will be lost from the mix. High-suction surfaces can be wetted with care before plastering to reduce the degree of suction. For lightweight aerated concrete blocks, a bonding agent can aid the plastering process. • BS 8000-10:1995 is the code of practice for workmanship on building sites for plastering and rendering. It sets out good practice that should be followed in the application of plasters. If the masonry surface is likely to remain damp or salts appear from drying then plastering work may need to be delayed until the masonry is dry and/or efflorescence has stopped. A cement/sand mix of 1:5, with waterproofing additives, can be used quite successfully on poor masonry backgrounds. • BS EN 998-1:2003 provides the specification for mortar for masonry including both rendering and plastering mortars. It gives a further choice of materials for mortar mixes. • BS EN 13279-1:2008 Gypsum binders and gypsum plasters. Definitions and requirements

Continued: Table 5.11 ………………Standard repair options for internal walls and partitions

Flood Damaged Element	Repair Strategies	Additional Information
Lime based plaster on a cement/sand rendered background over masonry	Controlled and monitored drying following removal of affected decorative finishes **Issue to consider:** Loss of bonding	PD CEN/TR 15123:2005 Design, preparation and application of internal polymer plastering systems.
Plasterboard on adhesive dabs applied to masonry or fixed to timber studwork	Remove affected plasterboard **Issues to consider:** 1. Visible joint between new and old plasterboard; 2. Continuity of vapour barrier on timber frame where removal is partial.	09/30185974 DC EN 520:2004/prA1:2009 BS EN 520 AMD1. Gypsum plasterboards. Definitions, requirements and test methods
Timber strip, sheet of veneer panelling	Remove and replace	
Ceramic tiles on cement/sand rendered background over masonry	Wash off and re-grout if required with a water resistant grout. Loose tiles to be replaced. **Issues to consider:** 1. Substrate 2. Insulation 3. Services 4. Integrity where removal is partial.	BS 5385-1:2009 Wall and floor tiling. Design and installation of ceramic, natural stone and mosaic wall tiling in normal internal conditions. Code of practice BS 5385-2:2006 Wall and floor tiling. Design and installation of external ceramic and mosaic wall tiling in normal conditions. Code of practice 09/30207407 DC BS ISO 13007-3. Ceramic tiles. Grouts and adhesives. Part 3. Definitions and specifications for grouts BS 5385-4:2009 Wall and floor tiling. Design and installation of ceramic and mosaic tiling in special conditions. Code of practice

Continued: Table 5.11 ……………….Standard repair options for internal walls and partitions

Flood Damaged Element	Repair Strategies	Additional Information
Paint finish, emulsion, eggshell or gloss	Wash down and remove loose and flaking finish. Repaint. **Issue to consider:** Entrapped moisture beneath certain impervious finishes	BS 6150:2006 Painting of buildings. Code of practice BS EN 13300:2001 Paints and varnishes. Water-borne coating materials and coating systems for interior walls and ceilings. Classification
Wallpaper	Remove and replace when new plaster is thoroughly dry. **Issue to consider:** Temporary microporous paint finish could allow plaster to dry before re-papering	BS EN 233:1999 Wall coverings in roll form. Specification for finished wallpapers, wall vinyls and plastic wall coverings
Timber stud partition with plasterboard	Controlled and monitored drying following removal of affected decorative finishes **Issue to consider:** Condition of timbers or other works may make replacement more economic.	Seal the junctions between walls and partitions and floors using good-quality sealants. Remove skirting board before the seals are applied and then replace. Use sealants appropriate for the purpose and of proven quality (specified to the requirements of BS 6213:2000). BS 5268-6.2:2001 Structural use of timber. Code of practice for timber frame walls. Buildings other than dwellings not exceeding four storeys 09/30185974 DC EN 520:2004/prA1:2009 BS EN 520 AMD1. Gypsum plasterboards. Definitions, requirements and test methods

Continued: Table 5.11 ………………Standard repair options for internal walls and partitions

Flood Damaged Element	Repair Strategies	Additional Information
Timber stud partition with lath and plaster or lime and horsehair plaster.	Controlled and monitored drying of timber. Replace laths with plasterboard. **Issue to consider:** Condition of timbers or other works may make replacement more economic.	Seal the junctions between walls and partitions and floors using good-quality sealants. Remove skirting board before the seals are applied and then replace. Use sealants appropriate for the purpose and of proven quality (specified to the requirements of BS 6213:2000). BS EN 15824:2009 Specifications for external renders and internal plasters based on organic binders BS EN 13279-1:2008 Gypsum binders and gypsum plasters. Definitions and requirements BS 8481:2006 Design, preparation and application of internal gypsum, cement, cement and lime plastering systems. Specification.
Masonry walls with gypsum plaster finish	Remove plaster to 500mm above floodline. Controlled and monitored drying. **Issues to consider:** 1. Visible joint between new and old plaster 2. Bonding of old plaster	Seal the junctions between walls and partitions and floors using good-quality sealants. Remove skirting board before the seals are applied and then replace. Use sealants appropriate for the purpose and of proven quality (specified to the requirements of BS 6213:2000). BS 5628-1:2005 Code of practice for the use of masonry. Structural use of unreinforced masonry BS 8481:2006 Design, preparation and application of internal gypsum, cement, cement and lime plastering systems. Specification BS EN 13279-1:2008 Gypsum binders and gypsum plasters. Definitions and requirements

Continued: Table 5.11 ………………Standard repair options for internal walls and partitions

Flood Damaged Element	Repair Strategies	Additional Information
Masonry walls with lime based plaster finish on cement and sand render.	Controlled and monitored drying following removal of affected decorative finishes. Use water resistant render and lime based plaster or hydraulic lime coatings. **Issue to consider:** Loss of bonding	Seal the junctions between walls and partitions and floors using good-quality sealants. Remove skirting board before the seals are applied and then replace. Use sealants appropriate for the purpose and of proven quality (specified to the requirements of BS 6213:2000). BS EN 13914-2:2005 Design, preparation and application of external rendering and internal plastering. Design considerations and essential principles for internal plastering PD CEN/TR 15123:2005 Design, preparation and application of internal polymer plastering systems BS 8481:2006 Design, preparation and application of internal gypsum, cement, cement and lime plastering systems. Specification
Metal framed partitions with plasterboard sheets or faced gypsum panels	Replace plasterboard or gypsum panels. **Issue to consider:** Corrosion of metal frame and fixings.	Seal the junctions between walls and partitions and floors using good-quality sealants. Remove skirting board before the seals are applied and then replace. Use sealants appropriate for the purpose and of proven quality (specified to the requirements of BS 6213:2000). BS 7364:1990 Specification for galvanized steel studs and channels for stud and sheet partitions and linings using screw fixed gypsum wallboards

Table 5-12: Standard repair options for floors

Flood Damaged Element	Repair Strategies	Additional Information
Vinyl floor tiles	Clean or replace **Issues to consider:** 1. Substrate 2. Duration of flooding 3. Type of floodwater 4. Aesthetics 5. Some vinyl tiles, tile backing and adhesive installed prior to the mid-1970s may contain dangerous asbestos.	09/30179615 DC BS ISO 10595. Resilient floor coverings. Semi-flexible/vinyl composition (VCT) poly (vinyl chloride) floor tiles. Specification
Sheet vinyl floor covering	Clean or replace **Issues to consider:** 1.Substrate 2. Duration of flooding 3. Type of floodwater 4. Aesthetics	09/30179608 DC BS ISO 10582. Resilient floor coverings. Heterogeneous poly (vinyl chloride) floor coverings. Specification
Quarry tiles	Clean or replace **Issues to consider:** 1. Substrate 2. Duration of flooding 3. Type of floodwater 4. Aesthetics	BS 5385-3:2007 Wall and floor tiling. Design and installation of internal and external ceramic floor tiles and mosaics in normal conditions. Code of practice BS EN 13888:2009 Grout for tiles. Requirements, evaluation of conformity, classification and designation

Continued: Table 5.12 ……………….. Standard repair options for floors

Flood Damaged Element	Repair Strategies	Additional Information
Solid concrete floor	Clean and monitor drying **Issues to consider:** 1. Substrate 2. Insulation 3. Services 4. Integrity	If the floor screed is found to be damaged then it either needs to be replaced or repaired. The options are: 1- Any crack through which liquid water can penetrate to be filled or repaired. Use good-quality sealant or proprietary repair materials. Where deterioration of the surface has also occurred, cut out the affected area and repair with a proprietary material. 2- In instances where there is damage or deterioration over one area (as a guide, less than 20 per cent of the total floor area) of the screed, cut out the affected area and repair with a proprietary system. 3- Where there is damage to the screed in more than one area or over more than 20 per cent of the floor area in any room, the damaged screed should be changed for a proprietary dense cement/sand screed. Drying times vary between eight weeks for a 50mm screed to 12 weeks for a 75mm screed. BR332 (BRE, 1997d), Digest 163 (BRE, 1974) and Digest 364 (BRE, 1991).
Suspended timber floor with chipboard	Recommend replacement of all floorboards. If the sleeper walls are constructed directly on the ground, it is recommended that a damp proof course (dpc) layer be installed in the present sleeper wall. **Issue to consider:** Controlled and monitored drying of structural timbers	BS 8103:Part 3:1996 Structural design of low-rise buildings. Code of practice for timber floors and roofs for housing.

Continued: Table 5.12 ……………….. Standard repair options for floors

Flood Damaged Element	Repair Strategies	Additional Information
Suspended timber floor with softwood tongue and groove floorboards	Clean or replace floorboards if damaged. Controlled and monitored drying of structural timbers.	BS EN 13990:2004 Wood flooring. Solid softwood floorboards
Oak blocks set in bitumen on solid concrete floor slab	Replace all floor covering (i.e. the oak blocks)	BS 8201:1987 Code of practice for flooring of timber, timber products and wood based panel products
Modern 'thin section' hardwood block or wood strip floors including parquet	Replace or repair **Issues to consider:** 1. Substrate 2. Entrapped moisture 3. Type of floodwater 4. Aesthetics.	BS 8201:1987 Code of practice for flooring of timber, timber products and wood based panel products
Suspended concrete floor of beams and hollow blocks	Clean and monitor drying	BS 8201:1987 Code of practice for flooring of timber, timber products and wood based panel products

Table 5-13: Standard repair for joinery and fittings

Flood Damaged Element	Repair Strategies	Additional Information
Painted softwood or treated hardwood external door	Clean and repaint or replace if warped. **Issue to consider:** Consider cost of replacement against salvage where of modest standard	Use microporous paint systems to allow timbers to dry without warping. BS 4787:Part 1:1980 Internal and external wood doorsets, door leaves and frames. Specification for dimensional requirements BS EN 14220:2006 Timber and wood-based materials in external windows, external door leaves and external doorframes. Requirements and specifications
Double glazed hardwood patio doors or window units	Clean and allow drying out before assessing damage. Replace glazing units only if seals have failed. **Issue to consider:** Corrosion of fixings, runners and ironmongery	Use microporous paint systems to allow timbers to dry without warping. BS 4787:Part 1:1980 Internal and external wood doorsets, door leaves and frames. Specification for dimensional requirements BS EN 14220:2006 Timber and wood-based materials in external windows, external door leaves and external doorframes. Requirements and specifications
Double glazed uPVC patio doors or window units	Clean and replace glazing units only if seals have failed. **Issue to consider:** Corrosion of fixings, runners and ironmongery	BS 7412:2007 Specification for windows and doorsets made from unplasticized polyvinyl chloride (PVC-U) extruded hollow profiles
UPVC external door	Clean and replace glazing units only if seals have failed. **Issue to consider:** Corrosion of fixings, runners and ironmongery	BS 7412:2007 Specification for windows and doorsets made from unplasticized polyvinyl chloride (PVC-U) extruded hollow profiles. BS EN 12608:2003 Unplasticized polyvinyl chloride (PVC-U) profiles for the fabrication of windows and doors. Classification, requirements and test methods

Continued: Table 5.13 ……………….. Standard repair for joinery and fittings

Flood Damaged Element	Repair Strategies	Additional Information
Wooden window frames submerged by floodwater	Clean and allow drying out before assessing damage. Replace double glazed units only if seals have failed. **Issue to consider:** Pre-flood condition of windows.	Use microporous paint systems to allow timbers to dry without warping. BS 4787:Part 1:1980 Internal and external wood door sets, door leaves and frames. Specification for dimensional requirements BS EN 14220:2006 Timber and wood-based materials in external windows, external door leaves and external doorframes. Requirements and specifications.
Cellular type internal doors	Replace	N/A
Timber staircase of softwood or hardwood submerged by floodwater	Clean and allow to dry out before assessing damage. Repair with strengthening to treads or replace. **Issues to consider:** 1. Shrinkage of glue blocks may cause squeaking when dried out 2. Some stairs may have MDF treads and risers	Use microporous paint systems to allow timbers to dry without warping.
Patio doors or window units—double-glazed uPVC	Remove dirt and residue, and replace glazing units if seals are found to have failed. **Issue to consider:** Corrosion of fixings, ironmongery and runners.	BS EN 12608:2003 Unplasticized polyvinyl chloride (PVC-U) profiles for the fabrication of windows and doors. Classification, requirements and test methods
UPVC external door	Remove dirt and residue, and replace glazing units if seals are found to have failed. **Issue to consider:** Corrosion of fixings.	BS EN 12608:2003 Unplasticized polyvinyl chloride (PVC-U) profiles for the fabrication of windows and doors. Classification, requirements and test methods

Continued: Table 5.13 ……………….. Standard repair for joinery and fittings

Flood Damaged Element	Repair Strategies	Additional Information
Wooden window frames submerged with floodwater	Remove dirt and residue, and allow to dry before establishing the level of damage. Replace double glazed units only if the seals are found to have failed. **Issue to consider:** Pre-flood condition of windows.	Use microporous paint systems to allow timbers to dry without warping. **BS 4787:Part 1:1980** Internal and external wood door sets, door leaves and frames. Specification for dimensional requirements
Built-in wardrobes and cupboards submerged by floodwater	Replace	N/A
Fitted kitchen units submerged by floodwater	Unless of solid hardwood and high quality, remove and replace	Use microporous paint systems to allow timbers to dry without warping.
Skirtings, door linings, architraves and trims of MDF or small section softwood	Replace	
Skirtings, door linings, architraves and trims of large section softwood or hardwood	Controlled and monitored drying, remove paint finish, prime and redecorate. **Issue to consider:** Joinery might require removal	Use microporous paint systems to allow timbers to dry without warping.

Table 5-14: Standard repair for services (electric)

Flood Damaged Element	Repair Strategies	Additional Information
Electrical installation comprising pvc sheathed cables, sockets, switches and fuse boards submerged by floodwater	Seek immediate advice from a qualified electrician. Presumption for replacing all components that have been in contact with floodwater. **Issues to consider:** 1. Remaining installation may not comply with current regulations and may be condemned. 2. Moisture may affect other components.	N/A
Fixed electrical appliances submerged by floodwater	Replace	N/A
Electrical metering equipment that has been in contact with floodwater	Immediately contact electricity supply authority	N/A

Table 5-15: Standard repair for services (gas installation)

Flood Damaged Element	Repair Strategies	Additional Information
Gas service pipes and apparatus that have been in contact with floodwater	Immediately contact gas supply authority and act upon their advice	
Gas wall-hung or floor mounted fire submerged by floodwater	Replace	

Table 5-16: Standard repair for services (central heating—wet system)

Flood Damaged Element	Repair Strategies	Additional Information
Steel panel radiators that have been in contact with floodwater	Clean and repaint the radiators	
Pipework and apparatus that has been in contact with floodwater	Clean and sanitise. Replace any electrical components of motorised valves or controls. Replace insulation	
Floor or wall mounted boiler that has been submerged by floodwater	Replace.	

Table 5-17: Standard repair for sanitary ware

Flood Damaged Element	Repair Strategies	Additional Information
Vitreous china sanitary ware submerged by floodwater.	Clean and sanitise. **Issue to consider:** May need removal to facilitate other works, salvage may be uneconomic	
Bath of pressed steel, cast iron or plastic submerged by floodwater	Clean and sanitise. **Issues to consider:** 1. Removal to facilitate other works, salvage and storage may be uneconomic. 2. Plastic bath may have chipboard frame.	BS 1189:1986 Specification for baths made from porcelain enamelled cast iron
Vanity unit in MDF or chipboard base unit	Replace	

Table 5-18: Standard repair for drainage

Flood Damaged Element	Repair Strategies	Additional Information
Underground drains and sewers that have backed up with floodwater	Flush through to remove debris and silt. CCTV survey if blockages encountered. **Issues to consider:** 1. Pre-flood condition of drainage/sewer	BS EN 1610:1998 Construction and testing of drains and sewers BS EN 752:2008 Drain and sewer systems outside buildings

Table 5-19: Resilient repair options for basement

Flood Damage Element	Repair Strategy
Basement	1- when replastering walls do not use gypsum plasters 2- repair floor screeds using dense cement/sand materials 3- position services in protected conduits, preferably at high level 4- replace all damaged white goods and fittings. Walls can be 'tanked' externally both underground and normally up to a height of 1 metre above ground level. Refer to: BS 8102:1990 and BS 8000-4:1989. Facilities for pumping out basements. Three types of sump pump are commonly used. 1- Pedestal. This type of electric pump stands upright, with a motor a few feet above the pump, which is designed to get wet. It has a float-activated switch that turns the pump on when the water reaches a certain level. 2- Submersible. A submersible electric pump is installed underground and is designed to work underwater. It has the same float-activated switch as the pedestal pump. While more expensive than the pedestal type, it is quieter and tends to have a longer life because its sealed, oil-cooled motor is protected from moisture and dust. 3- Water-powered. This type of pump runs off the water pressure of the home plumbing system and also has the same float-activated switch as the two types above. It handles water at a much slower rate than the electric types, but requires no electricity to operate it. A water-powered pump can be installed alongside an electric pump and is generally used as a back-up system during a power failure.

Table 5-20: Resilient repair options for external walls (external finishes)

Flood Damaged Element	Resilient Repair Strategies
External finish: brickwork, facing blockwork and stonework	N/A
External finish: unpainted render, smooth, roughcast, pebbledash, Tyrolean	N/A
External finish: painted finish - on various render backgrounds	Pressure clean- repaint if required using a microporous coating **Issues to consider:** 1. Aesthetics 2. Entrapped moisture beneath impervious coatings. 3. Bonding
External finish: hanging tiles, mathematical tiles, cedar shingles, pre-finished panels, upvc cladding	N/A

Table 5-21: Resilient repair options for external walls (structural elements)

Flood Damaged Element	Repair Strategies
Structural element: solid brickwork/stonework construction of various thicknesses	Controlled and monitored drying. Consider using water resistant coatings externally to 500mm above the flood line **Issue to consider:** Solid walls may need long time to dry above flood line
Structural element: cavity brick/blockwork construction of various thicknesses and materials	Controlled and monitored drying. Ensure airbricks are sleeved and cavity fully sealed where services penetrate. **Issues to consider:** 1. Type of insulation within cavity. 2. Silt entry to cavity through airbricks
Structural element: timber framed construction	Reconstruct using traditional materials and methods.
Chalk/clay cob or mud walls	Reconstruct using traditional materials and methods, subject to controls.
Structural element: system built properties of PRC or steel frame construction	1. Use specialist moisture-repelling coatings. 2. Self-draining insulation

Table 5-22: Resilient repair options form external walls (insulation)

Flood Damaged Element	Repair Strategies
Cavity brick/stone/block with uf or blown fibre insulation cavity filling	Use closed cell insulation foam
Cavity brick/stone/block with closed cell foam or self-draining mineral wool batts cavity insulation Solid masonry with external insulation of self-draining mineral fibre batts or rigid plastic behind cladding	Use stainless steel ties and fixings
Solid masonry with internal insulation behind plasterboard linings	1. Use stainless steel fixings. 2. Use low absorption insulating boards or semi-rigid self-draining mineral wool batts
Timber frame walls with mineral wool or other insulation	N/A

Table 5-23: Resilient repair options for internal walls and partitions

Flood Damaged Element	Resilient Repair Strategies
Gypsum plaster directly applied to masonry background	Remove plaster to 500mm above flood-line. Use water resistant render and lime based plaster or hydraulic lime coatings.
Lime based plaster on a cement/sand rendered background over masonry	1- Controlled and monitored drying following removal of affected decorative finishes. Use water resistant render and lime based plaster or hydraulic lime coatings. 2- An alternative to a plaster finish is to change to a tiled finish. Waterproof adhesive should be used.

Table 5-24: Resilient repair options for internal walls and partitions

Flood Damaged Element	Resilient Repair Strategies
Plasterboard on adhesive dabs applied to masonry or fixed to timber studwork	Remove affected plasterboard. Fix boards horizontally where re-flooding likely to allow for easier partial replacement. Not suitable for timber frame. **Issues to consider:** 1. Visible joint between new and old plasterboard 2. Continuity of vapour barrier on timber frame where removal is partial
Timber strip, sheet of veneer panelling	Remove and replace
Ceramic tiles on cement/sand rendered background over masonry	1. Wash off and re-grout 2. Loose tiles to be replaced using waterproof adhesives and grout **Issues to consider:** 1. Substrate 2. Insulation 3. Services 4. Integrity where removal is partial

Continued: Table 5.24 ………………... Resilient repair options for internal walls and partitions

Flood Damaged Element	Resilient Repair Strategies
Paint finish, emulsion, eggshell or gloss	Wash down and remove loose and flaking finish. Repaint using microporous paints. **Issue to consider:** Entrapped moisture beneath certain impervious finishes
Wallpaper	Remove and replace when new plaster is thoroughly dry. Avoid use of vinyl wall coverings. **Issue to consider:** Temporary microporous paint finish could allow plaster to dry before re-papering
Timber stud partition with plasterboard	Controlled and monitored drying following removal of affected decorative finishes. Use preservative impregnated timbers and fix plasterboard sheets horizontally. Use cement based boards. **Issue to consider:** Condition of timbers or other works may make replacement more economic.
Timber stud partition with lath and plaster or lime and horsehair plaster.	Controlled and monitored drying of timber. Replace laths with plasterboard. Use preservative impregnated timbers and fix plasterboard sheets horizontally. **Issue to consider:** Condition of timbers or other works may make replacement more economic.
Masonry walls with gypsum plaster finish	Remove plaster to 500mm above flood-line using water resistant render and lime based plaster or hydraulic lime coatings. **Issues to consider:** 1. Visible joint between new and old plaster 2. Bonding of old plaster
Masonry walls with lime based plaster finish on cement and sand render	Use water resistant render and lime based plaster or hydraulic lime coatings **Issue to consider:** Loss of bonding
Metal framed partitions with plasterboard sheets or faced gypsum panels	NA

Table 5-25: Resilient repair options for floors

Flood Damaged Element	Resilient Repair Strategies
Vinyl floor tiles	N/A
Sheet vinyl floor covering	N/A
Quarry tiles	N/A
Solid concrete floor	Clean and monitor drying. Use denser proprietary concrete screed. Dense cement/sand of proportion between 1:3 and 1:4.5 (by weight). ***OR*** Raise floor levels above the most likely flood level. In general, this is only applicable when floodwaters do not rise much above the existing floor level and where the ceiling height can accommodate it. Consider relocating services
Suspended timber floor with chipboard	Replace chipboard flooring with treated timber floorboards ***OR*** Replace with solid floor. Consider raising floor levels above the most likely flood level.

Continued: Table 5-25 ……………………. Resilient repair options for floors

Flood Damaged Element	Resilient Repair Strategies
Suspended timber floor with softwood tongue and groove floorboards	Replace timber wall plates with corrosion-resistant steel alternatives. Chipboard could be replaced by treated softwood tongue and groove boards. ***OR*** Replace with solid floor. Consider raising floor levels above the most likely flood level.
Suspended timber floor with softwood tongue and groove floorboards	Replace timber wall plates with corrosion-resistant steel alternatives. Chipboard could be replaced by treated softwood tongue and groove boards. ***OR*** Replace with solid floor. Consider raising floor levels above the most likely flood level. In general, this is only applicable when floodwaters do not rise much above the existing floor level and where the ceiling height can accommodate it.
Oak blocks set in bitumen on solid concrete floor slab	Replace blocks with screed and floor finish, e.g. carpet. ***OR*** Raise floor levels above the most likely flood level. In general, this is only applicable when floodwaters do not rise much above the existing floor level and where the ceiling height can accommodate it.

Continued: Table 5-25 ……………………. Resilient repair options for floors

Flood Damaged Element	Resilient Repair Strategies
Modern 'thin section' hardwood block or wood strip floors including parquet	Replace with screed if on concrete floor and covered. ***OR*** Raise floor levels above the most likely flood level. In general, this is only applicable when floodwaters do not rise much above the existing floor level and where the ceiling height can accommodate it.
Suspended concrete floor of beams and hollow blocks	Clean and monitor drying. Consider relocating services ***OR*** Raise floor levels above the most likely flood level. In general, this is only applicable when floodwaters do not rise much above the existing floor level and where the ceiling height can accommodate it. Consider relocating services.

Table 5-26: Resilient repair options for joinery and fittings

Flood Damaged Element	Resilient Repair Strategies
Painted softwood or treated hardwood external door	Replace with uPVC unit
Double glazed hardwood patio doors or window units	Replace with uPVC units
Double glazed uPVC patio doors or window units	Select units with stainless steel fittings and ironmongery
UPVC external door	Select units with stainless steel fittings and ironmongery
Wooden window frames submerged by floodwater	Replace with uPVC units
Cellular type internal doors	N/A

Continued: Table 5-26 ……………………..Resilient repair options for joinery and fittings

Flood Damaged Element	Resilient Repair Strategies
Timber staircase of softwood or hardwood submerged by floodwater	Use timber staircases of solid timber construction below flood line
Built-in wardrobes and cupboards submerged by floodwater	Build off floor with plastic legs concealed behind a removable plinth. uPVC units
Fitted kitchen units submerged by floodwater	Specify the least expensive kitchen units possible and expect to replace them after a flood ***OR*** Build off floor with plastic legs concealed behind a removable plinth. uPVC units. Consider moving washing machine to first floor. Replace ovens with raised, built-under type.
Skirtings, door linings, architraves and trims of MDF or small section softwood	Use hardwood or uPVC
Skirtings, door linings, architraves and trims of large section softwood or hardwood	N/A

Table 5-27: Resilient repair options for services (electric)

Flood Damaged Element	Repair Strategies
Electrical installation comprising pvc sheathed cables, sockets, switches and fuse boards submerged by floodwater	Seek immediate advice from a qualified electrician. Consider raising sockets and routing cables above flood line
Fixed electrical appliances submerged by floodwater	N/A
Electrical metering equipment that has been in contact with floodwater	Consider repositioning equipment above flood line

Table 5-28: Resilient repair options for services (gas installation)

Flood Damaged Element	Repair Strategies
Gas service pipes and apparatus that have been in contact with floodwater	Immediately contact gas supply authority and act upon their advice. Consider repositioning equipment above flood line.
Gas wall-hung or floor mounted fire	Replace. Consider repositioning equipment above flood line.

Table 5-29: Resilient repair options for services (central heating—wet system)

Flood Damaged Element	Repair Strategies
Steel panel radiators that have been in contact with floodwater	N/A
Pipework and apparatus that has been in contact with floodwater	N/A
Floor or wall-mounted boiler that has been submerged by floodwater	Replace. Consider repositioning boiler above flood line line

Table 5-30: Resilient repair options for sanitary ware

Flood Damaged Element	Repair Strategies
Vitreous china sanitary ware submerged by floodwater.	N/A
Bath of pressed steel, cast iron or plastic submerged by floodwater	Replace baths that have chipboard stiffening panels with cast iron or pressed steel models.
Vanity unit in MDF or chipboard base unit	Replace with plastic unit

Table 5-31: Resilient repair options for drainage

Flood Damaged Element	Repair Strategies
Underground drains and sewers that have backed up with floodwater	Install backflow (non-return) valve.

5.5 SUMMARY

This chapter discussed the method used for knowledge acquisition and the results of surveys carried out used to investigate the factors contribute to vulnerability of residential building to flood damage. Also, state the repair options based on the documents that provide technical information for this purpose summarized in the form of tables and charts. Finally, given the standard and resilient repair options that used by the prototype system which produced during the knowledge acquisition stage. The next chapter will discuss the development and operation of the prototype system.

CHAPTER 6 DEVELOPMENT AND OPERATION OF THE PROTOTYPE SYSTEM

6.1 INTRODUCTION

This chapter begins by providing a review of the prototype system's functions and architecture. It then goes on to describe in detail the process of developing the prototype system. The operation of the system is also demonstrated, with its main features highlighted.

6.2 DEGREE OF VULNERABILITY AND REMEDIATION ASSESSMENT OF FLOODED RESIDENTIAL BUILDING SYSTEM (VRAFRBS)

6.2.1 THE FUNCTIONS OF THE SYSTEM

The prototype knowledge base system named 'Vulnerability and Remediation Assessment of Flooded Residential Building System (VRAFRBS)' are aimed at helping some of the stakeholders involved in the remediation of residential buildings subjected to flood damage—especially insurance companies, flood remediation contractors and engineers. The main functions to be providing by the system are:

- To assess and evaluate the vulnerability of residential buildings subjected to flood damage;
- To help in damage assessment of building foundations and gives guides to damage repair;

- To help in the selection of repair methods and procedures of remediation of each building elements damaged by flood;
- To suggest resilience repair methods and material could be used in the remediation of residential building damaged by flood where it is applicable; and
- To help in establish a basic for flooded residential building risk assessment and repair.

6.2.2 THE SYSTEM ARCHITECTURE

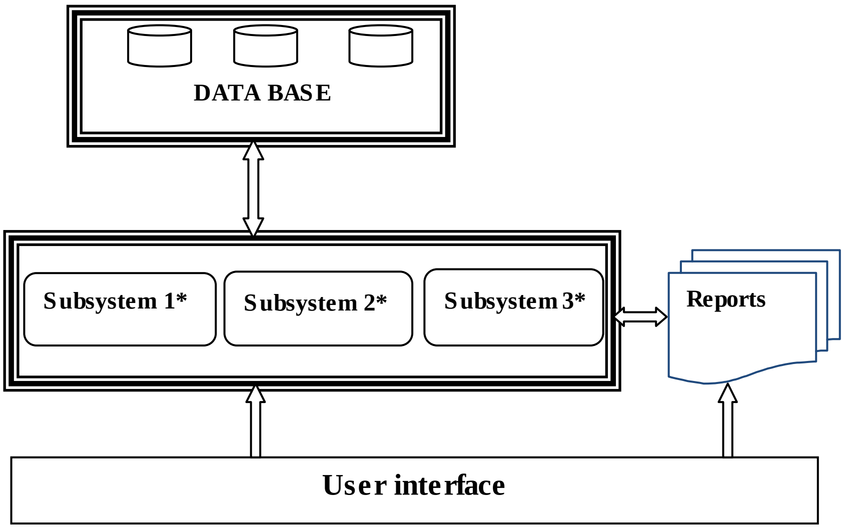
The system consists of five main modules:

- **Vulnerability assessment**: This module is responsible for accepting users' input regarding the case of study as well as users' answers in response to a predefined set of questions to help the system in evaluating the degree of vulnerability. Applying the user response to those questions, using its logical algorithm, the module will evaluate the case and indicate its degree of vulnerability, and accordingly save the case details and the assessment result in the database.
- **Remediation option selection**: The function of this module is to suggest the user the repair option to repair the damaged element to the case in hand according to its degree of vulnerability, this module fetches the information from the database each and every time the user is working on any particular case.
- **Foundation damage assessment**: This subsystem is used to assess the damage caused by flood, and suggest repair options for different situations.
- **Reports**: This module is utilising Crystal Reports engine to publish different reports from the database to the user, this reports are very useful for the user to

review all the cases and give the user the ability to print or export this reports in different types of format.

- **Database**: Using Microsoft access database, the system is able to store its information in the data table and access them for later use.

The general architecture of the prototype system is shown in Figure 6.1.



***Subsystem 1: Vulnerability assessment subsystem.**
***Subsystem 2: Remediation options selection subsystem**
***Subsystem 3: Foundations damage assessment and remediation subsystem**

Figure 6-1: The modular architecture of the prototype system

6.2.3 SYSTEM DEVELOPMENT

6.2.3.1 Building the VRAFRBS

Since the system is targeted for use in the assessment and repair of flooded and damaged buildings, and owing to the fact that most of the users will be site-based staff, practicality and transportability are important. Hence, this prototype system was developed using Microsoft Visual Studio, written in VB.NET, with dependence on Microsoft Access to store its data. This makes it ideal for running on any Microsoft operating system, which is both user-friendly and widely used.

In this research, the rapid prototyping methodology has been implemented in order to develop the prototype system. The rapid prototyping is a strategy used in system developing were preliminary system is developed in a short time, tested and accordingly improved in several repeated until the final model is ready (see Chapter 2, Section 2.3.2 for more details).

6.2.3.2 System design

The prototype knowledge base system comprises three subsystems: the Degree of vulnerability assessment, Remediation options, and Foundation damage assessment, as shown in Figure 6.2 and Figure 6.3. With this in mind, the degree of vulnerability assessment subsystem is used to determine the degree of vulnerability of the building subjected to flood damage in relation to a number of factors contributing to flood damage. The remediation options subsystem introduces the remediation options for repairing different building elements; the procedure is either through using the remediation selection subsystem directly, or is otherwise based on the degree of vulnerability calculated in the vulnerability assessment subsystem. Finally, the foundation damage assessment subsystem is applied with the aim of assessing the foundation damage caused by flooding, and accordingly gives guidance which facilitates the establishment of repair strategies. The subsystems will be discussed in the following sections.

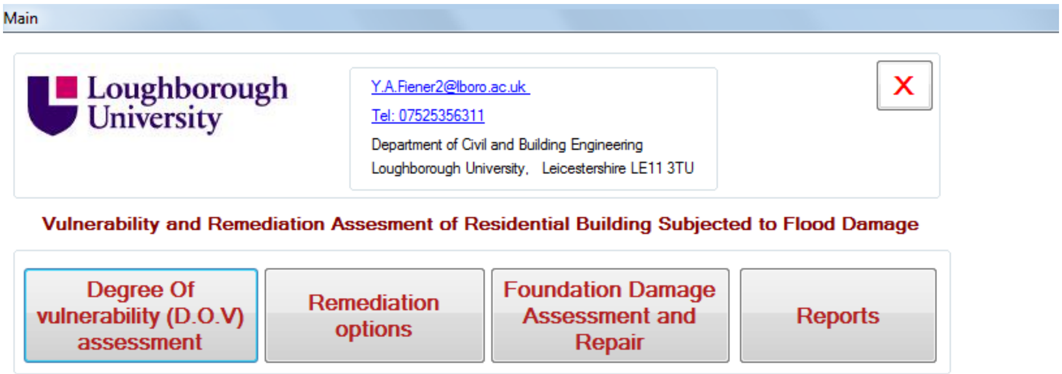


Figure 6-2: The main screen of the prototype system

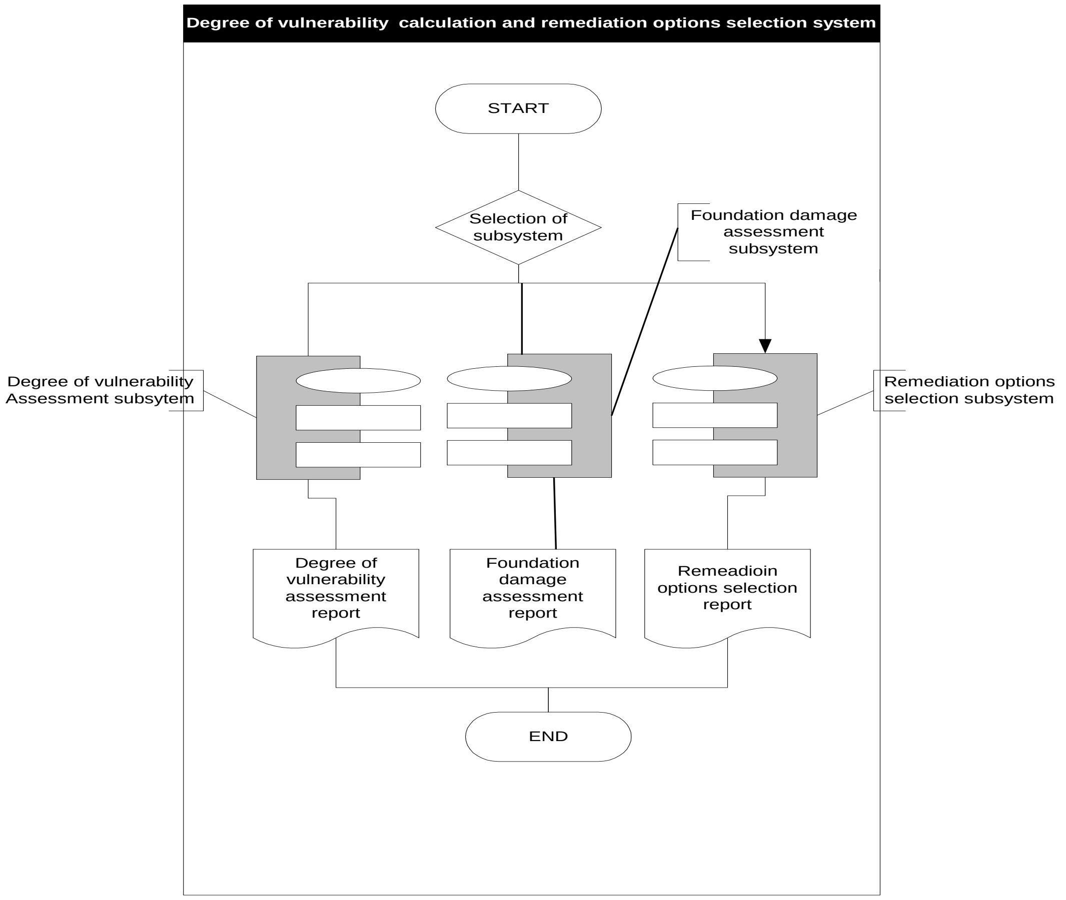


Figure 6-3: The operation flowchart of the prototype system

6.2.3.2.1 The degree of vulnerability assessment subsystem

The flowchart shown in Figure 6.4 highlights the steps of vulnerability assessment which is a part (subsystem) of the entire developed prototype system which calculates the degree of vulnerability of the building for flood damage.

The degree of vulnerability calculated is based on Equation 3.1 given in Chapter 3, Section 3.3.2.2.

Degree of Vulnerability (DOV) = SUM (weightings of factors in Group One) + (weightings of factors in Group Two) ....Equation 3.1

This degree of vulnerability is represented by how the buildings are vulnerable to damage by flooding. The factors assigned are either related to the building itself (such as in the case of building location), which makes the building more vulnerable to flooding, or otherwise related to the building material, which will subsequently increase the amount of damage and the cost of repair. This makes the degree of vulnerability calculated represent the susceptibility of building to flood damage and the cost of repair.

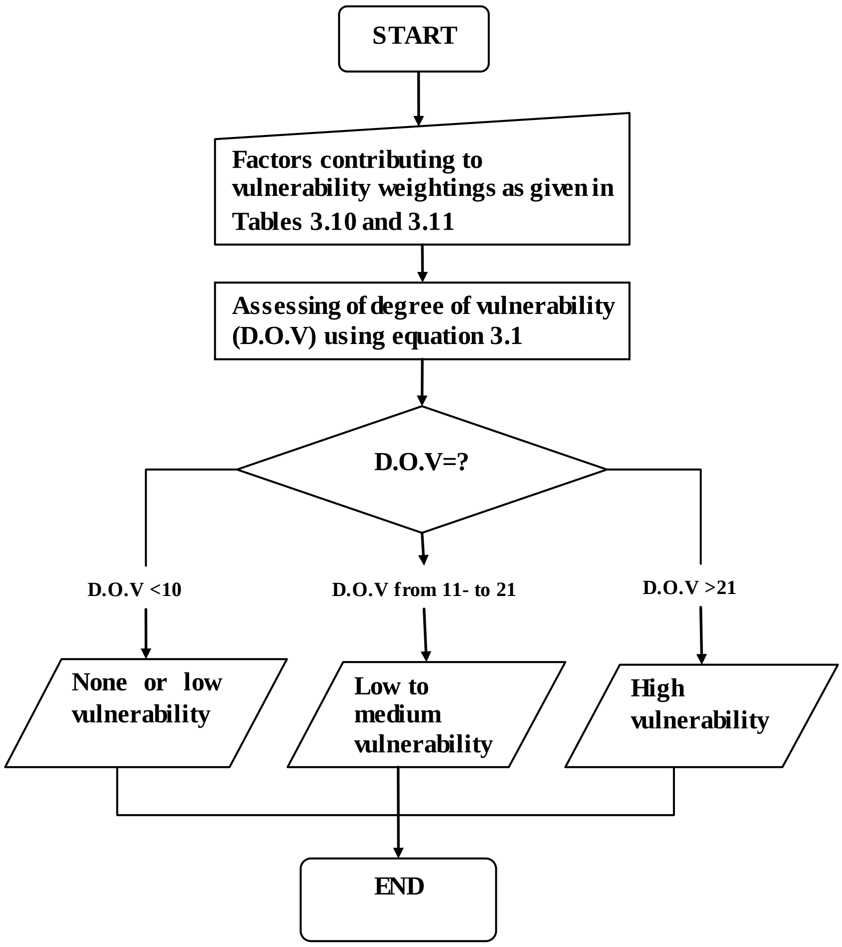


Figure 6-4: The degree of vulnerability assessment sub-system flowchart

The user has a choice of selecting either YES or NO for each factor, based on the situation of the case studied. For example, the factor 'Building protected by flood defences' considers whether the existing building is protected by the flood defence. In this regard, the answer will be either (YES) or (NO) as to whether there is flood defence.

The factors are given a value based on the user selection, with each factor falling into one of three values:

1- If the user selects (NO) and the factor is assigned either as important or very important factor, the value given to this factor in this case will then be '0' and will be used in the degree of vulnerability calculation.
2- If the user selects (YES) and the factor is assigned as an important factor, the value given in this case will then be '1' and will be used in the degree of vulnerability calculation.
3- If the user selects (YES) and the factor assigned is very important factor, then the value given in this case will be '2' and will be used in the degree of vulnerability calculation.

As can be seen from the previous example, if the answer was (YES), the values given will be '1' because this factor was assigned an important factor.

Table 6.1 shows the values given to each factor based on user selection either (YES) or (NO).

Table 6-1: Vulnerability assessment calculation (assumed case)

No.	Factor Description	The Given Value based on User Selection	
		Yes	NO
1	Geographic Location of the building within the flood risk zone based on the flood maps provided by the Environment Agency	1	0
2	Building is not protected by flood defences	1	0
3	Topography of the building site (the building is located at the bottom of a valley or foot of a hillside)	1	0
4	The building is close to an intermittent stream	1	0
5	Occurrence of sewer flooding in the past	1	0
6	The building has been flooded in the past	1	0
7	The building has cracks in the walls near the floor level	1	0
7	The condition of the building prior to the flood was poor	1	0
8	No water resistant doors, windows and kitchen units, made from PVC or other water resistant materials	1	0
9	Gas and electrical utilities are not located above the flood level	1	0
10	No flood resistance or resilience measures	1	0
11	No backflow devices on sewer system	1	0
12	The building is underlain by a chalk aquifer	2	0
13	The soil is often near saturation point or is impermeable	2	0
14	Duration of previous flood was greater than 12 hours	2	0
15	Depth of the previous flood was above the building's floor	2	0
16	Issuing of flood warnings for this area in the past	2	0
17	The building has timber walls or frames.	2	0
18	The building contains gypsum plaster	2	0
19	The building has a mineral insulation	2	0
20	The building has a chipboard, wood, vinyl, or rubber tiled floor	2	0

In the assumed case, if the user selection to calculate the degree of vulnerability of a given building was as coloured in Table 6.1 given above, the degree of vulnerability will then be the summation of these values given to such factors, which are: 1+1+1+0+0+0+0+1+1+1+1+1+2+2+2+2+2+2+0+2+2=24

Based on Table 3.12 given in Chapter 3, the degree of vulnerability is 24, which is greater than 21, and so the descriptive vulnerability is (High). Moreover, the degree of vulnerability will be then used in the selection of the remediation type, either standard or resilience remediation options. This will be discussed in the next section.

6.2.3.2.2 The remediation options assessment subsystem

This system aims to demonstrate remediation options for different damaged building elements based on the degree of vulnerability calculated by the vulnerability damage assessment subsystem; however, the user can still use the system alone in order to navigate all remediation options available.

Importantly, there are three cases of remediation options based on the degree of vulnerability as given below:

1- Ordinary remediation option whereby an ordinary remediation and material are used. These options are selected by the system when the degree of vulnerability is low.

2- The system gives the user a choice to choose between the ordinary and resilience options (where the resilience options are preferred), when the degree of vulnerability is medium.

3- If the degree of vulnerability is high is the case, then the resilience remediation options is suggested.

The system strategies, performance and outputs are designed in the form suggested by the system, owing to the following assumptions and reasons:

1- The system only deal with damage caused by flood to the foundations and floors if the flood depth was below the floor level;

2- The system suggested resilience option as one of the main options because;

- The resilience options are Limiting the damage, reducing time to repair, and reduce cost of repairs of any future flood (ABI, Norwich Union; ;Escarameia ,2007)
- The government response to Pitt Report on Flooding that recommend that the Building Regulations should be revised to ensure that all new or refurbished buildings in high flood-risk areas are flood resistant or resilient. The government consider incorporate flood resilience and resistance, and the regulations being laid in 2012 and coming into force in 2013 (Defra, 2010);

3- The system suggests a number of remediation options and not selected specific ones, owing to the fact that the repair strategies needed to be agreed by the owner, contractor and insurance company. In addition, the insurance company offers only the ordinary repair. In the case that the resilience options are selected, any extra costs will be paid by the owner. The system gives an opportunity to all stakeholders to discuss the options available and to accordingly make a decision in mind of such information;

4- In case the system is used for training, all options are stated and can be discussed;

5- To standardise the repair strategies, since the options are given and can be discussed for each flood damage case on the same basis;

6- There is more than one option which can be selected depending on a number of factors (e.g. the cost, the owner's opinion or the budget) so the system suggests a number of options rather than selecting a particular option. For example, in the case that the damaged element is tiles, the options applicable would be to replace all the tiles, clean and/or replace only the damaged tiles, or clean only. More than one option is therefore given in order to allow the contractor the opportunity to discuss things with the owner and come to a decision; and

7- Standards and any extra information are listed, if available, as a reference for each repair option or material used.

The building elements are divided into a number of categories, such as floors, walls, etc. These categories are then divided into subcategories based on their type and material. Remediation options are given for each subcategory based on technical manuals and/or surveys. The operational flowchart of the remediation option selection subsystem is shown in Figure 6.5.

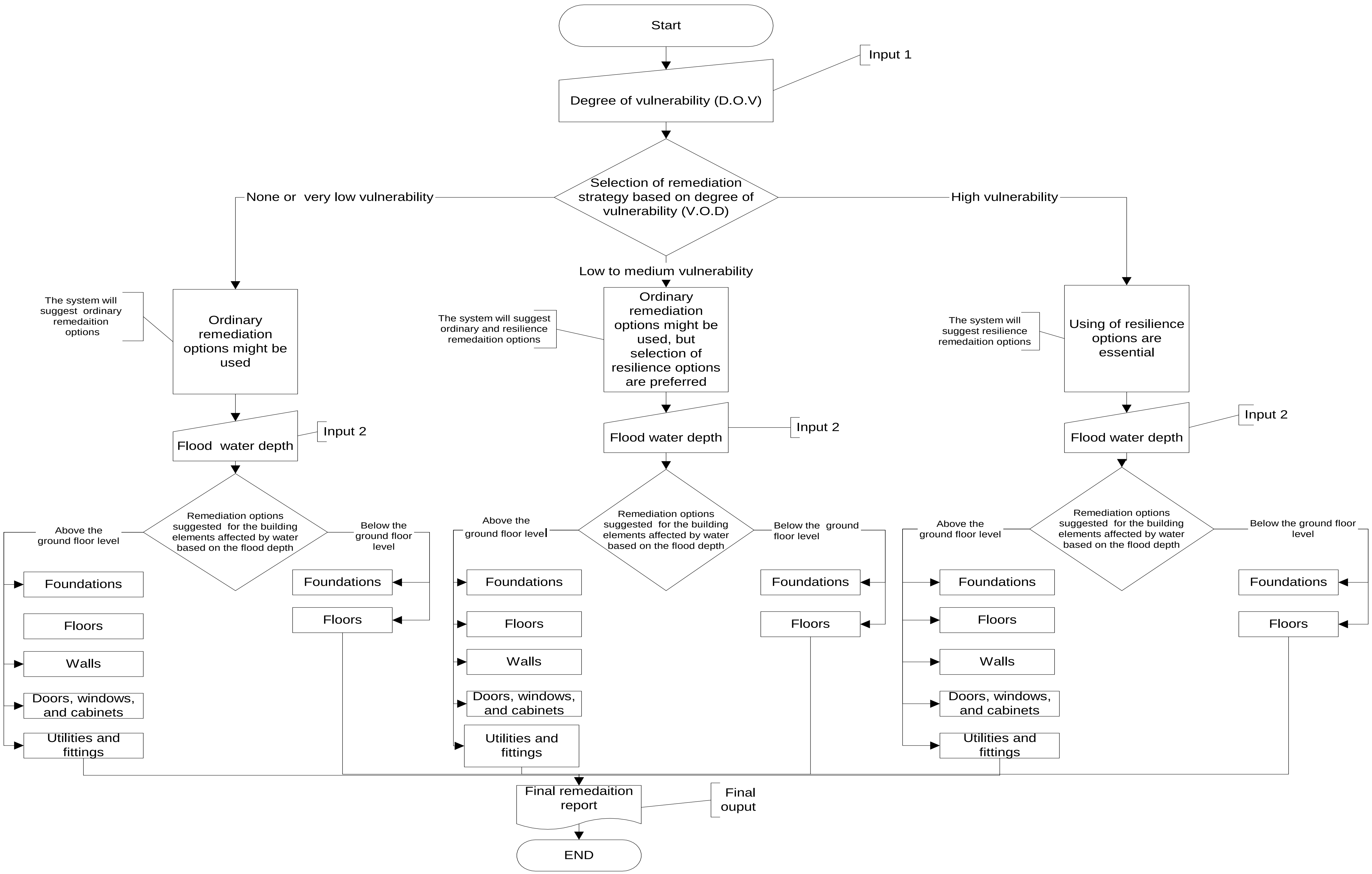


Figure 6-5: Remediation assessment subsystem flowchart

6.2.3.2.3 The remediation options selection subsystem

The main idea of this subsystem is based on two assumptions: first, the fact that, when the foundation moves, cracks will appear in the superstructure as a result of these movements, and there will be signs of foundation movements; and second, there is the assumption based on the fact that, after the flood, the damage caused by the flood to the building foundations will be either significant owing to clay soil or subsidence due to loose soil, saturation soils, or soil erosion.

The system starts with a diagnosis of the cracks due to foundation movement, and thereby suggests remediation options. The system then recommends continuous and detailed monitoring in order to avoid costly remediation options, such as underpinning in the early stages. Underpinning is only suggested if the situation becomes worse.

The diagnosis and remediation options suggested by the system are based on the technical manuals and reports, data sheets of some companies specialised in this field, and own experience. The operation flowchart of the foundation damage assessment subsystem is shown in Figure 6.6

6.3 OPERATION OF THE PROTOTYPE SYSTEM

6.3.1 SYSTEM REQUIREMENTS

This system will run on any Windows operating system which is able to support the .net framework (i.e. Windows XP, Windows 7.0, Windows server 2003, etc.), although the system will require a minimal disk space of 50MB to be installed and operated smoothly.

6.3.2 USER REQUIREMENTS

The end users of the prototype system will be mainly engineers working in the field of flooded residential building management and repair, or building insurance in order to evaluate how the building is vulnerable to damage by flooding. In addition, the system can be used for training purposes since the system contains considerable information on the flood damage assessment and remediation.

6.3.3 STARTING THE PROTOTYPE SYSTEM

The user starts by clicking the program icon which operates an executable file to run the program. The database file used by the program should be held on the same drive as the system operating file. The prototype system has a graphical user interface easy for use, through which the user can easily navigate the entire prototype system with user-friendly dialogue boxes and buttons which guide the user through the system, along with helpful screens.

When the icon is clicked, the program starts and the main screen appears, as is shown in Figure 6.7.

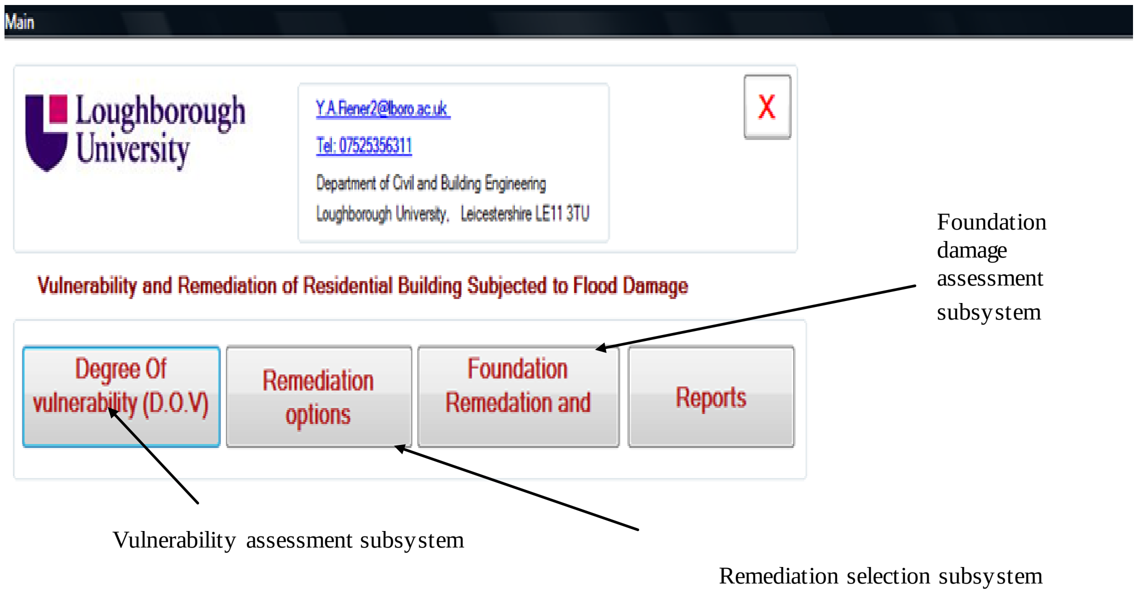


Figure 6-6: The main screen

There are four main buttons which appears on the main screen. The user can, through the main screen, conduct the following:

1. Go to the program that calculates the degree of vulnerability by clicking the button Degree of Vulnerability (DOV).
2. Gain access to the program for selecting methods of remediation by pressing the button Remediation options, whether for new or previous cases.
3. Go to the program to assess the damage to the foundations when the user clicks the Foundation remediation and damage assessment.
4. By clicking the Reports button, the user will be able to gain access to the previous cases, which was the degree of vulnerability calculated. This will be clarified in subsequent sections that explain the how the subsystems work.

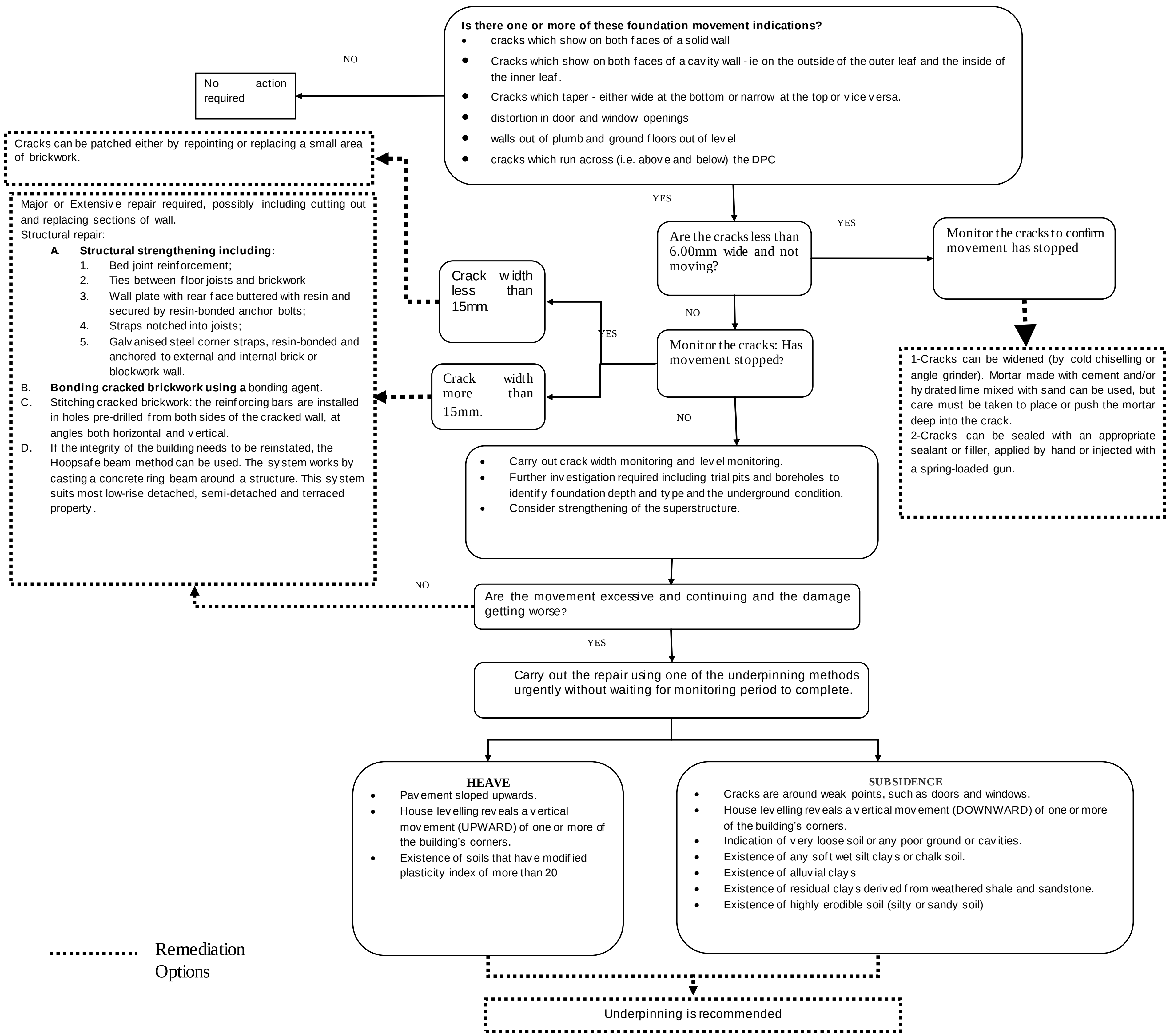


Figure 6-7: Foundation damage assessment flowchart

6.3.3.1 Degree of vulnerability assessment subsystem

6.3.3.1.1 Vulnerability assessment input data sheet

In order to assess the degree of vulnerability, the user needs to input information concerning the case to be assessed through the use of a data entry form. The data entry form is similar to the input screen, which facilitates the entry of the information directly without any modification, thereby leading to easier use of the program and thus saves time as well as making it possible to enter information directly when the user is located on-site. The data entry form contains a set of questions to be answered by the user (YES or NO) depending on the circumstances of the case being assessed, the information that has been collected, and the building survey. The data entry sheet for vulnerability assessment is shown in Appendix C.

6.3.3.1.2 Operating the degree of vulnerability assessment subsystem

When the user clicks the degree of vulnerability button, a new screen will appear, as illustrated in Figure 6.8. Using this screen, the user can calculate the degree of vulnerability. At the top of the screen, the user able to enter the case number or reference, as well as notes or comments using two text boxes provided known as Case and Notes, whilst the date are entered automatically by the system.

In order to calculate the degree of vulnerability, the user starts by answering a set of questions by selecting Yes or No using the selection button (Radio buttons) next to each of these questions based on the information collected using the data collection sheet for each case to be assessed. Finally, the degree of vulnerability can be calculated by clicking the Test the Degree of Vulnerability (DOV) button at the bottom of the screen.

The system then provides the degree of vulnerability, and accordingly recommends the repair strategy for this case. Furthermore, the user is also given the choice to start the remediation option subsystem to select the remediation options in a new screen, as shown in Figure 6.9. The degree of vulnerability and details of each case will be saved in the reports, as mentioned in Section 6.3.3.2.

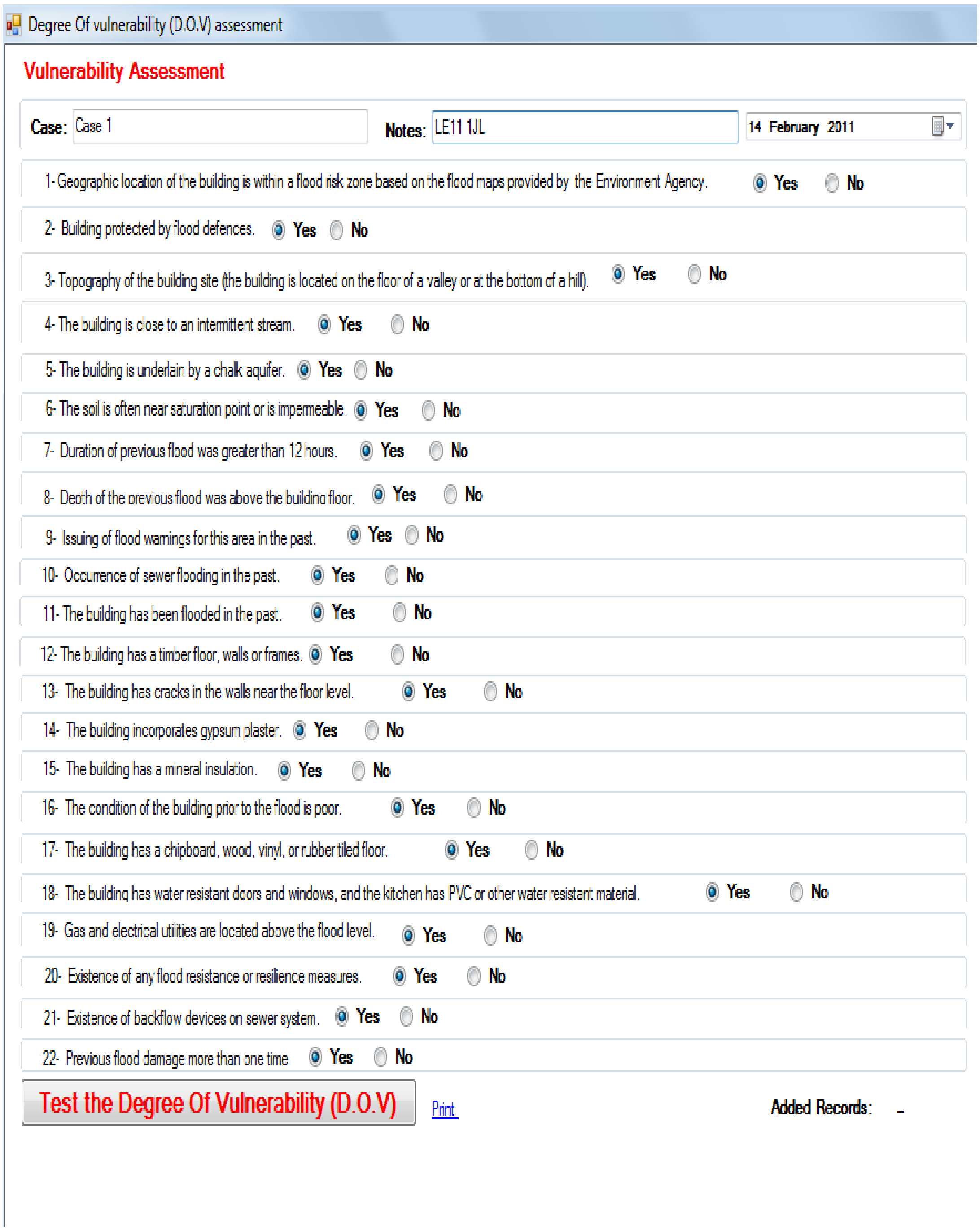


Figure 6-8: The degree of vulnerability assessment screen

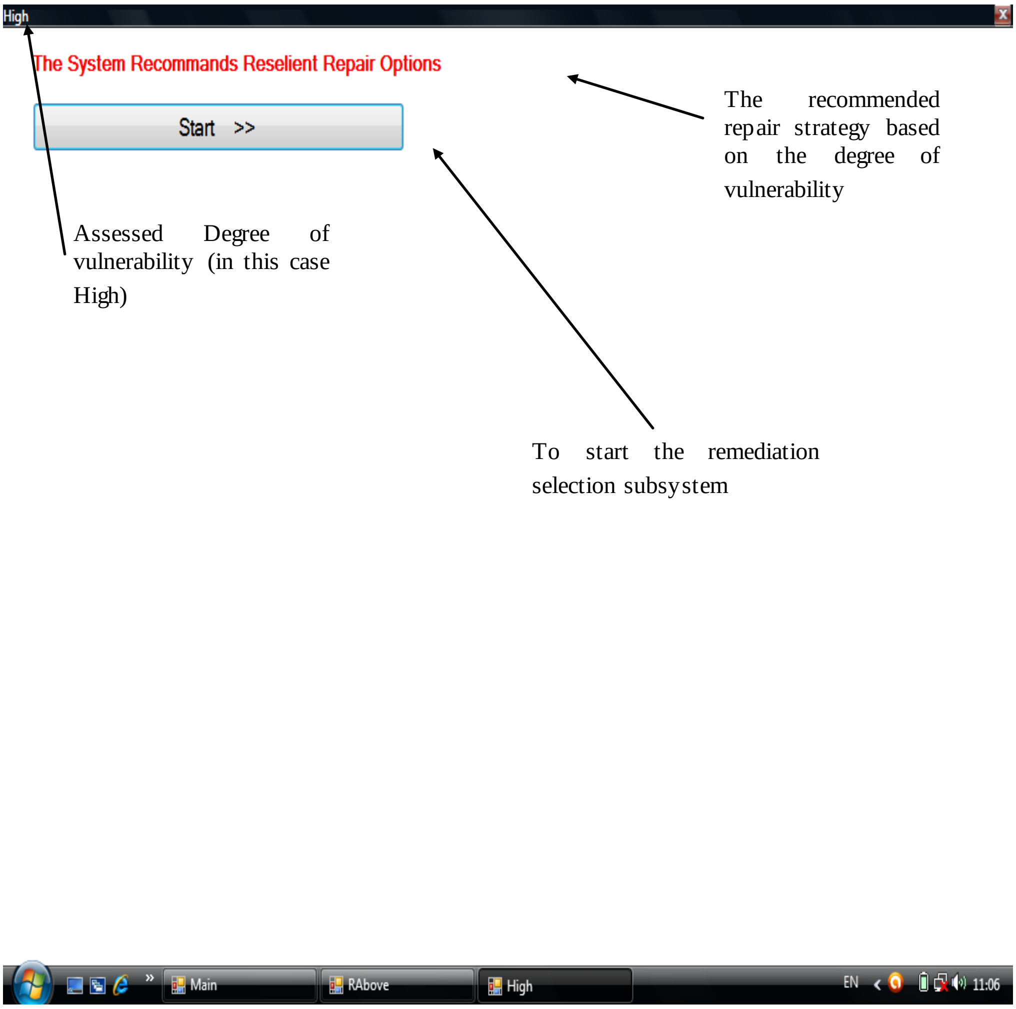


Figure 6-9: The output screen of the degree of vulnerability assessment

6.3.3.2 Reports

Information relating to the degree of vulnerability is stored in the data using a Microsoft Access database for all cases. The user is able to access this information and use it at any time by clicking the Reports button provided on the main screen, which opens a new screen, allowing the user to navigate the stored cases. The reports screen is shown in Figure 6.10.

When the screen is displayed, all the cases which have been assessed will be exhibited in the form of tables, and through this screen, the user can review only those cases that have been assessed as having low, medium or high vulnerability, by clicking the Low, Medium or High button respectively. In addition, the user can view the evaluations of all cases by clicking the All button. These buttons are located at the top right of the screen. The user can also search for a particular case by entering a keyword in the search box rectangle located on the top left of the screen, and then clicking the Search button. There are also buttons for moving between pages in order to facilitate the search. Reports can be printed, stored or exported, and earlier reports stored and displayed.

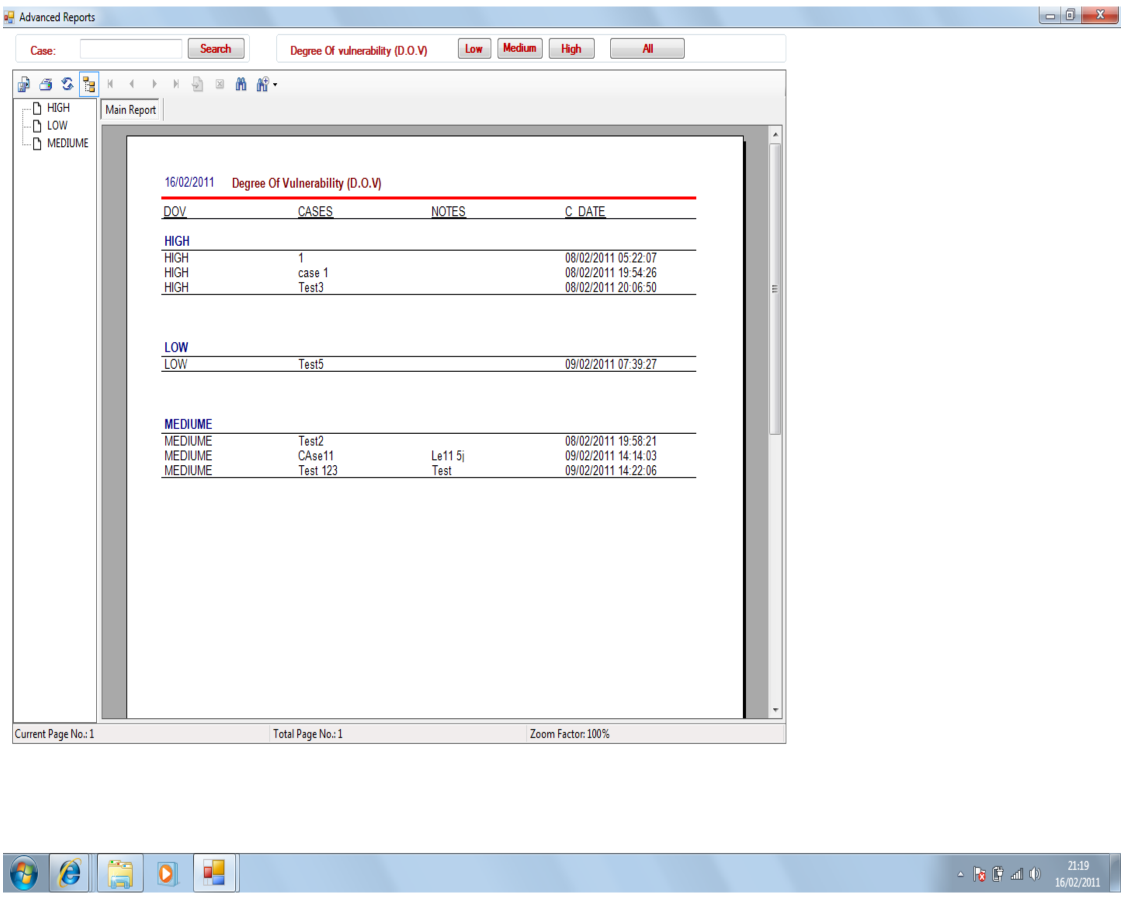


Figure 6-10: The reports screen

6.3.3.3 Remediation options subsystem

6.3.3.3.1 Building survey data sheet

The user needs to survey the damaged building and collect information in order to determine the information required to take advantage of the system, where the user needs to know the depth of flooding, as well as the parts of the building which have been damaged and therefore need maintenance. In addition, the type of construction, and the materials used can be determined. This information needs to be collected through a building survey, as well as through documents and drawings for the damaged building. A building survey data sheet is provided in Appendix C.

6.3.3.3.2 Operating the remediation options subsystem

The remediation option subsystem provides options for the repair of different building elements which are damaged by flooding. The idea of the system is that the general repair strategy (either resilient or ordinary) is selected based on the degree of vulnerability calculated by the degree vulnerability subsystem, and the system then displays the damaged elements based on the depth of the flood. The repair options are displayed for each element, with subcategories based on the type of construction or material. For example, under the building element (Floors), there will be a number of different types and construction of floors, such as sheet vinyl floors, quarry tiles floors, solid concrete floors, etc.

The subsystem demonstrates the repair options applicable in each case (there might be more than one option); this gives the user the opportunity to discuss matters with the owner before making a decision—particularly in the case of resilient options where the owner would have to pay any extra costs above the insurance value, or negotiate with an insurance company based on an insurance policy. There are also other reasons, as mentioned in Section 6.2.3.3.3.

When the user clicks the Remediation option button, a new screen will appear which allows the user to start selecting the remediation option for the new case or the previous cases which are listed in the screen, as shown in Figure 6.11.

The user can navigate the previous cases assessed and then press the Select Cast button to start viewing the remediation options available for this case. The other option is where the user is able to create new case to assess and select the remediation options by clicking the button Create New Case.

If the user selects to start viewing the remediation options available for one of the listed case by clicking the Select Case button, at which point a new screen will appear similar to that shown in Figure 6.9, where the user can start viewing the remediation options available for this case upon clicking the Start button. When the user select to start a new case by clicking the Create New Case button, then the degree of vulnerability assessment screen will appear similar to that shown in Figure 6.8.

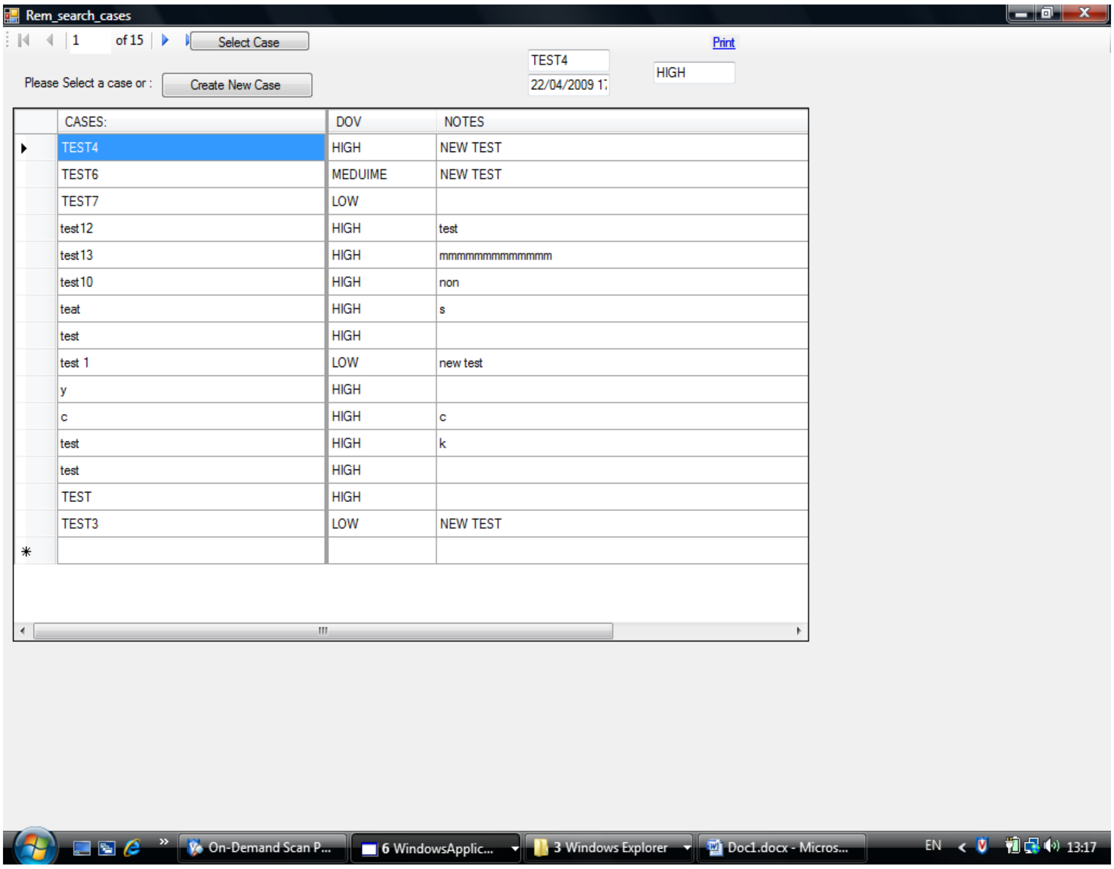


Figure 6-11: The screen displayed when the user clicks the remediation option button

When the user clicks the Start button to view the remediation options available as in the screen shown in Figure 6.12, a new screen will appear containing two buttons labelled Flood Depth Below the Ground Floor Level, and Flood Depth Above the Ground Floor Level, where the user is able to click one of these based on the case studied, as shown in Figure 6.13.

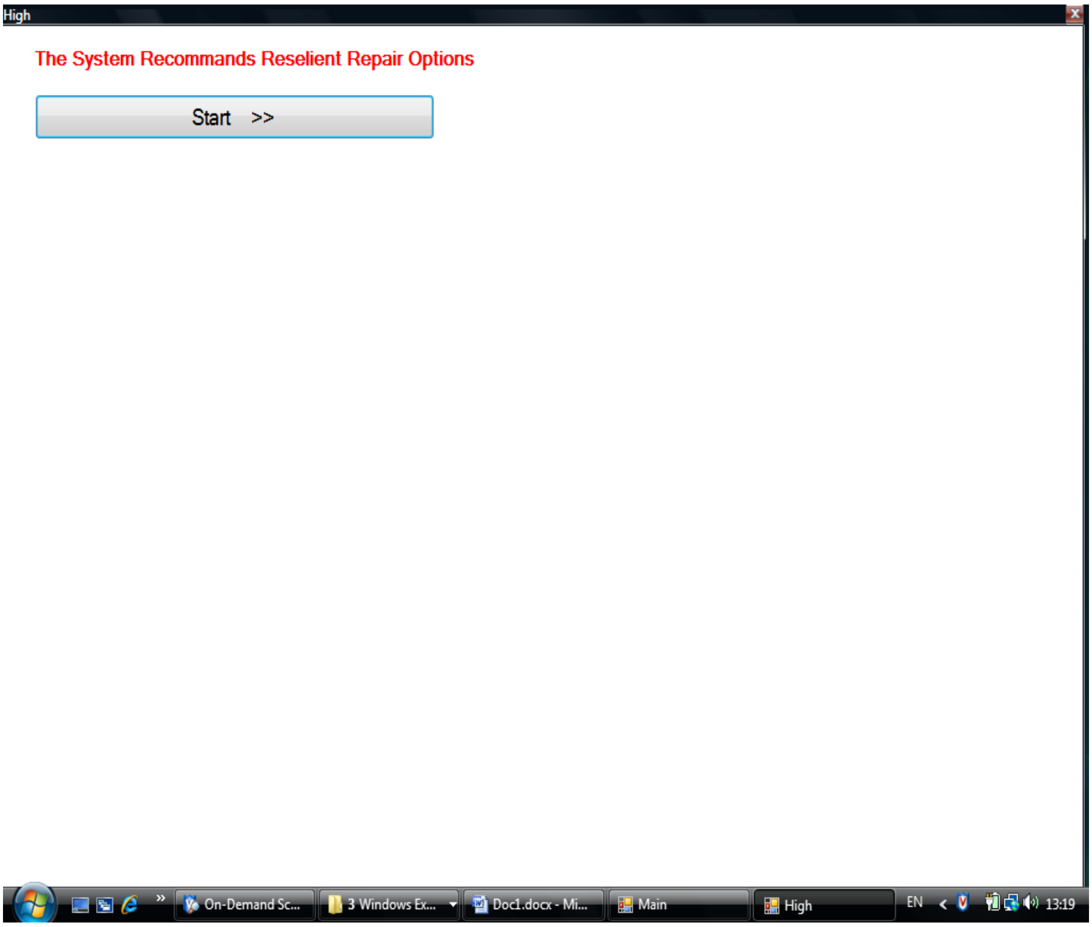


Figure 6-12: The start screen of the remediation option view

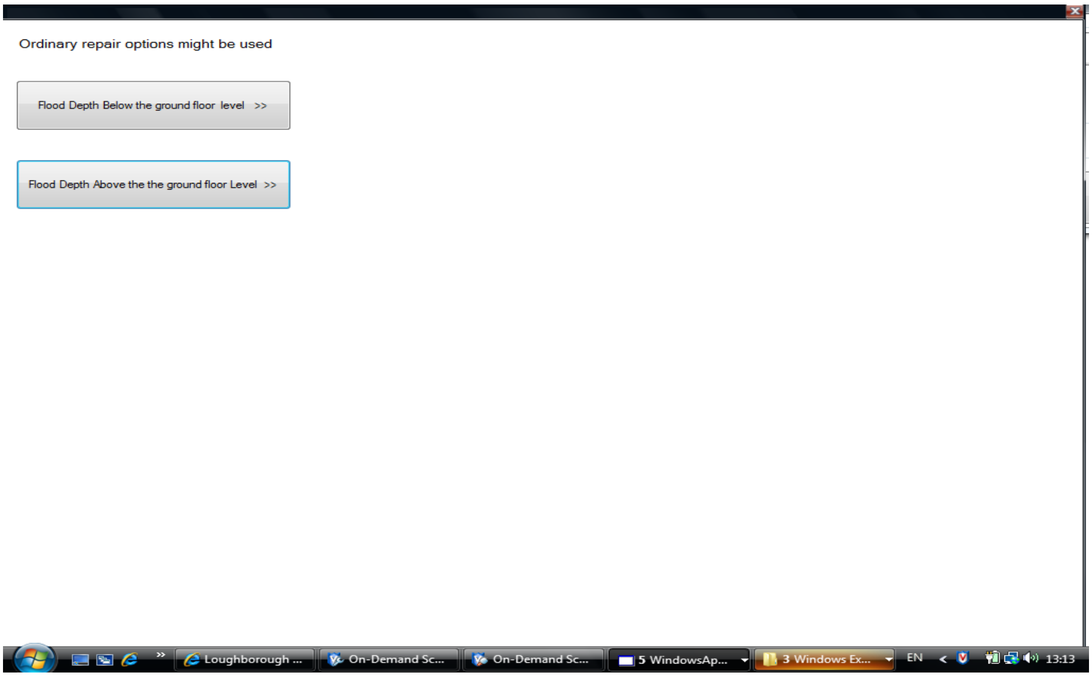


Figure 6-13: Flood depth selection

Based on the user selection, only the building elements damaged in this case will be shown. The elements will be shown in the form of buttons representing the building elements, as shown in Figure 6.14. If there are any subcategories under this element, these will be shown in the form of buttons, as shown in Figure 6.15, which show the subcategories under the element Floors.

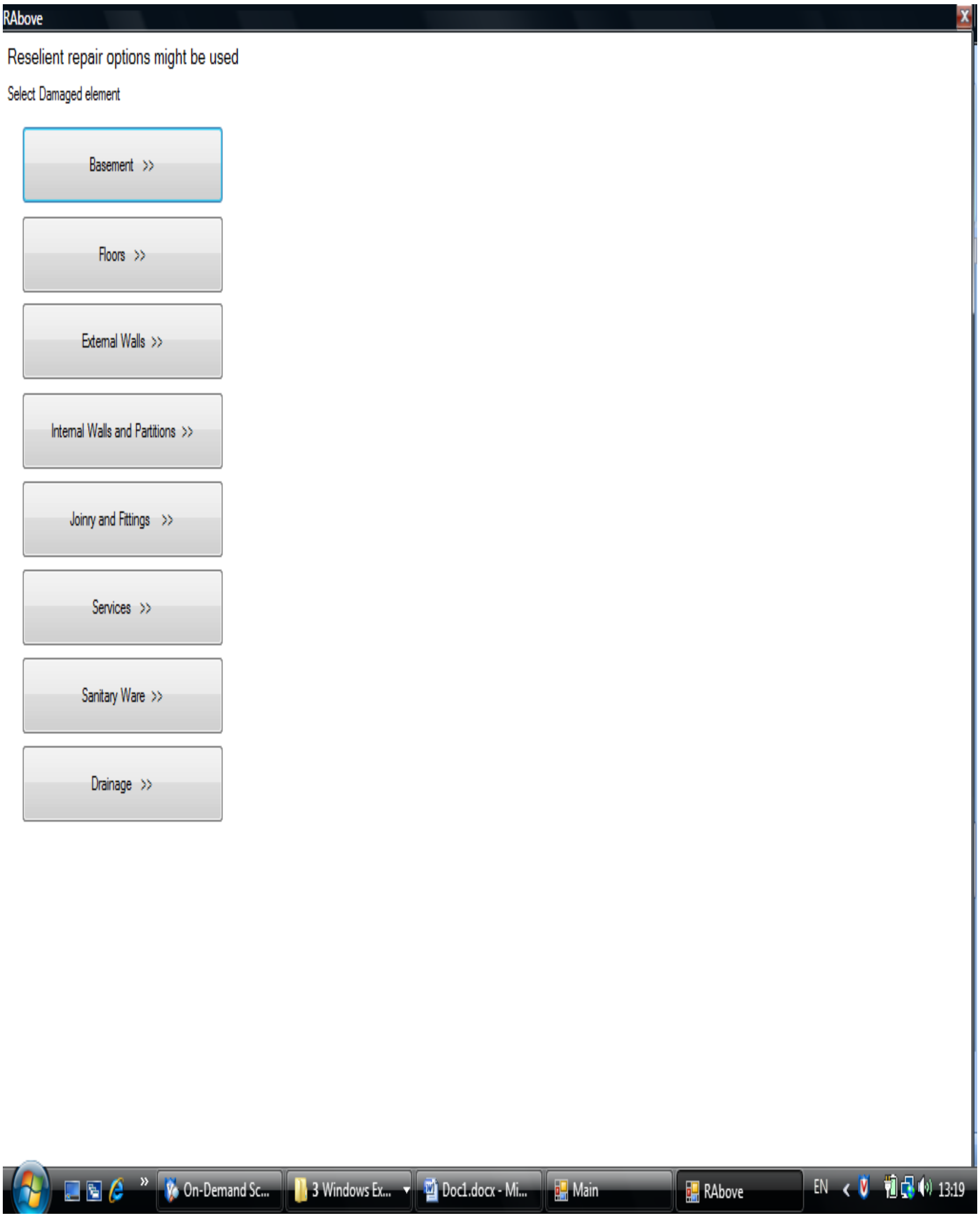


Figure 6-14: Building elements selection screen

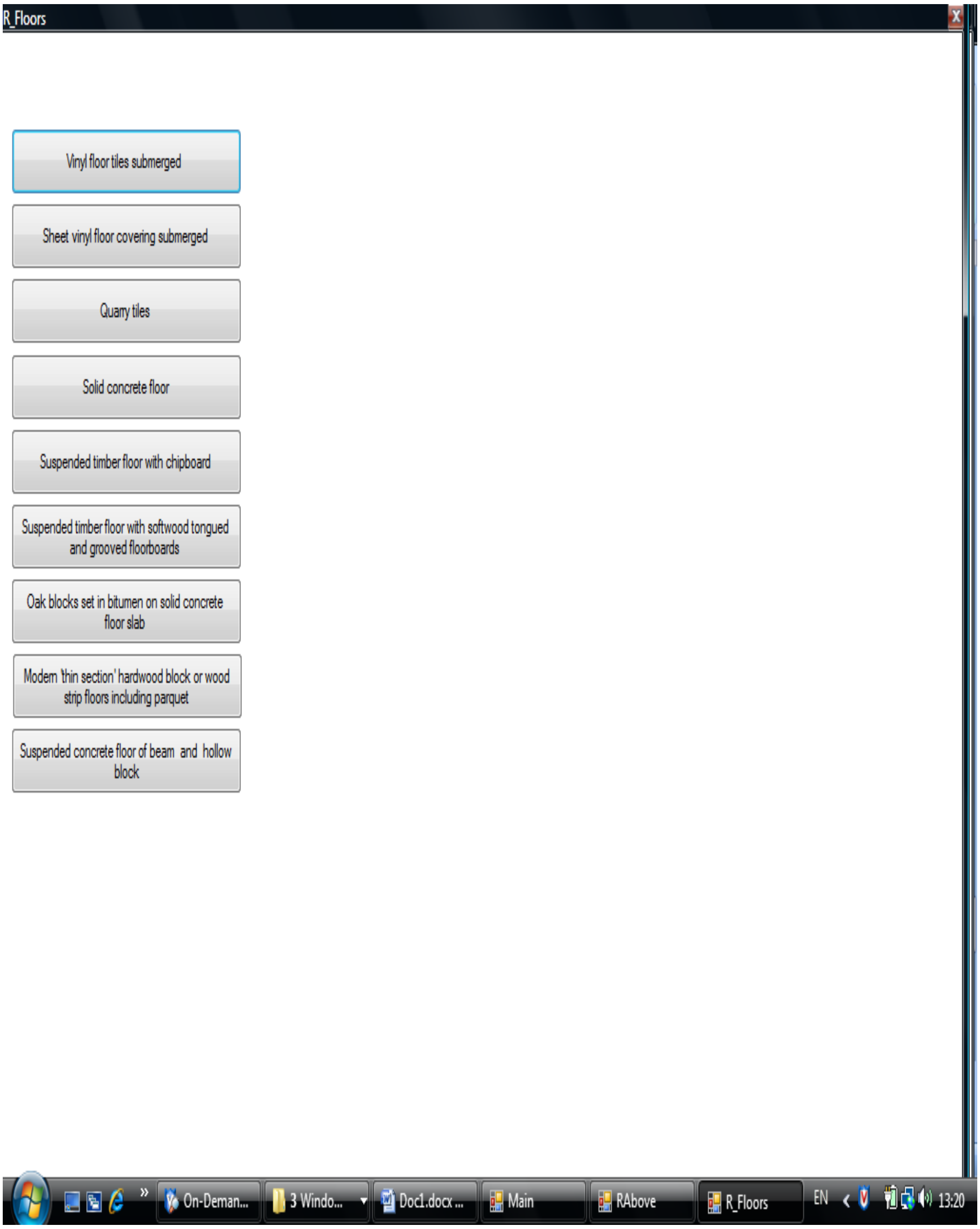


Figure 6-15: Subcategorise under the building element (Floors)

When selecting the element by clicking the related button, the remediation options will be viewed, as shown in Figure 6.16, where the user is able to print or save these options in different forms.

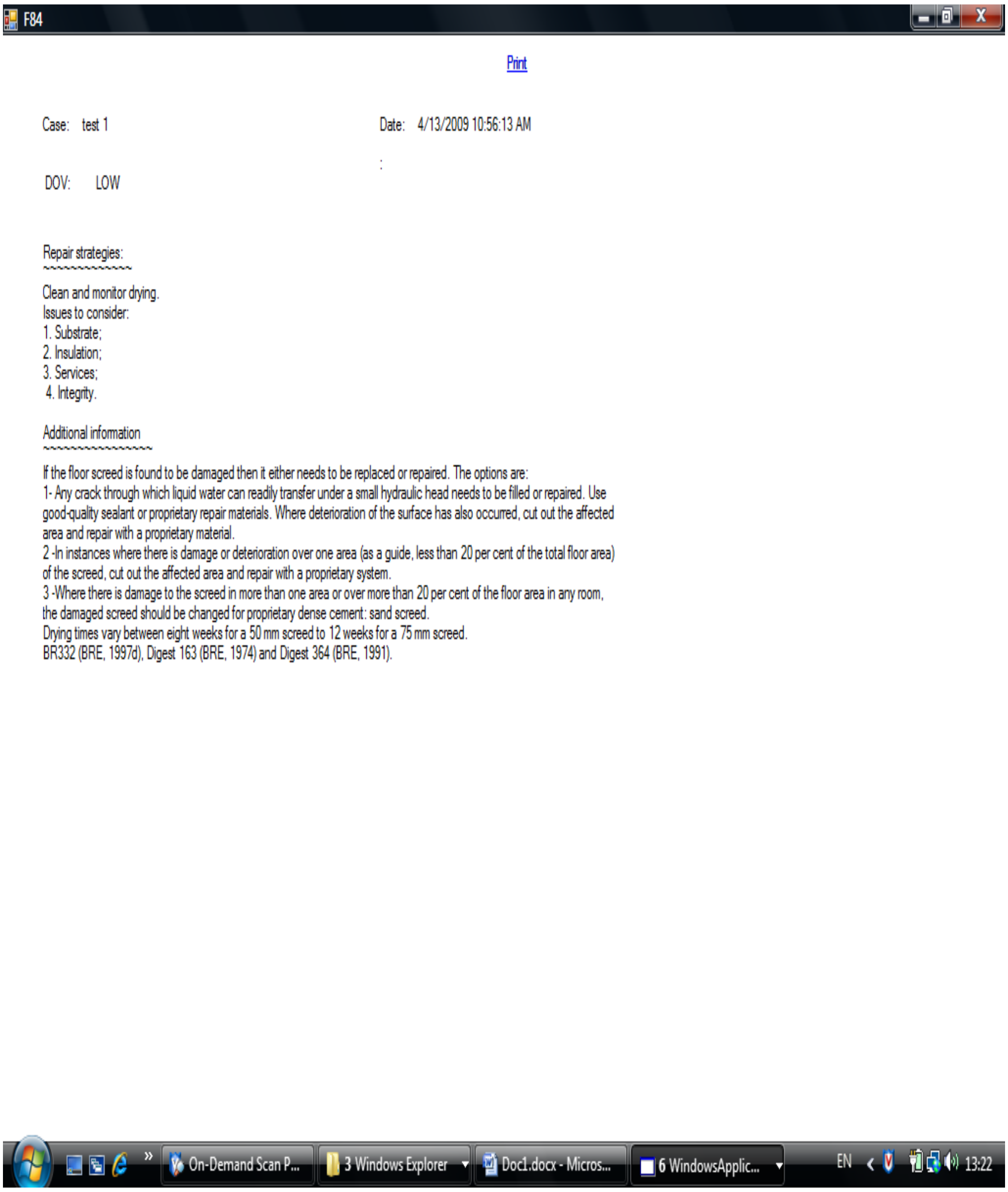


Figure 6-16: Example of the remediation viewed in case of concrete floor

6.3.3.4 Foundation damage assessment and remediation subsystem

When the user click the foundation damage assessment and remediation button in the main menu of the prototype system, the system will started with a list of questions the indicated the foundation movement and the user is required to choose either Yes or No by clicking on of the button s provided as shown in Figure 6.17.

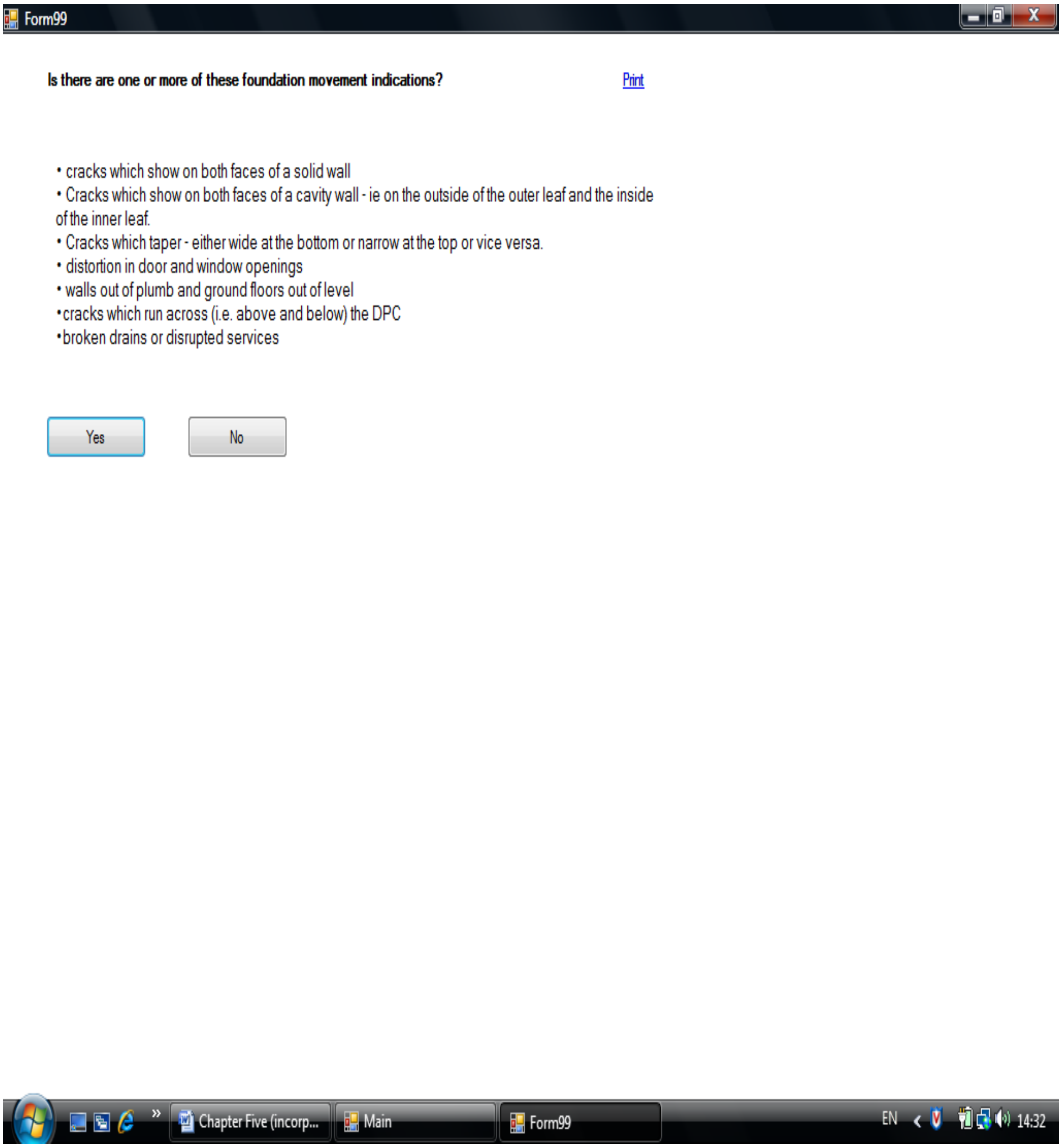


Figure 6-17: The start screen of the foundation damage assessment and remediation subsystem

The subsystem based on a number of dialogue boxes and the reply of the user for different circumstances for each individual case. The subsystem following the flowchart procedure given in Figure 6.6. The subsystem interact with user in different ways depends on the user response, in some case, giving inquiries where the user needs to answer a question, as given in Figure 6.17.

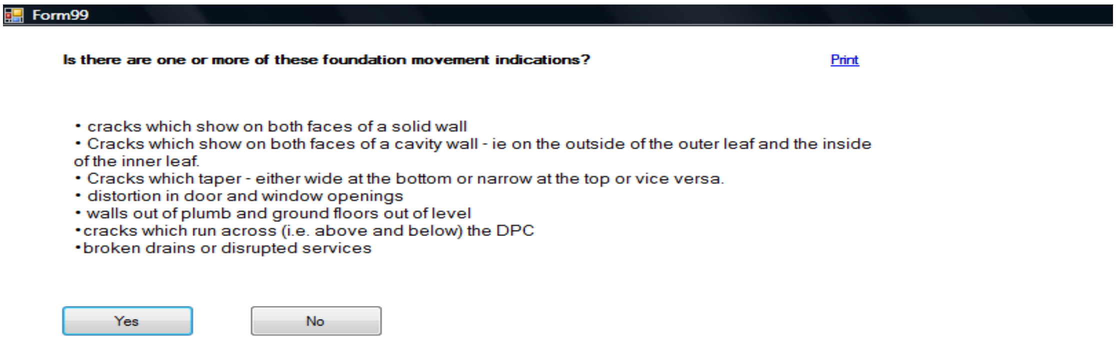


Figure 6-18: Example of questions used by the subsystem

In some cases, the subsystem gives instructions and inquiries, as given in Figure 6.18, or view a remediation option, as shown in Figure 6.19.

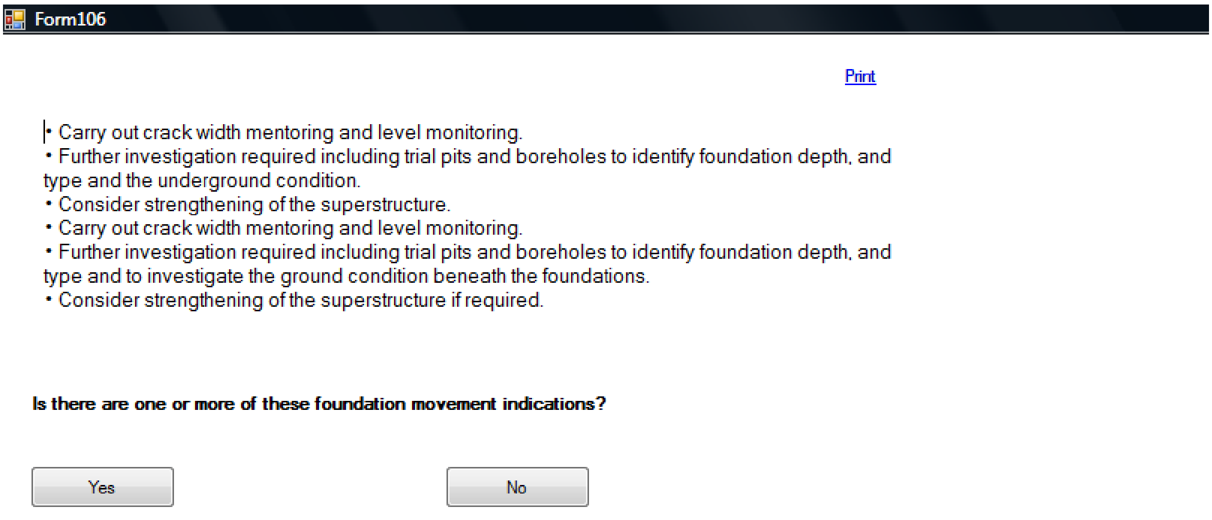


Figure 6-19: Example of instruction and inquiry used by the system

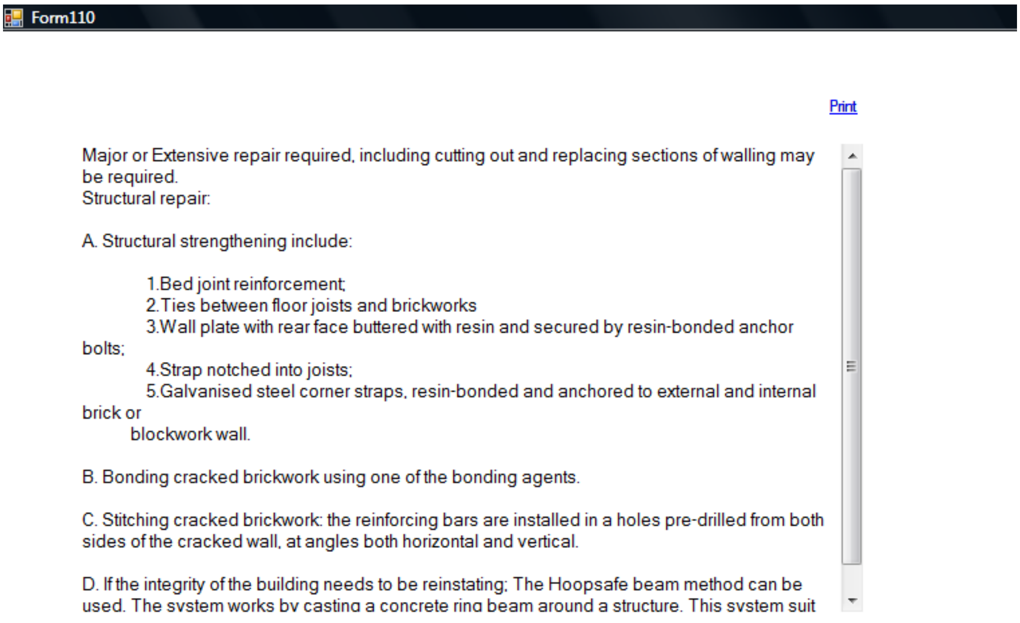


Figure 6-20: Example of remediation options viewed by the subsystem

In the case that underpinning is recommended, the system will then view a number of underpinning methods in the form of buttons to choose from, as highlighted in Figure 6.19.

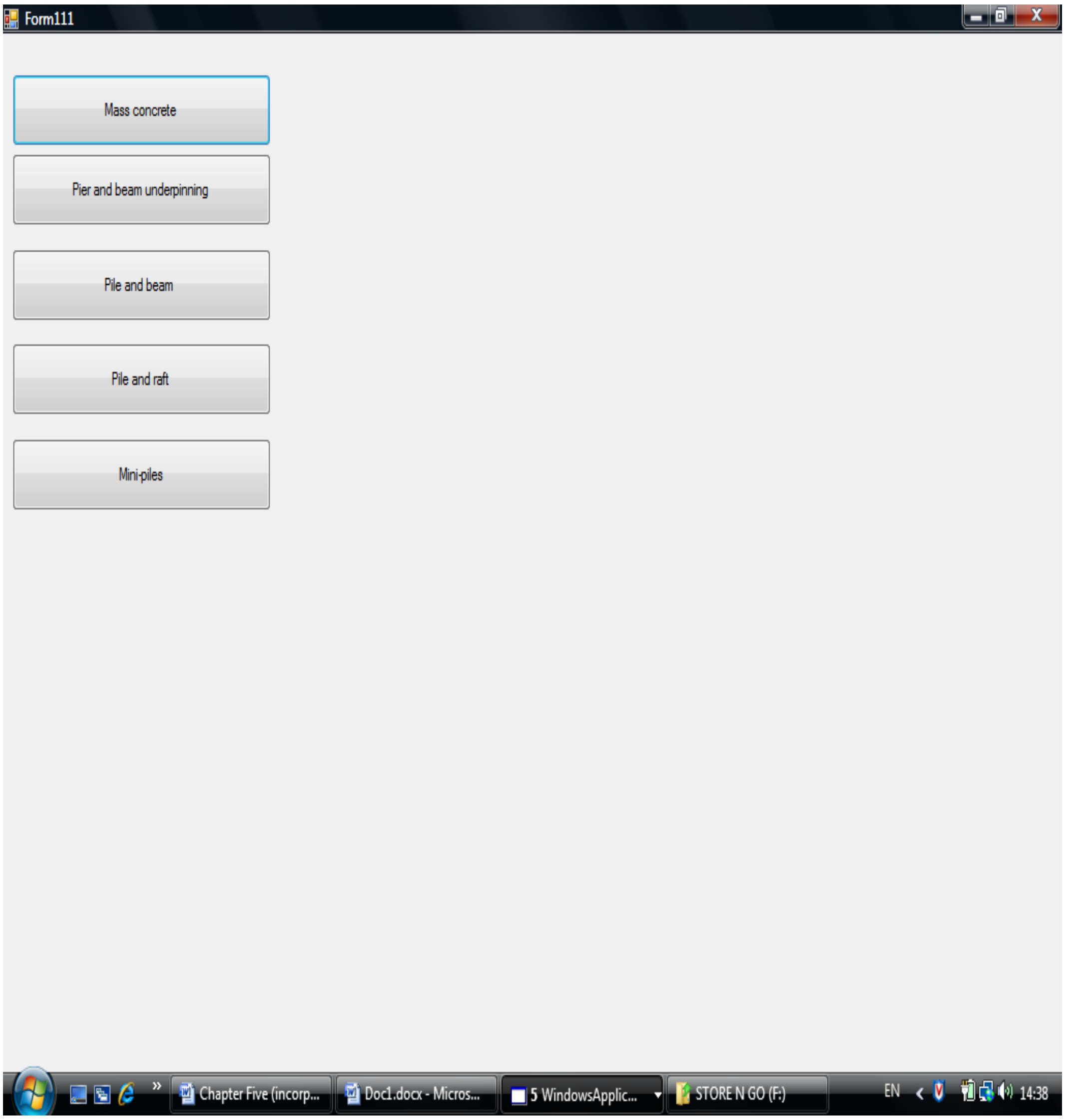


Figure 6-21: Underpinning methods viewed in the form of buttons

If the user chooses one of these methods by clicking a related name button, the system will provide a brief description of the method, showing the disadvantages and advantages of this method and, where it is applicable, as shown in Figure 6.21. Moreover, the user is able to print the remediation options each time.

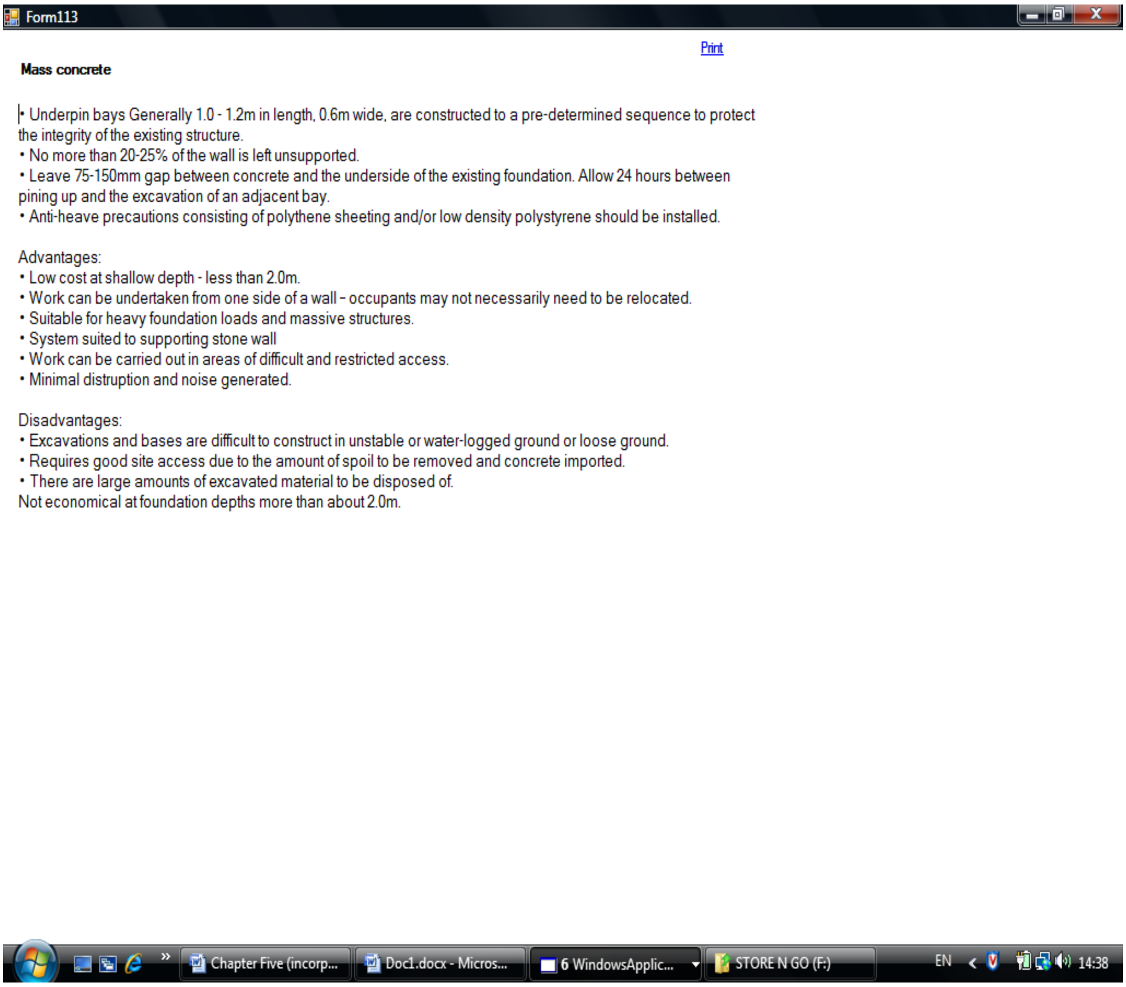


Figure 6-22: Example of the underpinning method viewed by the system

6.4 SUMMARY

This chapter has described the development and evaluation of the prototype system developed. The system is referred to as the 'Vulnerability and Remediation Assessment of Flooded Residential Building System (VRAFRBS)'. Notably, this system will run on any Windows operating system able to support the .net framework (such as Windows XP, Windows 7.0, Windows server 2003, etc.), and comprises three subsystems: the

Degree of vulnerability assessment, *Remediation options*, and *Foundation damage assessment* prototype system evaluation. The user can calculate the degree of vulnerability, which indicates the building's vulnerability to damage through flooding, selecting remediation option based on the damaged building element and the degree of vulnerability. Moreover, the user can assess the damage caused to the building foundations and accordingly recommend repair options based on damage caused and building foundation type. The system comprises user-friendly screen and easy-to-use navigation through the use of vb.net and database.

The next chapter will discuss the evaluation of the system.

CHAPTER 7 EVALUATION OF THE PROTOTYPE SYSTEM

7.1 INTRODUCTION

The validation of a system or prototype is commonly viewed as being the foundation of a validity assessment in the context of knowledge base systems. In this regard, a number of knowledge base systems are a combination of software and framework. Moreover, it is important to emphasise that the general process commonly implemented during the validation of traditional programmes cannot be applied when seeking to conduct knowledge base system validation.

This chapter describes the evaluation of the prototype system, and includes the aim and the objectives of the evaluation, methodology, results and discussions for the overall evaluation process. Moreover, the chapter concludes by providing a summary.

7.2 EVALUATION AIM AND OBJECTIVES

The overall evaluation was concerned with establishing the overall functionality and usability of the final prototype system. In order to achieve this goal, the particular objectives of the evaluation were:

- To assess the performance of this prototype system in general;
- To determine the extent of applicability of the system to use in assessment of vulnerability of residential buildings to flood damage and their remediation;
- To assess the effect of interaction on the user with the prototype system; and

- To obtain observations and suggestions on improving the status of the prototype of the system.

7.3 EVALUATION METHODOLOGY

During the course of this study, an assessment has been carried out throughout numerous different phases of the development of the prototype. During each of these stages, data gathered was considered, and all aspects of the system were evaluated and validating through interviews and discussions, such as with professionals attending relevant workshops. In this regard, it can be stated that validation is a critical phase of the evaluation, which is concerned with the overall performance of the system and the level of accuracy. With this in mind, it is accurate to state that the system has been put through a number of different changes and amendments.

Moreover, it is noteworthy to recognise that each time a researcher or professional in this field made a suggestion concerning the system's improvements, these were taken into account. Furthermore, upon completion of the prototype, professionals were provided with the opportunity to review the system and give their feedback, with researchers and experts in the field making various suggestions, which were subsequently used in order to provide final improvements to the systems. With this taken into consideration, the following section will discuss the evaluation approach implemented in order to satisfy the overall study's aims and objectives, as highlighted at the beginning of this paper.

7.3.1 EVALUATION APPROACH

The evaluation was carried out following the creation of the prototype, and involved experts from industry, academic experts, and group of experts from environment Agency (EA). The British Damage Management Association (BDMA) were asked to recommend one of the companies approved by them and working in the field of flood building damage management. Accordingly, one of the recommended companies was chosen, and a number of branches were then contacted in order to arrange for the evaluation process. Moreover, two academic experts (from civil engineering department, Loughborough university) working in the field of risk and vulnerability assessment were involved in the evaluation of the prototype system. The final group comprised a number of experts working in the field of risk assessment and flood damage management from the Environment Agency (EA).

The research adopted both single and focus groups with a questionnaire technique in the evaluation process. The focus group was adopted as the participants were then provided with the opportunity to discuss and give appropriate feedback concerning the prototype during the evaluation process. The questionnaire technique was adopted to measure the usability of prototype system.

The prototype was demonstrated in relation to each single expert, with the exception of the EA, in which case the prototype was demonstrated to a group of experts at the same time at the Birmingham branch. The demonstration began with a presentation of the prototype system background, and an explanation of how the system works and the relation between each system components. Subsequently, every participant was allowed to demonstrate the prototype himself using his own cases, and to navigate through the system and discover its operationally and outputs.

The details of the people evaluated the prototype system are listed below:

No	Company , institution/organization	Number of participants
1	Rainbow International (Loughborough branch)	1 (Managing director)
2	Rainbow International (Mansfield branch)	1 (Branch director) 1 (Technical manager)
3	Civil & building engineering department – Loughborough university	1 (lecturer in WEDC with a background in disaster risk management)
4	Civil & building engineering department – Loughborough university	1 (Research Associate working on the resilience of healthcare facilities to natural disasters, climate change and sustainability)
5	(EA) Environment Agency –Birmingham branch	3 (Flood risk management)

The participants were then asked to complete the evaluation questionnaire, which was the final aspect of the evaluation.

7.3.2 QUESTIONNAIRE DESIGN

The questionnaire was designed in order to satisfy the aim and the objectives of the evaluation, as presented in Section 7.2. A sample of the evaluation questionnaire is provided in Appendix D. The questionnaire was divided into three sections, as follows:

I. Section A requested information about the participant's name, position in their organisation and experience.

II. Section B contains 22 questions about various aspects of the prototype system. In all questions in section B, participants were asked to tick the box that present their assessment on the scale of 1 (poor), 2 (fair), 3 (satisfactory), 4 (good) and 5 (excellent). It was divided into three subheading as follows:

- The system performance;
- Applicability to vulnerability and remediation assessment of flooded residential building;
- General comments.

III. Section C requests three comments include the main benefits of the prototype system, the ways to improve the system, and any additional comments.

7.4 EVALUATION RESULTS

This section presents the feedback ascertained from the participants that responded to the questions and gave their comments for further improvements. Table 7.1 illustrates the results from Section B during the evaluation questionnaire. Notably, a detailed discussion will be given in Section 7.5.

Table 7.2 presents the comments relating to the benefits of the prototype system, as well as suggestions on how to improve the system from Section C in the questionnaire, which were provided by evaluators.

Table 7-1: Responses to evaluation questions

Evaluation Questions		**Rating**				
		1 (poor)	**2 (Fair)**	**3 (Satisfied)**	**4 (Good)**	**5 (Excellent)**
SYSTEM PERFORMANCE (overall rating, Figure 7.1)		**0%**	**12%**	**34%**	**42%**	**12%**
1	How clearly presented are the factors used in vulnerability assessment?			40%	40%	20%
2	How well does the system help in vulnerability assessment of buildings subjected to flood damage?		20%		80%	
3	How closely do the factors used contribute to vulnerability?		20%	40%	20%	20%
4	How useful will the system be in the selection of remediation options?				80%	20%
5	How clear are the remediation options?		20%	40%	40%	
6	How appropriate are the remediation options selected?		20%	40%	20%	20%
7	How useful is the degree of vulnerability determined by the system in the selection of remediation options?			40%	60%	
8	How clear are the resilient remediation options presented by the system?		20%	40%		40%
9	How well does the system provide information and save time in relation to building flood damage?			60%	40%	
10	How well are building elements presented by the system?		20%	40%	40%	
Applicability to Vulnerability and Remediation Assessment of Flooded Residential Building (Overall rating, Figure 7.2)		**5%**	**20%**	**28%**	**34%**	**13%**
11	How effective/accurate is the system as part of vulnerability assessment?		40%	40%	20%	
12	How effective is the system in evaluation of foundation damage assessment and repair?		20%	40%	40%	
13	To what extent does the system assess remediation options selection?		20%	40%	40%	
14	How convinced are you that professionals in the damaged flooded building industry will accept (or use) the system?		20%	20%	60%	
15	To what extent does it represent an improvement (or help) in selection of remediation options?		20%	20%	20%	40%
16	To what extent does it improve accuracy (or acceptance) in selection of remediation options?	20%		20%	40%	20%
17	How effectively will the system increase the speed of selection of remediation strategies?		20%	40%	20%	20%
18	To what extent is the system flexible in selection of the appropriate remediation options?	20%	40%		20%	20%
	GENERAL (overall rating, Figure 7.3)	**0%**	**10%**	**45%**	**40%**	**10%**
19	How well organised is the system?			40%	40%	20%
20	How user friendly is the system?			60%	40%	
21	How well integrated are the different components of the system?		20%	40%	40%	
22	What is your overall rating of the prototype system?		20%	40%	20%	20%

Table 7-2: Comments related to the benefits of the prototype system, and suggestions on how to improve the system

Benefits of the Prototype System	Suggestion for Improvements	Other Comments
• Concise. • Time saving. • Guidance to locate the required information when needed. • Aid the training of building surveyors /specialists in the flood resilience industry • Help prompt the use of flood resistance/resilience measures on a property that has suffered flood damage • Good possibility for insurance companies and their networks to use to help reduce costs. • Insurance industry could use this system to cover if resilience measures could be installed to property at flood risk. This could be before or after a flood event. The cost of resilience could be paid off in a lump sum by the resident or through a premium payment over a number of years to an insurance company.	• Accuracy in terms of improvement (i.e. case studies). • Provide H&S warnings where flood resilience will be unsuitable e.g. High water levels, no flood warning service • Provide the cost of different options (indication only) • Provide the cost benefit figures, helps to show resilience measures can be justified. e.g. home price vs. cost of remediation (resilience). • Provide a list of resilience options and provide preferred options, based on cost, H&S etc. • Provide more than one repair option. • Commercialised the system.	• Mobile version can be produced to use by public

7.5 DISCUSSION

The outcomes from the evaluation of the prototype system are discussed under five headings: results, suggestion for improvements; benefits; limitations; and appropriateness of the evaluation approach.

7.5.1 RESULTS

All the participants were satisfied with the prototype system performance and effectiveness. Figure 7.1 shows the overall rating from the experts on the system performance when referred to questions 1–10 based on Table 7.1. From the participants' points of view, the prototype system performance can be reflected as 'Good',' Satisfied', 'Excellent' and 'Fair'. Based on these findings, it can be summarised that the system gives an overall good performance.

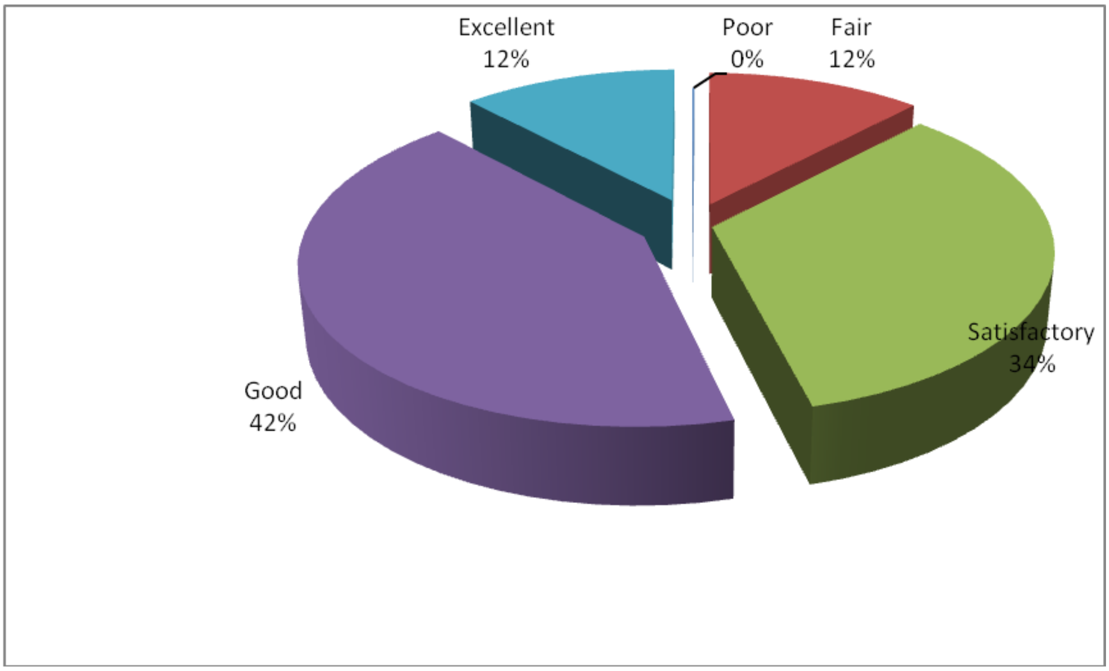


Figure 7-1: Overall rating from the experts on the system performance

The applicability of the prototype system to Applicability to Vulnerability and Remediation Assessment of Flooded Residential Building industry also demonstrates a positive view from evaluators. Figure 7.2 highlights the overall rating given by experts when asked about the applicability of the prototype system to the flooded residential building management industry (refer to Table 7.1, questions 11–18). The majority of the evaluators rate the applicability of the prototype system as 'Good', followed by

'Satisfactory' and 'Fair' and 'Excellent'. Based on these findings, it can be summarised that the prototype system is applicable to the flooded residential building damage management industry.

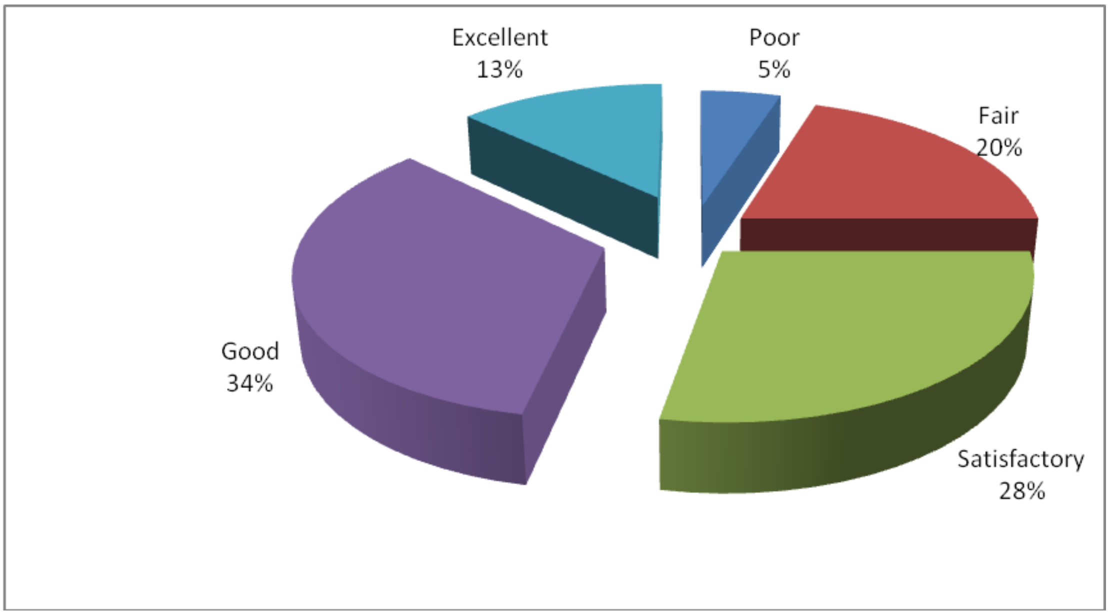


Figure 7-2: Overall rating of the applicability of the prototype system to the flooded residential building management industry

Figure 7.3 shows the overall rating given by the flood damage management experts (refer to Table 7.1, questions 19–22). The rating given by the experts regarding to this section is mainly 'Satisfactory' followed by 'Good' then 'Fair' and 'Excellent'. Based on these findings, most of the experts agree that the overall rating of the prototype system is 'Good'.

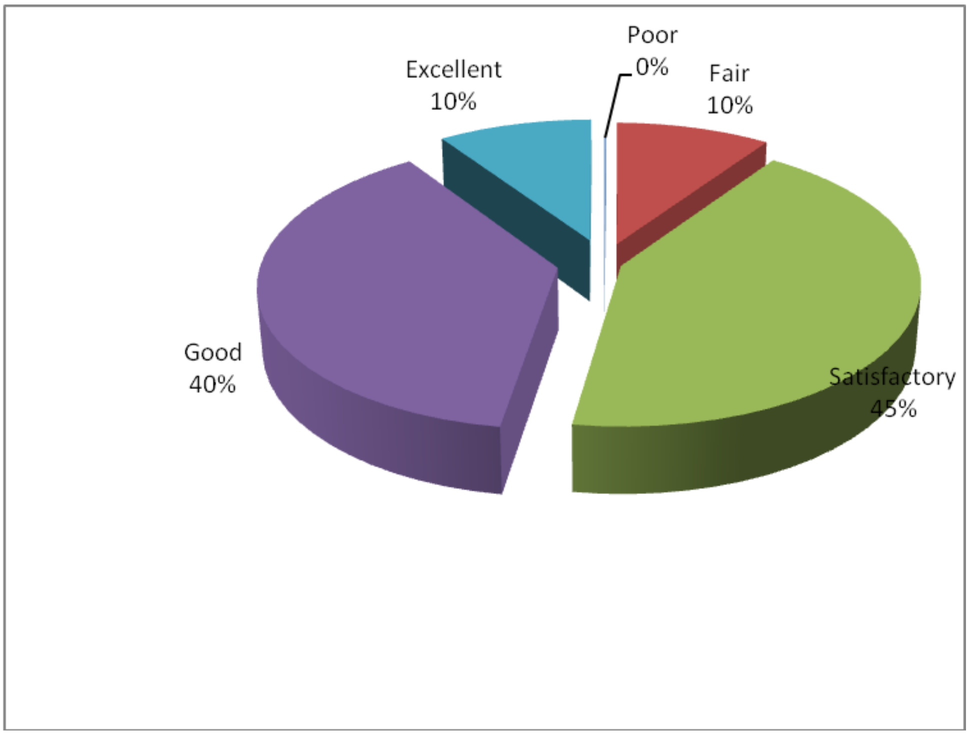


Figure 7-3: Overall rating of the prototype system

7.5.2 SUGGESTIONS FOR IMPROVEMENT

Most of the respondents made at least one comment throughout the evaluation questionnaire, as presented in Table 7.2. The main suggestions included providing the cost of different repair options, and the cost benefit figures, which help in justifying the selection of resilience options because of its extra costs compared with ordinary remediation options. One of the respondents suggested improving the accuracy of the prototype system based on previous case study. One of the respondents also suggested that the system could provide more repair options. Three of the respondents suggested that there was the potential for the system to be commercialised as well as the production of a mobile version for use by the public.

7.5.3 BENEFITS OF THE PROTOTYPE

Through the evaluation, the respondents identified several practical benefits of the prototype system, including:

- Concise: the system summarise the evaluation of vulnerability and selection of remediation options in short and concise form.
- Time-saving: the system can help in providing of repair strategies by demonstrating a repair options and flood damage scenarios.
- Guidance to locate the required information when needed: the system provides all the information required in organised form.
- Aid the training of building surveyors/specialists in the flood resilience industry
- Help prompt the use of flood resistance/resilience measures on a property which has suffered flood damage.
- Good possibility for insurance companies and their networks to use in order to assist with reducing costs.
- Insurance industry could use this system to establish if resilience measures could be installed to properties at flood risk. This could be before or after a flood event. The cost of resilience could be paid off in a lump sum by the resident, or otherwise through a premium payment over a number of years to an insurance company.

7.6 SUMMARY

This chapter has provided a summary of the prototype system evaluation. The research adopted questionnaire techniques in evaluating the prototype system. The results from the evaluation show that the prototype system illustrates good performance, and is suitable for use in the residential building flood damaged building industry. Finally, the comments and suggestion from the evaluation have been used to refine the prototype system. The next chapter presents the conclusion and recommendations of the research.

CHAPTER 8 CONCLUSION AND RECOMMENDATIONS

8.1 INTRODUCTION

This chapter concludes the research project, which has resulted in the development of a knowledge base system named 'Vulnerability and Remediation Assessment of Flooded Residential Buildings' (VRAFRB). This chapter summarises all the findings of the research, and is followed by the benefits and limitations of the prototype system. It also presents the conclusions, and makes recommendations for further research.

8.2 SUMMARY

The reason for conducting this particular study is the necessity to provide an improved tool for the management of residential flooding, with the potential to conduct an assessment to determine the vulnerability of properties, as well as recommending solutions. In order to fulfil such a requirement, the study pursued a fundamental goal, which was to create a systematic method of facilitating the selection of remediation options in direct consideration of the risk assessment. This goal was broken down into a number of different objectives:

- to review the exposure of residential buildings to the risk of flood damage, especially in the UK
- to review recent developments in research into the vulnerability assessment and remediation of residential buildings subjected to flooding

- to develop a method to assess the vulnerability of residential buildings subjected to flood damage
- to undertake detailed case studies with a view to establishing current industry practice, identifying opportunities for improvement and establishing end-user requirements
- to develop a framework and functional specification for an intelligent approach to the vulnerability assessment and remediation of residential buildings subject to flood damage
- to implement and evaluate a prototype system based on the functional specification developed above and on test cases from industry.

Various research methodologies and strategies have been adopted in order to achieve the defined objectives of the research. The initial strategies included an extensive literature review, participation at workshops and seminars to interact with other researchers and professionals in similar research areas, and discussions with practitioners in the flood damage industry. The knowledge acquisition process was undertaken following this initial stage in order to capture the knowledge relating to vulnerability assessment and management of flood damage to residential buildings. The methods applied include a survey using a postal questionnaire and interviews, and data-gathering through documents related to the topic. Following the capturing of knowledge, the rapid prototyping methodology was applied during the process of developing the prototype system. The prototype was evaluated after the development process in order to verify, validate and improve it. Chapter 2 described the basic concepts and principles of the research methodology.

Definitions of vulnerability, an explanation of vulnerability and hazard assessment with some examples, and the method developed to calculate the vulnerability of residential buildings to flood damage were all presented in Chapter 3. On the basis of the literature review of vulnerability assessment methods, it was highlighted that a comprehensive methodology for risk assessment of buildings subject to flooding has been missing.

With the aforementioned in mind, a method of estimating the vulnerability of buildings to flood damage was developed, based on various key factors—particularly the susceptibility of the building elements to damage by floodwater, as well as the susceptibility of the entire building to flooding (e.g. as a result of its geographical location), leaving aside other considerations (e.g. health risks). This means that only physical damage to the building's elements has been taken into account. The model developed calculates the degree of vulnerability, which indicates how vulnerable the building is to damage when subjected to flooding. The degree of vulnerability was also used to determine the use of either ordinary repair options (in the case of low vulnerability) or resilience options (in the case of high vulnerability). The calculation of vulnerability is one of the subsystems of the prototype system that is being developed.

The review of flood damage management and knowledge base systems was presented in Chapter 4, and was broken down into two parts. During this process, it became clear that, over recent years, the risks and consequences of flood events have become a reality for an increasing number of properties. The degree of damage caused by a flood when in contact with building elements is dependent mainly on flood depth and material type, as well as other factors relating to the location of the building and its condition prior to flooding. Flooding can damage buildings in many ways, although it is recognised that the most common flood damage consists of:

- direct damage at the time of flooding, caused by high speed flows and waves, erosion, or debris carried by the floodwater
- damage caused to building materials by water contact during the flood period and sometimes after.

Essentially, the building elements that are in contact with water during a flood event might be damaged and need repair or replacement. There are also various other issues to be taken into account in the context of flood damage management, including property owners' dissatisfaction with the performance of a particular contractor and/or insurance company, the costs associated with insurance cover, which are not related to risk, the lack of fairness (different standards applied by different companies), and the funding of flood repairs by those not at risk via higher premiums. These issues indicate that there is a fundamental need to improve the flood management of residential buildings, for example through establishing reinstatement repair strategies with not too much variation, increasing the satisfaction of homeowners, allowing better underwriting decisions, promoting fairness, and reducing time and the costs of repair by introducing resilience repair options.

The literature review reveals that there is no system that can be used to evaluate the vulnerability of residential buildings to flood damage, or to assess vulnerability in terms of the selection of remediation options. The selection of remediation options and risk assessment are based on the contractor's or building surveyor's judgment, with the result that two similar houses in the same area may have a different insurance premium or different repair costs if they are flooded. In view of this, the owners of the damaged buildings can benefit from using the knowledge base system to assess the vulnerability of such buildings in regard to flood damage, and in the selection of remediation options; this saves time and helps to standardise repair strategies and therefore provide fair insurance to the resident.

The knowledge acquisition process is an important part of the development of the knowledge base system for the Vulnerability and Remediation Assessment of Flooded Residential Buildings. Knowledge was acquired from different sources relating to vulnerability assessment and flood damage management with the aim of developing a prototype system, as presented in Chapter 5. The knowledge acquisition process involved capturing and gaining knowledge from different sources to develop a vulnerability assessment model including factors which contribute to flood damage, to assign weighting or rating to the factors, and finally to produce the vulnerability assessment model. Accordingly, the required information was arranged in the form of tables or charts, which could be used in the selection of remediation options to develop the remediation options selection subsystem and foundation damage assessment subsystem as parts of the prototype system.

An industry survey was carried out by postal questionnaire to study the factors considered to affect flood damage. The aim was to help in the weighting and rating of factors when developing the vulnerability assessment model, and thereby to reveal any other factors that might not have been considered. The knowledge relating to the remediation options and their selection was collected by postal survey and the review of related documents. Knowledge was also captured during attendance at workshops relating to the topic, with contributions from experts and professionals, and the information gained was accordingly developed and validated in each case through discussion with experts attending the workshops.

The proposed prototype system was named 'Vulnerability and Remediation Assessment of Flooded Residential Buildings System' (VRAFRBS). The development and operation of VRAFRBS was described in Chapter 6.

The prototype knowledge base system comprises three subsystems: degree of vulnerability assessment, remediation options, and foundation damage assessment. The vulnerability assessment subsystem is used to calculate the degree of vulnerability, which will be then used by the remediation options subsystem to select a remediation strategy. The vulnerability assessment subsystem can be used to calculate the degree of vulnerability of the building in relation to flood damage—even if it is not flooded. The remediation options subsystem recommends two strategy options: either ordinary remediation options, in cases where vulnerability is low, or resilience remediation options, in cases where vulnerability is high. The foundation damage assessment subsystem works alone, and is used to assess the damage caused by flood to the building foundation and to recommend a repair option based on damage caused and foundation type.

The evaluation of the prototype system after it had been developed was described in Chapter 7. The research adopted a questionnaire technique in evaluating the prototype system. The evaluators chose to approach different people related to different flood damage issues, including people from the industry, researchers, and experts in risk and vulnerability assessment. The evaluation confirms that, even though some improvements were required to make the system more effective, it does provide many benefits, demonstrates good performance, and is highly applicable for use in the flood-damaged buildings industry.

As can be seen from the above, the objectives of the research project have generally been achieved.

8.3 BENEFITS OF THE PROTOTYPE SYSTEM

The prototype system offers many benefits to engineers and others involved in management and damage assessment of flooded residential buildings.

- It provides a clear and structural framework which assists in the vulnerability and remediation assessment of flooded residential buildings. The repair strategies are recommended on the basis of the degree of vulnerability calculated, whether ordinary or resilience options are recommended.
- It saves time by providing in an organised manner all the information required to develop a repair strategy quickly. The system user is able to discuss the different options available with the client and display them more easily.
- The system can work as a guide to locate the required information when needed.

- The system can be used by insurance companies to assess the risk for different residential buildings and to provide an appropriate basis for insurance cost estimation. All the respondents emphasised this in their discussion during the evaluation of the system.
- The system can aid the training of building surveyors in the flood resilience industry.
- The system offers a good possibility for insurance companies and their networks to reduce costs through its utilisation.
- The system can help in the standardisation of repair strategies and insurance premium calculation for residential buildings.
- The system can help to provide repair strategies through demonstrating repair options and flood damage scenarios.
- The system provides all the information required in an organised format.
- The system can help to prompt the use of flood resistance/resilience measures on a property which in areas of high flood risk.
- The insurance industry could use this system to cover if resilience measures could be installed to property at risk of flooding. This could be either before or after a flood event. The cost of resilience could be paid off in a lump sum by the resident, or otherwise through a premium payment over a number of years to an insurance company.

8.4 LIMITATIONS OF THE PROTOTYPE SYTEM

The limitations of the prototype system include the following:

- The prototype system is designed for use in the case of residential buildings specifically in the UK.
- The vulnerability calculated represents the damage to building elements due to flooding and the cost of repair.

8.5 CONCLUSIONS

Several conclusions can be drawn from the research. These include:

- More homes will be at risk of flooding because of the impacts of climate change, which means that more attention needs to be directed to the area of flood risk management research, including the management of flood-damaged residential buildings. It is difficult to prevent floods from occurring, but the effects of floods can be managed in order to reduce risks and the costs of repair.
- There are some major issues related to the existing management of flood damaged buildings that require attention to improve this industry: these include an increased need for professional advice to both individuals and developers on designing for floods, the need for definitive guidance on repairing flood-damaged buildings to minimize variations in subsequent repair and reinstatement works, and the inclusion of flood resilience measures in the repair of flood-damaged buildings to reduce the cost of repair in the future in high flood risk areas.
- Defining vulnerability can help us decide how to reduce it. Assessing the vulnerability of buildings in flood-prone areas is a key issue when evaluating the

risk induced by flood events; nevertheless, a comprehensive methodology for risk assessment of buildings subject to flooding is still missing.

- Vulnerability of residential buildings can be assessed on the basis of the factors that are considered to contribute to vulnerability to flood damage.
- In this research a method of assessing the vulnerability of residential buildings to flood damage was developed, based on the factors that are believed to contribute to flood damage to buildings. The developed model is based on key factors—in particular, the susceptibility of the building elements to damage by floodwater, as well as the susceptibility of the entire building to flooding (e.g. as a result of its geographical location). These factors were then ranked and given numerical weight based on their importance, and these weightings were then used to calculate the degree of vulnerability (as a numerical value) which was then converted to a descriptive rating. The model is based on the weighting and rating of factors which are known to contribute to flood damage, and a simple mathematical equation has been used to calculate the degree of vulnerability, were then incorporated into a piece of software written by the author and accordingly used as a part (subsystem) of the entire developed knowledge base system.
- This research reveals that the knowledge relating to flood damage management is written in books and technical reports, as well as guides and journal papers, and codes of practice. This knowledge is either too general or too specialised for practical purposes, and the task of searching through many documents for information relating to a particular situation is time-consuming. So there is a need for an organised and concise system to evaluate the vulnerability of residential buildings subjected to flood damage, which should comprise all

information relating to repair methods and the procedure of remediation of buildings damaged by flood, and lead to standardised and speedy repair of flooded buildings. Such a system should also help in establishing the basis for the risk assessment and repair process of flooded residential buildings. In addition, the system should also include resilience options as another repair option which could reduce the time and cost of repairs in case the building is flooded in the future.

- The knowledge base system proposed in this research has the aim of achieving the following objectives:
    - to assess and evaluate the vulnerability of buildings to flood damage, and to consider factors contributing to building flood damage
    - to assist in the selection of repair methods and procedures to be followed when dealing with flooded buildings, based on the degree of vulnerability to flood damage
    - to aid in the selection of suitable flood damage reduction options by introducing resilience options as these will reduce the cost of future damage repair. The resilience remediation options are only recommended when the vulnerability of buildings to flood damage is high.
- The repair methods suggested by the knowledge base system are mainly based on the standard repair methods available in documents such as repair manuals and technical reports.
- The overall evaluation of the proposed knowledge base system was concerned with establishing the overall functionality and usability of the final prototype

system. In order to achieve this goal, the particular objectives of the evaluation were:

- to assess the performance of this prototype system in general
- to determine the extent of applicability of the system for use in the assessment of vulnerability of residential buildings to flood damage and their remediation
- to obtain observations and suggestions on improving the status of the prototype of the system.

- The proposed system could help in standardizing the repair and management of damage to flooded residential buildings.

8.6 RECOMMENDATIONS FOR FURTHER RESEARCH

This research project has revealed a number of areas for further research and development, including:

1. Further improvements to the prototype system, with respect to:
    - adding more repair options to the options suggested by the system, based on different real cases
    - updating the resilience repair options on the basis of new materials and new techniques
    - improving the user interface and adding more facilities and functions.

2. Further research should be carried out to improve the accuracy of the degree of vulnerability assessment on the basis of real data considering sub-factors and previous flood damage cases.

3. The system should be integrated with other systems which are applied to calculate the cost, to enable the system to estimate the cost of repair and make comparisons between different repair strategies based on their cost.

4. From observations during the research project, it seems that the literature available on damage to building elements caused by flooding and its relations with other factors (flood characteristics, building characteristics) is limited; therefore, more research should be carried out in order to investigate these relations.

5. More research is also needed to investigate the damage caused by flooding to different building foundations, since the literature available is very limited.

6. Further research should be carried out with the aim of improving the prototype system, which can be effectively used as a teaching and training tool.

7. The research has explored in detail the management of flood damage to residential buildings, and gathered various types of information; this can be used as a basis for further research in relation to the vulnerability of residential buildings to flood damage and the selection of remediation options.

8.7 CLOSING REMARKS

The development system will contribute to improving the management and repair of buildings damaged by flood; the system will not completely replace human experts, but will nevertheless help stakeholders in this industry. This research provides a small contribution to the improvement of the management and repair of flood-damaged residential buildings.

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APPENDIX-A

Loughborough University

Yusef A Fiener
Department of Civil and Building Engineering
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Survey on the factors contributed to vulnerability of residential building to flood damage

A- BASIC INFORMATION
1-Name of respondent (Optional):...R. Soetanto... Position:...Senior Lecturer...........
2- Experience in the field of property damage assessment and repair (in years): 8
3-Company or organisation name and address
(Optional):....Coventry...University....Dept of Built Environment.......Coventry... CV1 5FB
4-Tel/Fax:................................. 5- Email /URL known

This questionnaire aims to investigate the factors contributed to vulnerability of residential building to flood damage. The factors seem to be contributed to vulnerability of residential building to flood damage are listed below. You can add any addition factors you thought they should be included. Please (tick one) *Not important, Important* or *very important* in front of each factors listed in the table below.

No	*Factor description*	*Not Important*	*Important*	*Very Important*
1	Geographic Location of the building within the flood risk zone based on the flood maps provided by the Environmental Agency			✓
2	Building protection by flood defenses.			✓
3	Topography of the building site (the building located at the base of a valley or bottom of hillside).			✓
4	The building is close to intermittent stream.			✓
5	The building is underlain by chalk aquifer.			✓
6	The soil is often near saturation point or impermeable.			✓
7	Duration of previous flood was greater than 12 hours.		✓	
8	Depth of the previous flood was above the building floor.		✓	
9	Issuing of the flood warning for this area in the past.			✓
10	Occurring of the sewer flood in the past.		✓	
11	The building has been flooded in the past.			✓
12	The building has a timber (walls or frames).		✓	
13	The building has a crakes in the walls near the floor level.		✓	
14	The building has a gypsum plaster.		✓	
15	The building has a mineral insulation.		✓	
16	The condition of the building prior the flood.			✓
17	The building has a Chipboard floor; wood, vinyl, and rubber tiles floor		✓	
18	The building has a water resistance doors and windows and kitchen like PVC or any other water resistant material.			✓
19	Gas and electrical utilities are located above the flood level			✓
20	Existing o any flood resistance or resilience measures			✓
21	Existing of backflow devices on sewer system.			✓
22	Previous flood damage			✓
23	Other factors (Please specify)			
24				
25				

Room for Additional comments

-Please tick the following box if you wish to receive of the result summary. ☑

If you have any queries please contact me via email at Y.A.Fiener2@lboro.ac.uk or Tel: 07525356311.

Thank you for taking the time to complete this questionnaire. Please return it in the addressed, prepaid envelope provide or Email

APPENDIX-B

Loughborough University

Yusef A Fiener
Department of Civil and Building Engineering
Loughborough University
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This questionnaire aims to collect data about the previous dwelling flood damage cases and investigate the different remediation options with respect to flood damage of different building elements, finally rank the factors contributed to flood damage. The data required include general data, flood characteristics, building characteristics and selection of remediation options.

Part 1 General and flood characteristics

1-Location: LONDON N7 2- When flooded: 2007 & 2007

3- Post code (Optional): 4-Building Age in years: 170 5- Flooded Basement: Y/N YES

6-Type of building (Please tick one)

Bungalow	Detached	Semidetached	Terrace	Ground flat	Other Please speci
			✓		

7- Depth of flooding outside the building (measured from ground level): m. 0.2
8- Depth of flooding inside the building (measured from floor level): m. 0.2
9-Depth of flooding measured with respect to Damp Proof Course (DPC) - Below DPC: cm. 0.5M –Above DPC: cm N/A.

10-Type of flooding water (Please tick one)

Fresh water	Salt water	sewage water	Other (please specify)
THAMES WATER			

11-Duration of flooding (Please tick one)

1-3 hours	3-6houres	6-12 hours	12-24hours	>24 hours(please specify)
	✓			

12- Flood velocity: ~~Slow~~ / High

13-Flood deposits and contaminants content (Please tick one)

No contaminants	Silt	Fuel , oil or grease	Other Hazardous material	Sewage water	Other (please specify)
✓					

14- Flood sources (Please tick one)

The sea	The river	Overland flow	Rising ground water	Blocked drains or sewers	Broken water mains	Other (please specify)
					✓	

15-Flood defence (Please tick one and fill)

No flood defence exist	Flood defences exist	Approximate distance to flood defence in m.	Flood defence type
✓		5m	

Part 2 Building characteristics and damage

1-Times the home being flooded (Please tick one)

This is the first time	One time before	Two times	Three times	Four times	More than four times (please specify)
	✓				

2-The building condition before being flooded (Please tick one)

Excellent	Very good	Good	fair	Poor	Not available
		✓			

3- General damage assessment (Please tick one)

Building components	*No damage*	*Slightly damage*	*Moderate damage*	*Highly damage*	*Completely damage*	*Estimated percent of damage*
Foundation						
Floors			~~✓~~		✓	
Internal walls			~~✓~~		✓	
External walls						
Utilities						
Kitchen						
Other (please specify)						

1

Part 3 Damaged remediation

A - Building Drying methods (Please tick one)

No.	Drying method	Please tick one
1	Install temporary heating	
2	Install refrigerant dehumidifier	
3	Install desiccant dehumidifier	✓
4	Increase ventilation with fans	
5	Building's heating system	
6	Natural ventilation	

B-Foundation damage

No	*Type*	*Please tick one*	*Damage caused*	*Repair strategy*
1	Masonry and brick foundations	✓	NONE	
2	Strip foundation			
3	Pier on beams foundations			
4	Timber piles			
Other (Please specify)				

C -Flooring remediation options

Flooring type (Please tick one)

No	*Flooring type*	*Please tick one*	*Go to*
1	Vinyl floor tiles		Please go to 1 below
2	Vinyl sheet floor		Please go to 2 below
3	Quarry tiled floor		Please go to 3 below
4	Solid concrete floor	✓	Please go to 4 below
5	Suspended timber (Chipboard)		Please go to 5 below
6	Suspended timber (Chipboard) floor with tongue and grooved floorboards		Please go to 6 below
7	Concrete floor		Please go to 7 below
8	Other (Please specify)		

1- Vinyl floor tiles

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend replacement of all floor tiles	
Option 2	Recommend replacement of floor tiles that have become unbounded from the floor.	
Option 3	Raise the floor above the most likely flood level.	
Option 4	Replace with solid concrete floor	
Other (Please specify)		

2- Vinyl sheet floor

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend replacement of floor covering.	
Option 2	Recommend replacement of floor covering if has been damaged by the flood water.	
Option 3	Recommend the floor covering is carefully removed and cleaned and then re-laid	
Option 4	Recommend the floor covering is cleaned in place.	
Option 5	Raise the floor	
Option 6	Replace with concrete floor	
Other (Please specify)		

3-Quarry tiled floor

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend replacement of floor tiles.	
Option 2	Recommend replacement of floor if they have been damaged by flood water.	
Option 3	Recommend the floor tiles be carefully removed and cleaned and then re-laid.	
Option 4	Recommend the floor tiles be cleaned in place.	
Option 5	Recommend the floor tiles be cleaned in place and replaced only where damaged by flood water.	
Option 6	Raise floor levels	
Option 7	Raise the floor level	
Option 8	Replace with concrete floor	
Other (Please specify)		

4-Solid concrete floor

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the floor screed be removed, the floor allowed to dry and then the screed replaced.	✓
Option 2	Recommend that the floor be cleaned and allowed to dry.	
Option 3	Recommend the whole floor construction be replaced.	
Option 4	Raise the floor level	
Other (Please specify)		

2

5-Suspended timber (Chipboard) floor

Options	*Repair strategy*	*Please tick one*
Option 1	Recommend removal and replacement of all timber components	✓
Option 2	Recommend replacement of chipboard	
Option 3	Recommend replacement of only warped and rotten timber components	
Option 4	Recommend removal of certain sections of chipboard so that drying can be aided	
Option 5	Allow floor to dry and then assess replacement of timber components that have warped	
Option 6	Recommend replacement of Chipboard and only warped and rotten timber components	
Option 7	replacement of Chipboard, allow floor to dry and then replace timber components that have warped	
Option 8	Replace floor with treated timber	
Option 9	Raise floor levels	
Option 10	Replace with concrete and cover with tiles	
Other (Please specify)		

6- Suspended timber (Chipboard) floor with tongued and grooved floorboards

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend removal and replacement of all timber components	
Option 2	Recommend replacement of all floorboards.	
Option 3	Recommend replacement of only warped and rotten timber components.	
Option 4	Recommend removal of certain floorboards so that drying can be aided.	
Option 5	Allow floor to dry and then assess replacement of timber components that have warped.	
Option 6	Replace floor with treated timber	
Option 7	Raise floor levels	
Option 8	Replace with solid concrete	
Other (Please specify)		

7- Concrete floor

Option	*Repair strategy*	*Please tick one*
Option 1	Replace all floor covering (i.e. the oak blocks)	
Option 2	Replace sections of blocks that have become unfixed from the concrete floor.	
Option 3	Lift all blocks, dry them and then replace them after the floor has dried.	
Option 4	Leave the floor alone.	
Option 5	Allow floor to dry and then assess replacement of timber components that have warped.	
Option 6	Sand the floor and revarnish it.	
Option 7	Assess after the floor has dried	
Option 8	Raise floor levels	
Option 9	Option 2 and option 5.	
Option 10	Option 3 and option 5.	
Other (Please specify)		

D. Flood damaged Walls 1- Brickwork with cement mortal joints External wall

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the wall be cleaned.	
Option 2	Recommend the wall be cleaned and painted.	
Option 3	Recommend the wall be sandblasted to remove any flood debris.	
Option 4	Leave the floor alone.	
Option 5	Recommend the wall to be left alone.	
Option 6	Recommend the wall be demolished and reconstructed	
Option 7	Install air bricks above expected flood level	
Option 8	Re-point brickwork	
Other (Please specify)		

2-An Internal wall of brickwork with a paint finish applied directly to it

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the wall be repainted.	
Option 2	Recommend the wall be sandblasted to remove any germs.	
Option 3	Recommend the wall be repainted.	
Option 4	Recommend the wall to be cleaned and repainted.	
Option 5	Recommend the wall be cleaned, plastered and decorated.	
Other (Please specify)		

3

3-External wall has a rendered finish

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the render be cleaned	
Option 2	Recommend the wall be sandblasted to remove any flood debris.	
Option 3	Recommend the wall to be left alone	
Option 4	Recommend the wall be demolished and reconstructed	
Option 5	Recommend the render be removed and replaced.	✓
Option 6	Recommend areas of the render that have spalled be replaced	
Option 7	Recommend areas of the render that have become unbounded from the wall substrate be replaced.	
Option 8	Option 1&7	
Option 9	Option 6&7	
Other (Please specify)		

4-An Internal wall covered with ceramic tiles

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the wall be left alone.	
Option 2	Recommend that only loos tiles be replaced.	
Option 3	Recommend that all tiles be replaced.	
Other (Please specify)		

5-An Internal wall covered with a wood veneer on timber grounds

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the wood veneer be cleaned.	
Option 2	Recommend the veneer in contact with floodwater be replaced.	
Option 3	Recommend the veneer be replaced	
Other (Please specify)		

6-External wall has a pebbledash finish

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the pebbledash render be cleaned.	
Option 2	Recommend the wall be sandblasted to remove any flood debris	
Option 3	Recommend the wall to be left alone.	
Option 4	Recommend the wall be demolished and reconstructed	
Option 5	Recommend all the pebbledash render be removed and replaced.	
Option 6	Recommend areas of the pebbledash render that have spalled be replaced.	
Option 7	Recommend areas of the pebbledash render that have become unbounded from the wall substrate be replaced.	
Option 8	Option 1&7	
Option 9	Option 6&7	
Other (Please specify)		

7-An Internal wall has evidence of a rising damp problem

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the wall be injected with damp proof course (dpc) and the plaster replaced.	
Option 2	Recommend the client be approached to pay for curing the rising damp problem and the plaster be replaced.	
Option 3	Recommend the plaster be replaced with cement/sand render and skimmed with gypsum	
Option 4	Recommend the wall be patched up	
Option 5	Recommend the wall be repaired after it has dried	
Other (Please specify)		

8-An Internal wall decorated with wallpaper

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the wallpaper be replaced.	
Option 2	Recommend that only flood damaged wallpaper be replaced.	
Other (Please specify)		

4

9-An Internal block wall has a gypsum plaster finish

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the plaster be cleaned	
Option 2	Recommend the plaster be replaced up to the flood water line (or 15-30cm above).	
Option 3	Recommend the entire wall's plaster be replaced.	
Option 4	Recommend the sections of plaster that have disbanded from the block work be replaced.	
Option 5	Recommend the, plastered be replaced with a cement/sand render and a skim finish.	
	Recommend the, plastered be replaced with a lime plaster	
Other (Please specify)		

10-An Internal block wall which has cement /sand mix undercoat and a 1mm plaster skim applied to it.

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the plaster be cleaned	
Option 2	Recommend the plaster be replaced up to the flood water line (or 15-30cm above)	
Option 3	Recommend the entire wall's plaster be replaced.	
Option 4	Recommend the sections of plaster that have disbanded from the block work be replaced.	
Option 5	Recommend the, plastered be replaced with a cement/sand render and a skim finish.	
	Recommend the, plastered be replaced with a lime plaster.	
Other (Please specify)		

11-An Internal timber partition wall

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend all the plasterboard be replaced	
Option 2	Recommend plasterboard that has been in contact with flood water be replaced.	
Option 3	Recommend the timber components and the plasterboard be replaced.	
Option 4	Recommend the timber and plasterboard that have been in contact with flood water be replaced.	
Option 5	Attempt to dry and sanitise the wall and reassess after it dry.	
Other (Please specify)		

12-An Internal brick wall which has a lime/ox-hair mix and lime putty finish

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the plaster be cleaned	
Option 2	Recommend the plaster be replaced up to the flood water line (or 15-30cm above).	
Option 3	Recommend all the wall's plaster be replaced.	
Option 4	Recommend the sections of plaster that have disbanded from the block work be replaced.	
Option 5	Recommend the, plastered be replaced with a cement/sand render and a skim finish.	
Other (Please specify)		

13-Internal timber partition wall

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend all the plasterboard be replaced	
Option 2	Recommend plasterboard that has been in contact with flood water be replaced.	
Option 3	Recommend the timber components and the plasterboard be replaced	
Option 4	Recommend the sections of plaster that have disbonded from the blockwork be replaced.	
Option 5	Recommend the, plastered be replaced with a cement/sand render and a skim finish.	
Other (Please specify)		

14-An Internal metal-framed partition wall

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend all the plasterboard be replaced	
Option 2	Recommend plasterboard that has been in contact with flood water be replaced.	
Option 3	Recommend the metal components and the plasterboard be replaced.	
Option 4	Recommend the metal and plasterboard that have been in contact with flood water be replaced.	
Option 5	Attempt to dry and sanitise the wall and reassess and check for corrosion after it is dry.	
Other (Please specify)		

E- Doors and windows **1**-Soft wooden front door

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the door be replaced.	
Option 2	Recommend the door be repainted.	
Option 3	Allow the door to dry out and then assess the damage	
Option 4	Clean the door only	
Option 5	Replace with water resistance alternative.	
Other (Please specify)		

5

2-Double glazed hardwood patio doors

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the door be replaced.	
Option 2	Recommend the door be repainted.	
Option 3	Allow the door to dry out and then assess the damage	
Option 4	Clean the door only.	
Option 5	Recommend replacement of the glazing units if the seals have perished.	
Option 6	Option 3 and 5.	
Option 7	Replace with water resistance alternative.	
Other (Please specify)		

3-PVC external door

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the door be replaced	
Option 2	Recommend the door be repainted.	
Option 3	Allow the door to dry out and then assess the damage	
Option 4	Clean the door only	
Option 5	Recommend replacement of the glazing units if the seals have perished	
Option 6	Option 3 and 5.	
Option 7	Option 4 and 5.	
Other (Please specify)		

4-Wooden window frames

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the windows be replaced.	
Option 2	Allow the windows to dry out and then assess the damage	
Option 3	Allow the windows to dry out and then assess the damage	
Option 4	Clean the windows and frames only.	
Option 5	Recommend replacement of the glazing units if the seals have perished.	
Option 6	Replace with water resistance alternative.	
Other (Please specify)		

F- Utilities and fittings 1-Steel panel radiators

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the radiator and valves be replaced.	
Option 2	Recommend the radiator valves be replaced	
Option 3	Recommend the radiator be left alone	
Option 4	Allow the radiator to dry, clean/sanitise, and then repaint.	
Other (Please specify)		

2-Gas fired heater

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the heater be serviced	
Option 2	Recommend the heater be replaced.	
Option 3	Recommend the heater be fitted with new controls.	
Option 4	Inspection and report by specialists	
Other (Please specify)		

3-Gas meter

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the meter be replaced.	
Option 2	Recommend the meter be checked for leaks.	
Option 3	Recommend the heater be fitted with new controls.	
Option 4	Inspection and report by specialists	
Option 5	Recommend the connections to the meter be made again	
Option 6	Refer to gas supplier.	
Option 7	Move the meter above likely flood level	
Other (Please specify)		

4-Wall- hung gas fire

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the fire be serviced.	
Option 2	Recommend the fire be replaced.	
Option 3	Recommend the fire be fitted with new controls.	
Option 4	Inspection and report by specialists (qualified gas engineer)	
Other (Please specify)		

6

5-Electric circuit containing sockets

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend complete replacement of this installation	
Option 2	Recommend replacement of electrical wiring and fittings installed below the flood line.	
Option 3	Recommend electrical circuit be checked by an electrician and any faults rectified.	
	Move electrics well above likely flood level	
Other (Please specify)		

6-Wall-hung electrical heater

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend the heater be replaced.	
Option 2	Recommend the heater be left alone.	✓
Option 3	Recommend electrical circuit be checked by an electrician and any faults rectified.	
Option 4	Recommend that the heater be checked by an electrician.	
Other (Please specify)		

7-Timber skirting boards

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend replacement of all skirting boards.	
Option 2	Recommend replacement of skirting boards that are damaged by flood water.	
Option 3	Allow skirting boards to dry and recommend replacement of damaged sections of boards.	
Option 4	Leave existing skirting boards in place.	
Other (Please specify)		

8-Staircase constructed from timber

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend complete replacement of the staircase.	
Option 2	Recommend replacement of timber components that have been in contact with the flood water.	
Option 3	Recommend the stair be allowed to dry and then assess any damage caused.	
Option 4	Recommend the stair to be left alone.	
Other (Please specify)		

9-Built-in wall cupboards

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend complete replacement of the cupboards	
Option 2	Recommend replacement of timber components that have been in contact with floodwater.	
Option 3	Recommend the stair to be left alone.	
Option 4	Replace with plastic equivalent.	
Other (Please specify)		

10-Fitted kitchen

Option	*Repair strategy*	*Please tick one*
Option 1	Recommend replacement of the complete kitchen	
Option 2	Recommend replacement of those units that have been in contact with flood water.	
Option 3	Allow the units to dry out and replace only those kitchen unit panels that have been damaged.	
Option4	Replace with plastic equivalent.	
Other (Please specify)		

Time taken to complete all remediation : 10 Days.

Part 4- Flood damage factors (Pleas rank these factors based on their contribution to building flood damage (1 is more important

Factor	*Rank*	
Flood depth	✓	3
Flood speed	✓	2
Flood Type		4
Contaminants content		8
Flood duration	✓	1
Building Age		5
Building condition prior to flood		7
Building material type		6
Other (please specify)		

5- Room for Additional comments

____

____

____

____

____

____

7

-Please tick the following box if you wish to receive of the result summary.

-Company name/Consultant:

If you have any queries please contact me via email at Y.A.Fiener2@lboro.ac.uk or Tel: 07525356311.

Thank you for taking the time to complete this questionnaire. Please return it in the addressed, prepaid envelope provided.

8

APPENDIX-C

Data entry sheet for vulnerability assessment of residential building to flood damage

1-Case Number:………………… Date:……………… Time:………………..
2-Address:…………………………………………………………………….
…………………………………………………………………………………

No	*Factor description*	*Please tick Yes or No*
1	Geographic location of the building is within a flood risk zone based on the flood maps provided by the Environment Agency	Yes ( ) No( )
2	Building protected by flood defences.	Yes ( ) No( )
3	Topography of the building site (the building is located on the floor of a valley or at the bottom of a hill)	Yes ( ) No( )
4	The building is close to an intermittent stream	Yes ( ) No( )
5	The building is underlain by a chalk aquifer	Yes ( ) No( )
6	The soil is often near saturation point or is impermeable	Yes ( ) No( )
7	Duration of previous flood was greater than 12 hours	Yes ( ) No( )
8	Depth of the previous flood was above the building floor	Yes ( ) No( )
9	Issuing of flood warnings for this area in the past	Yes ( ) No( )
10	Occurrence of sewer flooding in the past	Yes ( ) No( )
11	The building has been flooded in the past	Yes ( ) No( )
12	The building has a timber floor, walls or frames	Yes ( ) No( )
13	The building has cracks in the walls near the floor level	Yes ( ) No( )
14	The building incorporates gypsum plaster	Yes ( ) No( )
15	The building has a mineral insulation	Yes ( ) No( )
16	The condition of the building prior to the flood	Yes ( ) No( )
17	The building has a chipboard, wood, vinyl, or rubber tiled floor	Yes ( ) No( )
18	The building has water resistant doors and windows, and the kitchen has PVC or other water resistant material	Yes ( ) No( )
19	Gas and electrical utilities are located above the flood level	Yes ( ) No( )
20	Existence of any flood resistance or resilience measures	Yes ( ) No( )
21	Existence of backflow devices on sewer system	Yes ( ) No( )
22	Previous flood damage	Yes ( ) No( )

Surveyor Name:……………………..
Signature:……………………………..

comments :

…………………………………………………………………………………………

…………………………………………………………………………………………

APPENDIX-D

Vulnerability and Remediation Assessment of Flooded Residential Building System

Evaluation Questionnaire

This evaluation questionnaire should be completed following a demonstration of the prototype system.

A. *Information about the participant*

Name (optional): ....NIGEL HEWITT....

Your position (e.g. senior engineer, researcher): ....TECHNICAL MANAGER....

Experience in /with flood management/damage restoration industry (years): ....27....

B. *Evaluation of the prototype system*

(Please put a tick in the box that best represents your assessment of a question)

(**1** is **Poor, 2** is **Fair, 3** is **Satisfactory, 4** is **Good, and 5** is **excellent**)

Questions		Rating			
		1	2	3	4
THE SYSTEM PERFORMANCE					
1	How well clear are the factors used in vulnerability assessment?				✓
2	How well does the system help in vulnerability assessment of buildings subjected to flood damage?				✓
3	How well the factors used are contributed to vulnerability?			✓	
4	How useful will the system be in selection of remediation options?				
5	How clear are the remediation options?				✓
6	How appropriate is the remediation options selected?				
7	How useful the degree of vulnerability determined by the system useful in selection of remediation option?				✓
8	How clear are the resilient remediation options presented by the system?				
9	How well the system provide information and save time related to building flood damage?				✓
10	How well the extent of building element presented by the system?				✓

Additional comments:

Questions		Rating				
		1	2	3	4	5
Applicability to Vulnerability and Remediation Assessment of Flooded Residential Building						
11	How effective /accurate is the system in the vulnerability assessment?				✓	
12	To what extent the system assess in remediation options selection?			✓		
13	How convinced are you that damaged flooded building industry professionals will accept (or use) the system?				✓	
14	To what extent does it represent an improvement (or help) in selection of remediation options?					✓
15	To what extent does it accurate (or accepted) in selection of remediation options?				✓	
16	How effectively will the system increase the speed of the selection of remediation strategies?				✓	
17	To what extent is the system flexible in selection of the appropriate remediation option ?					✓

Additional comments:

18	**GENERAL**	**1**	**2**	**3**	**4**	**5**
19	How well organized is the system?				✓	
20	How user friendly is the system?				✓	
21	How well integrated are the different components of the system?				✓	
22	What is your all over rating of the prototype system?				✓	

Additional comments:

C. General comments

1. What do you consider the main benefits of the prototype system?

CLEAR 'AUDIT TRAIL' FROM ASSESSMENT TO REMEDIATION

CONCISE

2. In what ways can the system be improved?

PRICING OF WORK

3. Additional comments

GOOD POSSIBILITY FOR INS COMPANIES + THEIR NETWORKS TO USE TO HELP REDUCE COSTS.