

Building flood resilience measures

Outline design guidance including roadmap for accelerated acceptance

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Lead Author	Manuela Escameia
Contributors	Rutger de Graaf, Wenneke Lindemans, Nicholas Walliman, Flora Anvarifar, Chris Zevenbergen, Kinga Szymanska-Rzeznik, Pawel Poneta, Andy Tagg
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Summary

This report describes work undertaken as part of Task 4.3 of the EC- FP7 Project FloodProBE “Technologies for the cost-effective protection of the built environment” which focuses on critical urban infrastructure. Task 4.3 is part of WP4 which is concerned with construction technologies and concepts for flood defences and damage mitigation. The present report constitutes Deliverable 4.4 “Building flood resilience measures - outline design guidance including roadmap for accelerated acceptance”.

Building for resilience against floodwater has become an increasingly important target for new constructions as a means of complementing formal flood protection measures provided by municipalities, relevant authorities or organizations with responsibility for flood defences. Such measures are important where there is a residual or local risk of flooding, or where a large scale, publicly-funded scheme is not feasible.

Guidance on the selection of flood proofing construction methods for buildings is given in this report taking into account flood duration and expected flood depth. Flood proofing is a way of constructing buildings to make them resilient against flooding and can be achieved by avoiding contact with floodwater or by making the building resilient to the potential damage caused by floodwater. Particular emphasis has been given in this project to understanding the role of building materials and for that purpose a comprehensive review was undertaken of existing guidance on resilience of building materials across Europe and elsewhere. A number of gaps in knowledge were identified, namely the scarcity of quantitative-based guidance and, despite the endorsement of resilience, the lack of translation of this aim into either national Building Regulations or International Standards.

The study also presents the steps necessary to conduct a cost-benefit analysis (CBA) for flood resilient measures. The method can be used to analyse the outcome of different resilient measure activities. It aims to offer a transparent and accessible approach where the costs of mitigating adverse flood impacts are taken into account. It has also been highlighted that factors other than monetary should be included in any option appraisal analysis. These factors include considerations of waste minimisation, carbon emissions reduction, sustainability of natural resources and use of recycling materials.

The application of a tool for the estimation of flood damage of individual buildings that has been developed under the FloodProBE project (WP2, Task 2.2) is also described in this report for the case of a flooded retail outlet and warehouse. This case study illustrates how the tool will enable informed and quantifiable decisions to be made with regard to the most suitable construction types to minimise flood damage. This is considered an important step in helping the decision process of those designing new critical buildings or retrofitting them. This also provides owners and insurers with an enhanced basis for decisions regarding the value of implementing new measures and the timing of such measures.

A roadmap for increased uptake of building flood resilience has been outlined and recommendations made for new European/national standards as important vehicles for the wider spread of resilient building materials and techniques. For an effective uptake of building resilience, it is suggested that regulation should be supported by European legislation. Could an EU Directive on Flood Resilience provide the

necessary legislative push? European norms covering the definition of flood resilience and building flood resilience as well as testing protocols for materials and construction assemblies would be useful standards for the promotion of flood risk management at building level. European-funded projects are currently assessing the feasibility of new codes and norms to increase the trust in, and therefore uptake of the various flood resilient measures that are already available for limitation of flood damage at building level.

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1 Introduction

1.1 Background

FloodProBE is a European research project with the objective of providing cost-effective solutions for flood risk reduction in urban areas. FloodProBE aims to develop technologies, methods and tools for flood risk assessment and for the practical adaptation of new and existing buildings, infrastructure and flood defences leading to a better understanding of vulnerability, flood resilience and defence performance. This research supports implementation of the Floods Directive through the development of more effective flood risk management strategies. The work is being undertaken in close partnership with industry, and is utilising pilot sites across Europe, to help provide practical industry guidance and cost effective construction solutions.

The FloodProBE activities have been structured according to the following work packages (WP):

- *WP2* addresses issues related to the vulnerability understanding and assessment of the vulnerability of urban areas or systems.
- *WP3* deals with failure modes and the assessment and identification of weak spots in urban flood defences.
- *WP4* investigates cost-effective construction technologies and concepts for improving the performance of existing and new flood defences and for increasing the flood resilience of urban systems and assets
- *WP5* supports integration of the research and newly developed knowledge into existing decision support models or systems, the production of industry guidance and the interaction and integration of pilot site studies across Europe.
- The dissemination and stakeholder-involvement activities are addressed under *WP6* whilst *WP1* comprises all activities related to the management of the consortium.

The work described in this report is part of *WP4* “Construction technologies and concepts for flood defences and damage mitigation” and is Deliverable 4.4 “Outline design guidance on building and infrastructure resilience measures”. It was produced by HR Wallingford with contributions from DeltaSync (in Section 2), Oxford Brookes (in Sections 3 and 5), Mostostal (in Section 3) and Dura Vermeer (in Section 4).

Building for resilience against floodwater has become an increasingly important target for new constructions as a means of complementing formal flood protection measures provided by municipalities, relevant authorities or organizations with responsibility for flood defences. Such measures are important where there is a residual or local risk of flooding, or where a large scale, publicly-funded scheme is not feasible. It can also help shift the responsibility of protecting property to private owners avoiding sole dependence on public funding. Although total independence from public funding is not possible or desirable, resilience/resistance at property level can be an attractive option to owners of private buildings

with a critical function in the urban environment, such as private hospitals and providers of telephone/internet/mobile phone communications services.

It is accepted that achieving flood resilience in new builds is easier than for retrofits; this stems often from a lack of regulatory or legislative push, but also from the fact that older buildings pose more technical limitations to choices of methods/materials and owners can have a more defined aesthetic view of what can or cannot be achieved. However, along with the inherent difficulties associated with existing buildings, for critical building infrastructure retrofitting opens up a major opportunity for implementation of preventative flood protection measures.

Resilience at property level can be achieved by the use of adequate construction materials and methods of construction, layouts and flood protection products, combined with careful site considerations that minimise the potential for exposure to floodwater. The provision of safe access to the building is also of paramount importance – this is dealt with in other deliverables from this project.

1.2 Scope

The present report is aimed at professionals in the field of flood management, in particular those interested in urban flooding (planners, design engineers, surveyors, architects and owners of critical infrastructure buildings as well as researchers of building flood resilience).

The specific research actions on building flood resilience comprised:

- Identification of requirements and development of concepts for critical (or hotspot buildings), i.e. buildings on which the functioning of urban societies rely in times of flooding (see Section 2 of this report)
- Definition of methods for flood proofing of buildings and guidance on their applicability (see Section 2)
- A review of the state-of-the-art in resilient building materials and constructions across and outside Europe (see Section 3)
- Definition of cost benefit analysis for critical buildings (see Section 4)
- Cost assessment of building resilience measures for critical buildings (see Section 5)
- Outline of roadmap for implementation of resilience measures at building level (see Section 6).
- Conclusions, presented in Section 7.

2 Critical Buildings

2.1 Definitions

In the context of FloodProBE, the building types considered are those that are critical for the functioning of urban societies, i.e. buildings where essential services are housed and which, should they be affected by flooding, would severely disrupt the running of urban societies.

The schematic in Figure 2.1 illustrates the point that functionality is dependent on three main parameters: the actual building (i.e. how it is built), the measures used to minimise the risk of flooding (i.e. where it is built) and the measures adopted to ensure it can operate effectively (i.e. reliance on external suppliers of services and goods).

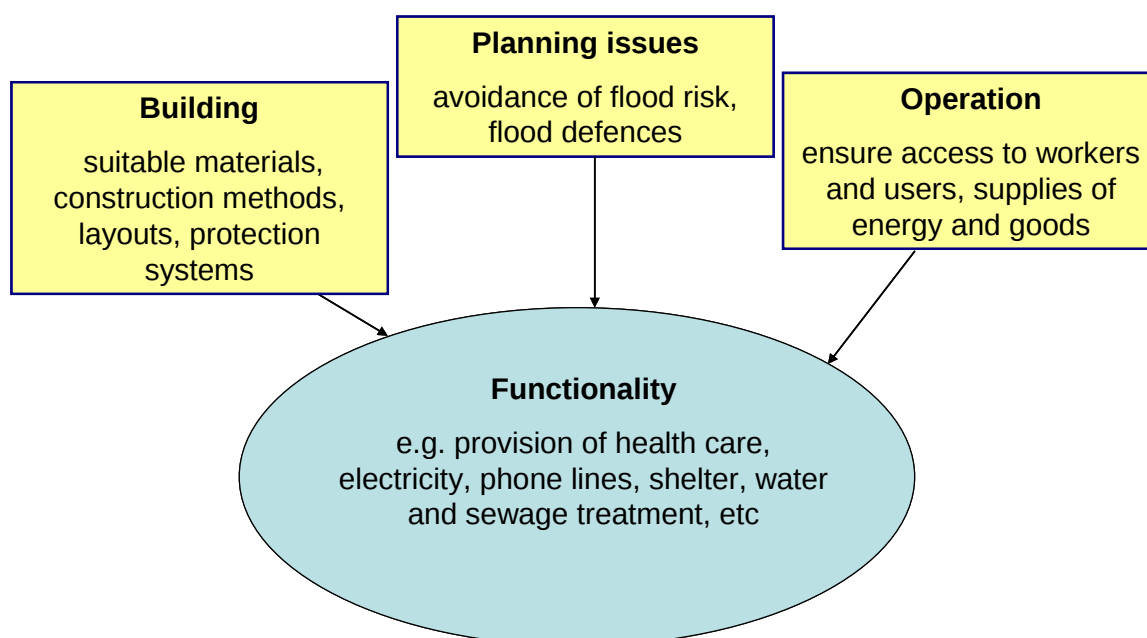


Figure 2.1 Dependence of building functionality

Assuming that a building remains structurally sound, retaining the functionality of a critical building in times of flooding is the primary objective. This differs from the case of domestic buildings where protecting the contents (as well as evacuating occupants) is the main objective. Some examples of critical buildings, their functions and possible measures to reduce flood vulnerability are presented in Table 2.1.

Table 2.1 Functional requirements of some critical buildings

<i>Type of building</i>	<i>Function</i>	<i>Functional requirements</i>	<i>Examples of measures</i>
Water treatment works	Provide drinking water	Avoid contamination with flood water	Ensure pool of mobile generators to provide energy
		Ensure energy supply	Storage at levels not prone to flooding
		Ensure supply of chemicals	Improve procurement work orders for out-of-hours incident management
		Access to site by workers	
		Limited flooding acceptable	
Sewage treatment works	Provide treated sewage and ensure safe discharge	Avoid contamination of flood water with sewage	Check/change fuel storage levels
		Ensure energy supply	
		Ensure supply of chemicals	Liaise with other sectors to ensure deliveries are possible and access to workers
		Access to site by workers	
		Limited flooding acceptable	
Electricity sub-stations	Provide electricity	Avoid flood water reaching controls	If sufficient warning, shut down controls and redirect to other substations ¹
		Access to site by workers	
		Limited flooding acceptable	Locate switch boards above design flood level
			In urban areas build permanent perimeter wall (concrete) and/or raise control boxes above design flood level
			Liaise with other sectors to ensure access to workers is possible ²
Hospitals	Provide healthcare	Avoid entry of flood water, particularly into	Provision of flood resistant materials up to

	(normal and emergency)	basements	design flood level
		Ensure energy supply	Tanking of basements;
		Ensure supplies as normal	barriers at entrances to basements; pumping facilities in parking
		Access to site by workers and users	basements to allow staff parking
			Arrangement of services within building to house more vulnerable services/equipment above flood level
			Liaise with other sectors to ensure deliveries are possible
			Provision of fuel storage facilities to allow generators to work
			Redundancy of generators
			Liaise with other sectors (i.e. highways authorities within cities and surrounding areas) to ensure access to workers is possible
Fire stations	Fire engines, rescue vessels and personnel availability	Avoid entry of flood water	Provision of flood resistant materials up to design flood level
		Ensure energy supply (mainly fuel for fire engines and rescue vessels) and communications	Liaise with other sectors (i.e. highways authorities within cities and surrounding areas) to ensure access to workers is possible
		Access to site by workers	
Communications buildings	Provide land and mobile phone networks and	Avoid entry of flood water, particularly into	Provision of flood resistant materials up to

	internet services	basements	design flood level
		Ensure energy supply	Liaise with other sectors (i.e. highways authorities within cities and surrounding areas) to ensure access to workers is possible
		Access to site by workers	
Shelters (e.g. schools, community centres)	Provide safe haven for victims of floods (space, food, water, sanitary facilities)	Avoid entry of flood water, particularly into basements	Provision of flood resistant materials up to design flood level
		Ensure energy supply	Liaise with other sectors to ensure deliveries are possible
		Ensure stock of food, water, sanitary goods	
		Access to site by workers and users	Provision of fuel storage facilities to allow generators to work
			Liaise with other sectors (i.e. highways authorities within cities and surrounding areas) to ensure access to workers and rescued flood victims is possible

Notes: In a review of UK critical infrastructure (CIRIA, 2010) it was found that:

1 – Much of the vulnerable high risk equipment in substations such as the primary circuits, are at a safe height, above flood levels. However, circuit trips are still a real possibility because many control circuits (switch boards) and secondary wiring are at a lower level.

2 - Although much of the equipment is remotely operated, failures of substations are possible due to staff not being able to access the switch board due to flood water.

3 - About 500 British Telecom major assets are in floodplain areas and in town centres and are housed in old buildings.

Critical urban buildings can also be termed “hotspot buildings” which are high value nodes in critical infrastructure networks (like energy supply, transport services, water supply, information and communication services) that are made flood proof in order to secure the functioning and welfare of urban areas during flooding. Financial centres can also be considered hotspot buildings in urban areas as they contain vital functions for the functioning of these areas.

Failures of hotspots can cause major damage to society and economy: hence, there is a need to identify these “risk hotspots” and develop potential protection technologies. Hotspot buildings can only provide this high value to the urban system by connectivity to this system. A flood proof and functioning power station has no significance to an urban area if all the power lines are broken and the energy cannot be delivered to the city. A flood proof hospital can only function if it can be reached by patients, staff and suppliers. Therefore, flood protection of hotspot buildings should not be considered in isolation. The critical functions need to be guaranteed during flooding in order to retain the function of the flood proof hotspot. This includes both protecting the building against the effects of flooding and protecting the connections to the hotspot building to ensure supplies and delivery. An important design requirement is the critical time of flooding. This depends on the location of the hotspot and the user requirements.

Table 2.2 gives examples of hotspot buildings and the critical requirements to secure their functioning during floods.

Table 2.2 Hotspot buildings and their critical requirements to secure functioning during floods

	Supplies for production	Access to site by workers	Water and sanitation	Energy supply	Food supply	Waste collection and transportation	Indoor climate control (temperature, moisture)	Connection to infrastructure network essential to deliver critical function	Connection to communication network
Water treatment works	X	X	X	X		X			X
Sewage treatment works	X	X	X	X		X		X	X
Electricity substations and transformer stations		X		X				X	X
Energy storage	X			X					X
Hospitals	X	X	X	X	X	X	X		X
Fire stations		X	X	X	X	X		X	X
Police stations		X	X	X	X	X		X	X
Communications buildings		X		X			X		X
Food distribution centres	X	X	X	X		X	X		X
Financial centres	X	X		X					X
Airports	X	X		X					X
Bus stations	X	X						X	X
Train stations		X		X				X	X
Metro stations		X		X			X	X	X

2.2 Flood proof construction methods

Flood proofing is a way of constructing buildings to make them resilient against flooding. This can be done by avoiding contact with floodwater or by making the building resilient to potential damage caused by floodwater. In Urban Flood Management (Zevenbergen et al., 2011) the following methods of flood proofing are mentioned:

- Wet flood proofing
- Dry flood proofing
- Raising or moving structures
- Floating and amphibious structures
- Active or temporary flood proofing
- Passive or permanent flood proofing.

In Engineering Principles and Practices for retrofitting flood-prone residential structures (FEMA, 2001) the same principles are mentioned. The methods mentioned above, with the exception of moving, or relocating, structures, will be described in the following paragraphs. FloodProBE is a research project with a focus on flood resilient building techniques. Because relocation or moving of a structure is not a building technique, this method will not be taken into account in this research project.

2.2.1 Wet flood proofing

Wet flood proofing or wet proof construction is a building method that allows temporary flooding of the lower parts of the building. To prevent damage, preferably building materials are applied that are water resistant. As an alternative, materials can be used that can be easily repaired or replaced. Another important design aspect is the location of electrical lines and delivery points above the expected flood level. Construction parts have to be designed in such a way that they can easily be dried after the flood.

Design considerations:

Because (part of) the ground floor is not useable during a flood, this method is commonly used for parking spaces, building access areas and similar functions. It is not employed in spaces where residential or commercial activities take place (Zevenbergen et al, 2011). These activities would be extremely hindered by the water in the building. During a flood there are two options for entering the building. People can use the existing entrance that is in the flooded area. Secondly an additional entrance can be designed above the expected flood level to be used during the flood. The footprint of the building is preferably small to minimise damage. Wet proofing can be used to protect new as well as existing buildings. Because the building gets flooded and needs to be repaired afterwards, this solution is most suitable when flooding does not occur frequently.

Wet proofing is especially suitable when short periods of floods are expected. The expected flood level is preferably between 1 metre and one floor (flood level is taken in this section as above a certain fixed

threshold). In that case the higher floors of the building can still be used. For flood levels lower than 1 metre, dry flood proofing is the preferred option because in that case it would be easier and more efficient to keep the water out instead of letting it in.

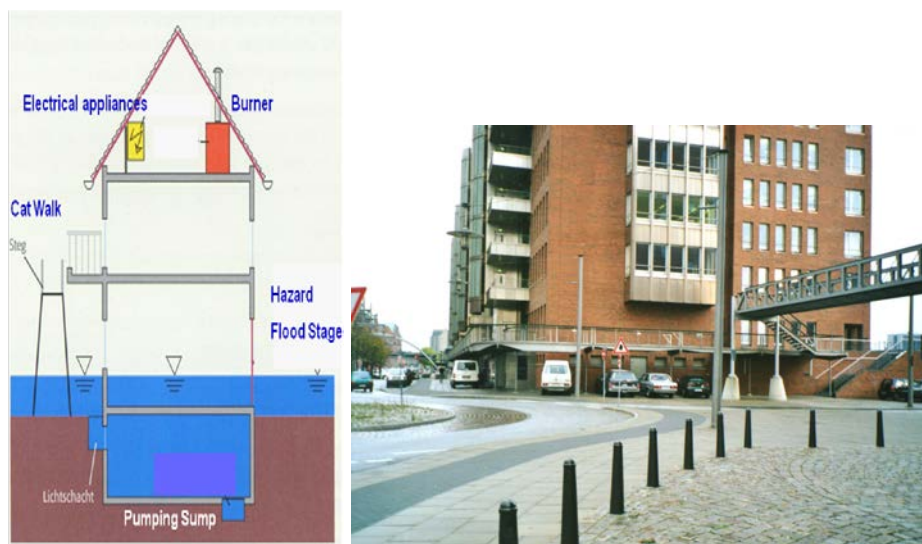
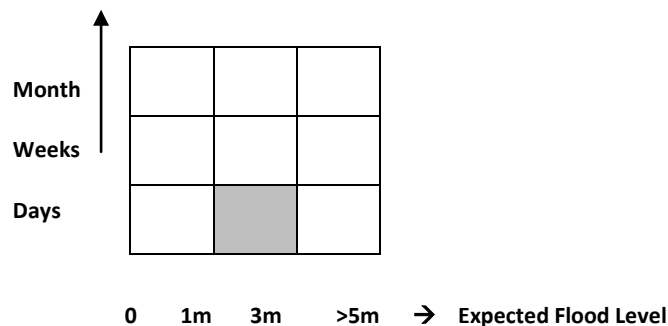


Figure 2.2: Scheme of wet proof method (Pasche, 2008); Figure 2.3: Example of floodgates, Hamburg (D) (Pasche, 2008)

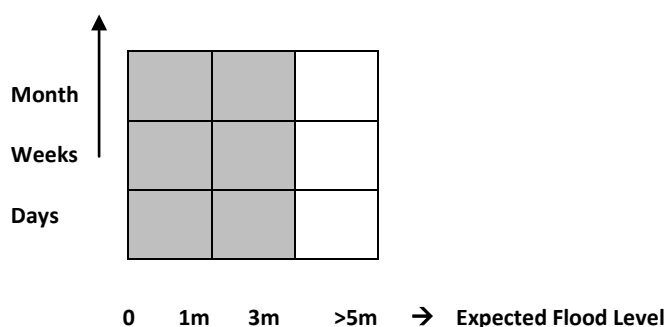
2.2.2 Dry flood proofing

With **dry flood proofing** or **dry proof construction**, the water is prevented from entering the building. The building is made waterproof by treating the facades with coatings, using resistant materials or buildings with a low permeability. In addition the building materials should have a good drying ability and a good integrity. Openings in the facades can be closed off with flood shields, panels or doors. These can be temporarily installed or can be permanent features, but in both cases, dry proofing is an integrated part of the building. An alternative approach is to erect temporary barriers located outside and around the building in order to prevent the floodwater reaching it.

Design considerations:

Dry proofing is an excellent method to flood proof buildings. Because entrances on the ground floor are not accessible during a flood, it is important that in the design an alternative entrance is added above the expected flood line. This can be the regular entrance or an emergency entrance only. Dry proof is most efficient when the footprint of the building is small or when the perimeter of the building is small in comparison with the footprint. This results in a minimum area of the façade that has to be treated. Dry proofing can be used to flood proof new and existing buildings.

This method is particularly suited when short durations of flooding are expected. In situations of larger durations or high water levels, the water pressure could cause the walls to succumb. A point of attention is the accessibility of the building during the flood. Dry flood proofing is a suitable option for relatively low flood levels (usually < 1metre). There are known examples, for instance Hamburg Havencity, where the entire ground floor is dry proofed. With higher flood levels the water pressure to the walls requires additional construction measures to resist the load on the walls and floors. Therefore it is recommended that it is not used with expected floods above 1 floor. If the connection to the roads and other infrastructure is protected against flooding, the flood duration is not a limitation.



2.2.3 Raising structures

Another method to protect a building from floods is to raise the entire building above the expected flood level in order to prevent damage. To enable the continuing functioning of such a building, the connection to infrastructure is to be secured against flooding as well. An example is an access road that is also elevated. There are several ways to construct such a building. In this research project the focus is on two alternatives. They will be discussed separately.

2.2.3.1 Building on stilts

Buildings on stilts are founded on stilts that extend above the ground, they are 'lifted' above the ground. This type of building can be built above land as well as water. It enables multifunctional use of space; in the first case with for example parking, with the latter as water retention. With this type of construction, points of attention are the spatial quality under the building and the access during a flood.

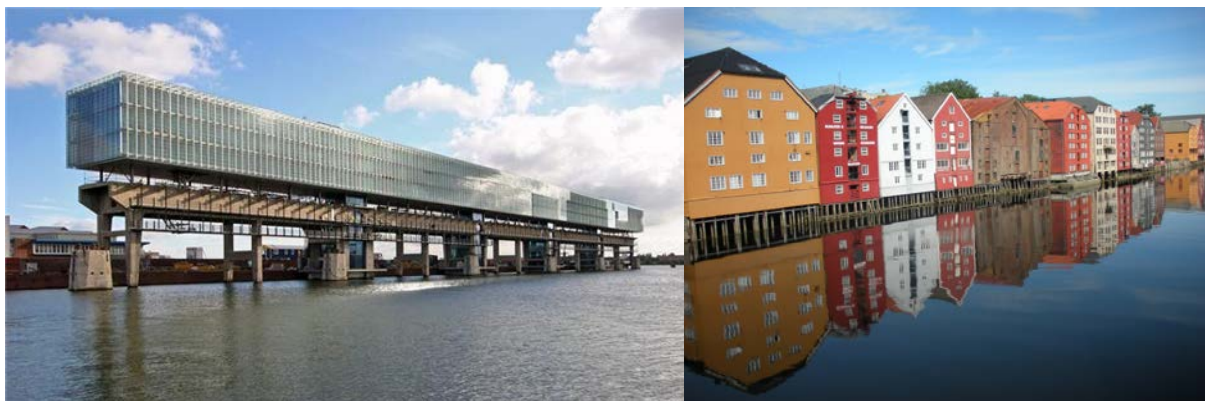
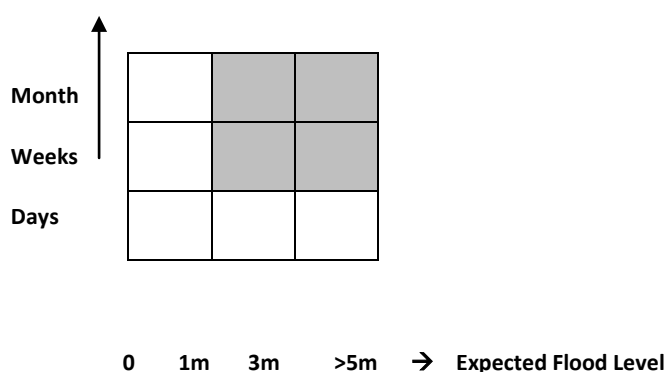


Figure 2.4: Office building on stilts, Amsterdam (NL) (Groene.nl, 2011); Figure 2.5: Buildings on stilts, Trondheim (NO) (Blogspot.com, 2011)

Design considerations:

When a building is elevated, the entrance to the building is a point of attention. This will have to be carried out as a ramp or stairs. With large buildings this method might not be the preferred one. When buildings have a large space demand, the area underneath the building can become a dark and unpleasant space where people will not dwell. When heavy buildings have to be elevated, this might need special constructional reinforcement. This method is not applicable for the flood proofing of existing buildings or as a renovation.

Building on stilts above land is preferable when the expected flood levels are considerably high. When the expected flood levels are 2 metres or higher, the space underneath the building can be used for other activities like parking, storage of non-essential goods or other purposes. Above water, building on stilts can also be applied for lower expected flood levels. The expected flood duration can be months, or in case of building on stilts above water, even permanent.



2.2.3.2 Building on mounds

A mound is an artificial hill. In the Netherlands this is a traditional way of building flood resilient. They were first designed to act as safe havens but changed over time into places where houses were built on. Even

entire villages were constructed on these mounds. They can still be seen in the northern part of the country. Similar constructions are known in France, Germany and Denmark.

In the modern use of a mound, the building is raised from the ground level by an artificial hill. The benefits of this method are that gardens or surrounding grounds are also protected from the flood and that multiple buildings could be built on the mound, assuming the mound is large enough. On the down side extensive earth works are needed to build the mound.

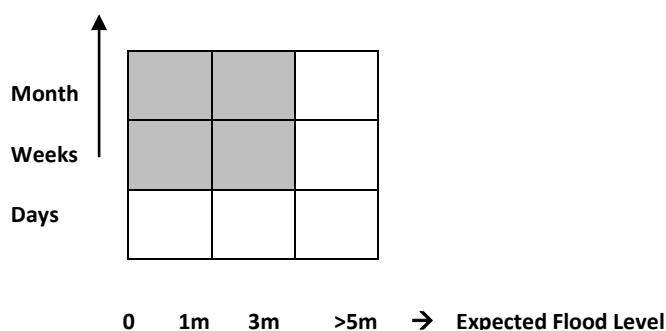


Figure 2.6: Synagogue on mound, Sliedrecht (NL) (Refdag.nl, 2011)

Design considerations:

A mound is a landscaping element and therefore building on mounds can be a remarkable addition to the surrounding landscape. It is often used near a new or existing dike to ensure the accessibility of the mound during a flood. On the other hand excessive ground displacement is needed to create the mounds. Therefore, if buildings have a large footprint other options are more suitable, such as permanent barriers. This method is not applicable for the renovation of buildings.

Compared to building on stilts, building on mounds is preferable with expected flood levels that are lower than 3 metres. For higher buildings much ground displacement is required, also due to the required slope around the mound. The expected flood duration can be weeks or even months as long as there are functioning connections.



2.2.4 Floating and amphibious structures

2.2.4.1 Floating structures

A floating building is a building that is founded on a floating structure that is permanently located in the water. The building has to be moored with mooring posts. Because of the water fluctuation, the connection with the land has to be flexible. It is possible to move the building and moor it somewhere else. It is a flexible and reversible mode of construction and therefore responds to the societal objective to increase the capacity to adapt the built environment to climate change.

Houseboats are the oldest examples of floating structures in the Netherlands. Recently, a new trend has emerged in the Netherlands, and also abroad. New floating houses and buildings are constructed that look like modern houses and have no similarity to the traditional houseboats or barges.

In the Netherlands, most floating houses are constructed on a hollow concrete foundation. This system is relatively cheap and technically robust. Concrete segments can be connected to realise large platforms. The largest building in the Netherlands that was built on this type of platform is a prison in Zaandam. The floating foundation is 100 metres long and 22 metre wide. Disadvantages of this system are the required depth which is usually about 1.5 metres for a single house. In Canada and the USA an Expanded Polystyrene (EPS) and concrete combination is the most used technique. The polystyrene decreases the density of the floating construction which provides higher buoyancy. Advantages of this system are a lower required depth of the surface water. In addition the system is unsinkable and enables the construction of larger platforms. The system is more suitable for shallow surface water. A depth of 1.0 metre can be sufficient. However, the material costs are higher than the concrete system.



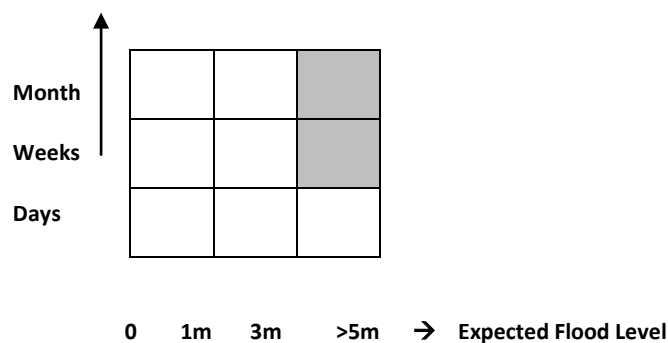
Figure 2.7: Floating prison, Zaandam (NL) (Volkskrant.nl, 2011); Figure 2.8 Floating Pavilion, Rotterdam (NL) (De Wit, 2010)

Design Considerations:

Because floating structures need permanent water, it is preferable to use this method in locations where there is already existing water or where additional water retention is needed. This is especially interesting in cities where space on land is lacking. Stability is an important aspect of floating construction. Therefore it

is important that the floor space to volume ratio is high. For instance high rise buildings would experience stability problems when executed as a floating construction. Also should the building mass be evenly distributed over the floating construction to prevent leaning. When planning hotspot buildings with a high mass it is important to take in account that to make such a building float a lot of buoyancy is needed. This can either be done by creating a large platform or a high depth under the waterline. Floating can only be applied to new buildings.

Floating structures are preferable for large water level fluctuations (>3 metres). In that case constructing a barrier is a costly option. The building will adapt to any water level. The area can be permanently flooded because the building is located in the water.



2.2.4.2 Amphibious structures

An amphibious structure has a traditional foundation combined with a floating body. In a normal situation the building is situated on the ground. When a flood occurs the building will start to float. For that reason the building has to be fixed in a horizontal direction by mooring posts. An example of amphibious housing project in the Netherlands is Maasbommel where 32 amphibious houses have been constructed.

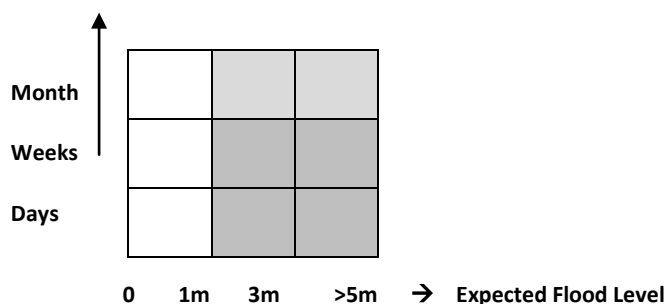


Figure 2.9: Amphibious dwelling in Maasbommel (NL) (Waterbestendigbouwen.nl, 2011); Figure 2.10: Amphibious house, New Orleans (Louisiana, USA) (Treehugger.com, 2011)

Design Considerations:

Amphibious construction is only possible for new buildings. In particular in floodplains where floods frequently occur and in emergency water retention basins, this construction method can be applied. When

planning hotspot buildings with a high mass it is important to take in account that to make such a building float a high buoyancy is needed. Floating of the amphibious building will only take place if the flood level is higher than the depth of the building in a floating situation. Amphibious construction can only be applied to new buildings. A flood level of higher than 1 metre is needed for the building to start floating. For higher flood levels than one floor the method can be preferable compared to the construction of barriers and dry flood proofing. The costs of amphibious structures are high because both a ground foundation and a floating foundation are required. The flood duration can range from days to months.



2.2.5 Active or temporary flood proofing

Temporary flood barriers are placed only if a flood is expected to damage buildings. After the flood the barrier is removed again. Temporary barriers can protect high value buildings, infrastructure nodes or hotspots. Temporary barriers are made from wood, steel, aluminium or plastics. They have to be attached to the ground to be able to withstand the water pressure.

Design considerations:

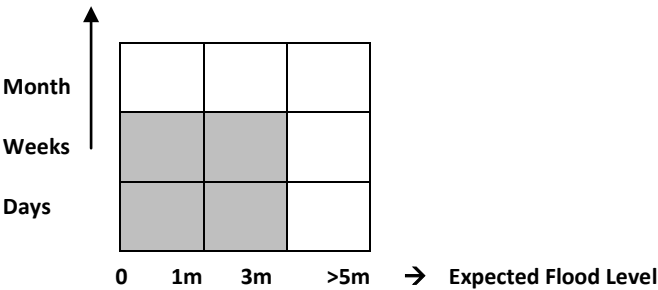
Temporary barriers are applied in places where the space to construct a permanent barrier is lacking and relatively short floods of days or weeks occur. An example is the city of Prague where the historical city centre had to be protected against the floods from the river Vltava. In this case, temporary barriers are built up in one day to protect the city centre. Temporary barriers require sufficient space around the hotspot building. In addition, temporary barriers are only useful if the flood can be forecast. In case of flash floods and very short and steep river basins, the required time to place temporary flood barriers is lacking. The flood level should be lower than 3 metres to prevent a required heavy reinforcement of the temporary barrier due to high water pressure on the barrier. This method is most suitable when the floods do not occur frequently. Temporary barriers can be used to flood proof new and renovation projects.



Figure 2.11: Temporary barrier, Bewdley (UK) (Singletrackworld.com, 2011); Figure 2.12: Temporary barrier at metro entrance, Tokyo (JP) (TU Delft, 2011)



Figure 2.13: Temporary barriers in Prague (CZE) (VRV company, 2007)



2.2.6 Passive or permanent flood proofing

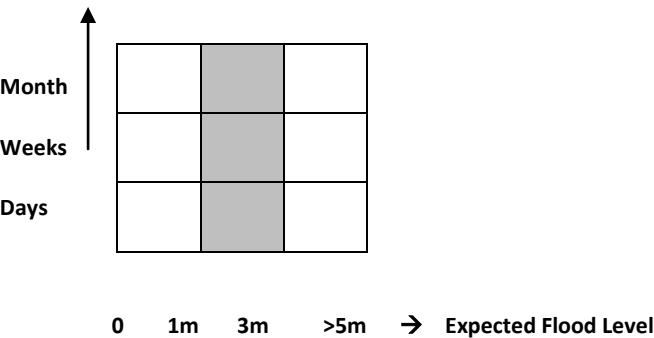
Permanent flood barriers that are specifically constructed to protect one or a couple of buildings are a strategy to prevent flooding. Permanent flood barriers can either be a dike around the hotspot or an integrated flood defence in the surrounding area of the hotspot such as walls, gates or other structures.

Dikes require more space than temporary barriers. In particular in flood plains with a low building density making a dike for one or a few buildings may be a good strategy – in cases of high flood levels evacuation may be possible only by helicopter (see Figure 2.14). In a situation with a high building density, one could either protect the whole area with one dike or protect the hotspots with other flood proofing measures.

Permanent flood barriers are in particular suitable for flood levels lower than one floor that frequently occur. Also in case floods cannot be predicted permanent barriers can be a preferable option.



Figure 2.14: House with dike, Vicksburg (Mississippi, USA) (Popularmechanics, 2011); Figure 2.15: Permanent flood gate Meppel (NL) (Floodbarrier.nl, 2011)



2.3 Conclusion

Whether or not a flood proofing method is suitable for the building that has to be protected, depends on the shape of the building, the expected flood level, the duration, the expected flooding frequency, and the predictability of the flood. By choosing a location for the building this has to be taken into account. Preferably the building will be located above sea level or on terrain where no floods will occur. However if this is not possible, choosing the right flood proof method is crucial.

In Table 2.3 an overview is given of all the methods discussed in this chapter and the most eminent design considerations that were mentioned. Different hotspots have different requirements. The table shows that not all the methods combine well with these requirements. Some are not applicable, others are of no influence. This scheme can be used to make the decision making of designing a hotspot easier.

For example when wet proofing is chosen, the building should have a small footprint. Also if the hotspot has a large space demand or has important functions on the ground floor, wet proofing is not a suitable solution. Whether or not the building is heavy or high is of no influence on the choice for this method. Interesting to note is that wet proofing and dry proofing are applicable only on buildings. The other options are also suitable for other constructions, such as runways or stations. On the other hand all the methods are integrated part of the building, except for the temporary and permanent barrier. These are separate entities. Therefore a lot of requirements and limitation that deal with the building itself, are not applicable for the barriers and vice versa.

Table 2.3 Overview design considerations for flood proofing concepts

		Flood proofing techniques							
		Wet proof	Dry proof	Stilts	Mounds	floating	amphibious	Temp barrier	Perm barrier
Design considerations	Small footprint	Green	Grey	Green	Green	Grey	Grey	White	White
	Large space demand	Red	Grey	Red	Red	Grey	Grey	Green	Green
	Large building height	Grey	Grey	Grey	Grey	Red	Red	White	White
	Heavy building	Grey	Grey	Grey	Grey	Grey	Red	White	White
	Weight evenly distributed	Grey	Grey	Grey	Grey	Green	Green	Grey	Grey
	Permanent water	White	White	Grey	White	Green	Red	White	White
	Important functions on ground level	Red	Grey	Grey	Grey	Grey	Grey	Grey	Grey
	Sufficient space around hotspot	White	White	White	White	White	White	Green	Green
	New	Green	Green	Green	Green	Green	Green	Green	Green
	Retro-fit	Green	Green	Red	Red	Red	Red	Green	Green

Green = requirement, red = limitation, grey = not of influence, white = not applicable

When floods with a low flood level (less than 1 metre) are expected, dry proofing, mounds or temporary barriers are the most suitable solutions (see Table 2.4). Dry flood proofing or temporary barriers are an option because in that case only the lowest 1 metre of the building has to be made flood proof. The duration of the flood is of no influence on the performance of dry proofing. Temporary barriers are only useful if the flood can be forecast. Temporary barriers are most suitable for short floods that stay for days or weeks. A mound is a good solution for low flood levels, because in that case the building can still function and the costs for ground displacement are relatively low. This solution is most suited for a flood that stays for weeks or months.

Table 2.4 Overview of most suitable flood proofing concept classified according to flood level and flood duration

duration	expected water level		
	0	1	3
months	dry proof mounds	dry proof mounds stilts permanent barrier	stilts floating
weeks	dry proof mounds temporary barrier	temporary barrier stilts permanent barrier dry proof mounds	stilts amphibious floating
days	temporary barrier dry proof	temporary barrier wet proof dry proof permanent barrier	amphibious

When the threat consists of flood levels up to 3 metres, there are more options to choose from. Next to dry proofing, mounds and temporary barriers, wet proofing, stilts and permanent barriers are options to consider. Wet proofing is a good solution when short periods of floods are expected and the expected frequency of flooding is comparably low. Elevation on stilts creates multiple use of space and is therefore only interesting when the expected flood levels are from 1 floor or higher. Because it is a permanent solution, it is recommended for an expected flood duration of weeks or months. Permanent barriers may be a good strategy when flood levels lower than one floor occur frequently. Also in case floods cannot be predicted permanent barriers can be a preferable option. The duration of the flood is not of influence on this method.

When extreme floods are expected of up to 5 metres, different options are preferred. Because of the height of the water, elevation of the building, floating and amphibious constructions are the most obvious options. With stilts it is quite simple to design and construct a building that is elevated high enough to not be threatened by a flood. If in a location extreme floods are known or expected, this should be considered

in the design of the building. Because building on stilts is a permanent solution, it is recommended for expected flood durations of weeks up to months. Floating and amphibious building can adjust easily to changing water levels. Because of the ambiguity of the amphibious construction, this may be more suitable for floods of medium duration. If the expected flood will be for several weeks or months floating is the preferable solution. With this technology the double foundation of the amphibious building is not required.

It is assumed in the above guidance that the building and its foundations (including mounds) will be structurally/geotechnically sound to withstand the speed of floodwater. However, this needs to be checked in advance of any option appraisal. The vulnerability to flood water velocity is an area that requires further research.

3 State of the art of flood resilient building construction

3.1 Overview of flood resilient materials and construction practices

This section presents the findings of a review of construction materials and practices from the point of view of their performance under flood conditions.

A useful classification of building materials is provided in FEMA's Technical Bulletin 2 (FEMA, 2008), an American publication by the Federal Emergency Management Agency which administers the US National Flood Insurance Program. Under this classification, materials are divided into structural and finish materials as follows:

Structural materials include all elements necessary to provide structural support, rigidity, and integrity to a building or building component. Structural materials include floor slabs, beams, subfloors, framing, and structural building components such as trusses, wall panels, I-joists and headers, and interior/exterior sheathing.

Finish materials include all coverings, finishes, and elements that do not provide structural support or rigidity to a building or building component. Finish materials include floor coverings, wall and ceiling surface treatments, insulation, cabinets, doors, partitions, and windows.

As can be seen in the above definition, Finish Materials encompass a wide range of materials which are considered here to be too disparate in their responses to floodwater to be in the same category. Hence, it is proposed to introduce two further categories in addition to Finish materials, which will be adopted in this report (definitions are given below): Apertures and Insulating materials. In this project therefore the categories considered were:

- Structural frame materials
- Finish materials
- Apertures
- Insulating materials.

3.1.1 Structural frame materials

Definition:

Based on FEMA's definition above, for the purposes of this report, structural materials are those that provide the support, rigidity and integrity to a building. Examples include:

- Floor slabs
- Framing
- Beams
- Weight supporting wall panels
- Interior and exterior panels that provide rigidity to the structure
- Trusses.

Country construction practices and resilience:

UK

Steel frame is by far the most common structural material used in the UK in multi-storey new build. Although in the early 1980s reinforced concrete frames had the market share, since then steel has taken prevalence and recent surveys show that steel is preferred as a framing solution for over 73% of multi-storey commercial buildings, whilst insitu concrete accounts for 18%. The remaining 9% of the market is attributed to load bearing masonry, pre-cast concrete and timber (Corus, undated). The shift for steel frame has been attributed primarily to the speed of construction when compared with in situ concrete; in addition to this there are arguments that point out to steel being highly recyclable and therefore having lower embodied carbon than concrete frames but this can be reverted when considering operational carbon emissions due to concrete's higher thermal inertia (Weight, 2006). It is important to note that the flood resilience characteristics of steel frames cannot be dissociated from the floor and wall components linked to them.

A laboratory study of the seepage and drying characteristics of mass concrete slabs was undertaken by HR Wallingford as part of an investigation of flood resilient construction (CIRIA, 2006, CLG, 2007) – see Figure 4.1. The scope of the study allowed for testing several different arrangements of floors simulating the ground floor of domestic buildings and the specification followed closely recommendations in the UK National House-Building Council (NHBC) Standards.

The different test arrangements were devised to cover the aspects considered to be most relevant by the members of the project steering group and other consultees: effect of slab thickness, effect of concrete strength, moisture barrier (i.e. membrane) effectiveness, overlap in membranes and wall/floor joints. Precast slabs 0.5m by 0.5m (non reinforced and cured for 28 days minimum) were tested with minimum thickness of 100mm as per NHBC recommendations. The arrangements tested are described in Table 3.1.



Figure 3.1 Test slab and adjacent corner wall

Table 3.1 Floor arrangements tested (CIRIA, 2006)

Arrangement	Thickness of concrete	Concrete mix (cement strength*)	Moisture barrier/screed/joints	Adjacent wall
Arrangement 1	100mm	32.5 ^a	-	-
Arrangement 2	150mm	32.5 ^a	-	-
Arrangement 3	150mm	42.5 ^b	-	-
Arrangement 4	150mm	42.5 ^b	Polythene sheet below slab (300mm overlap) ^c	-
Arrangement 5	150mm	42.5 ^b	Taped lap in membrane (50mm overlap)	-
Arrangement 6 ^d	150mm	42.5 ^b	Polythene sheet below slab	Blockwork foundation (side wall only)
Arrangement 7 ^d	150mm	42.5 ^b	Polythene sheet below slab + foundation block course in concrete trench	Blockwork foundation (side wall only)
Arrangement 8 ^e	150mm	42.5 ^b	Polythene sheet below slab + foundation block course in concrete trench	Blockwork foundation (corner wall)

* NHBC Standards, Table 1 in Appendix 2.1B:

Standard Prescribed Mix ST2, Slump Class S2

a – 1 bag of 25kg cement; 50 litres fine aggregate; 75 litres coarse aggregate

b - 1 bag of 25kg cement; 55 litres fine aggregate; 80 litres coarse aggregate

Max aggregate size: 20mm

c – lap of 300mm in membrane (as min. recommended in NHBC Standards)

d - dimensions of concrete slab were 0.5m by 0.35m to allow construction of block wall in test rig

e - dimensions of concrete slab were 0.35m by 0.35m to allow construction of a corner block wall in test rig.

The test slabs were subjected to uplift forces caused by 1m head of water during three days and any seepage rate through the slabs was monitored; the weight of the slabs was measured before and after the test and a portion of the slab was broken off to allow continuous weighing during the drying phase (under uncontrolled environmental conditions present in the laboratory). The following conclusions were drawn:

- Mass concrete slabs are effective at preventing water ingress under 1m head of uplift pressure; no seepage was observed through any of the slabs tested;
- Increasing the concrete slab thickness from 100mm to 150mm is beneficial to counterbalance uplift forces caused by 1m head of water and therefore a minimum thickness of 150mm is recommended in flood-prone areas (for domestic buildings). It should be noted that slab deformation in response to uplift loads can induce cracking and lead to the creation of preferential paths for water ingress. In the present tests this was not observed but could be due to the fact that the tests were carried out on small test slabs which had a ratio perimeter/area considerably bigger than for typical real slabs;
- Water absorption by mass concrete floor slabs under the current test conditions (three-day exposure to 1m head of uplift pressure) was found to be a small percentage of their weight, typically less than 1% for 150mm thick slabs;
- As expected, it was found that the 100mm thick slab was easier to dry than the 150mm slabs. However, in view of the minimal water absorption of concrete slabs in general, this is considered to be of less importance than achieving sufficient weight to counterbalance severe uplift forces;
- The strength class of the cement used in the concrete mixture (Class 32.5 or 42.5) was found to be of little relevance with regard to flood resilience and therefore standard cement was considered adequate.

Netherlands

Despite its pioneering position with regard to flood protection of properties by dykes and avant-guard building design (or possibly because of this), the Netherlands has not developed specific guidance or regulations on building materials. The emphasis has been on providing external flood defences and, in recent years, suitable site location of the buildings and innovative designs that reduce the exposure of buildings to floodwaters (e.g. floating buildings/cities). A recent guide by the Provincie Utrecht (2010) on robust flood protection measures lists the advantages of using flood resistant materials as limiting damage, allowing faster repairs, giving opportunity for sustainable materials and providing robustness in the design. It includes general guidance on materials that are considered suitable for flood prone areas: concrete, floor polythene membranes, water resistant floor finishes. The current practice in these areas is stated as using water resistant floor finishes. Key points that need to be considered when using such materials are given as: dependency on water depth, availability of materials and lack of case studies. The guidance produced in the UK (CLG 2007) is mentioned in this publication as being at the forefront of developments in this area.

Poland

In Poland it is forbidden to place public buildings such as hospitals, wastewater treatment systems and chemical storehouses on flood retention areas. Even though it is not recommended to place residential

buildings on flood route areas, there is no strict law which defines and forbids it. That is why many residential buildings are placed on flood prone areas located close to rivers.

Because of the recent flood which occurred in 2010 (May-June), the Polish authorities decided to start working on an act, which will implicitly forbids building placement on areas endangered by flooding.

In Poland there is no specific law defining what kind of structural materials should be used for building construction on flood prone areas. However, there are some recommendations formulated such as:

- Buildings located on flood prone areas should be built on embankments or pillars. In Poland we can find some buildings which are built on pillars (see Figure 3.2), but they are mostly old buildings. The solution is nowadays hardly ever accepted by architects due to aesthetic reasons and maximisation of available internal space.
- The building weight should be large enough to protect it against uplift
- Waterproof materials should be used for the construction of the lower part of a building
- Basement walls and floors should be insulated (most often by bitumen insulation) and reinforced to enable it to remain dry in case of high groundwater levels
- Building entrances should be placed above the probable flood level
- Doors and windows should be waterproof, open out, should have a mechanism which enable their automatic opening and be resistant to water pressure
- Electrical installations need to be protected against flooding
- Buildings should be surrounded by drainage installed below spot-footing (see Figure 3.3) – (Bednarczyk *et al*, 2006).



Figure 3.2 Public building built on reinforced concrete pillars, Poland

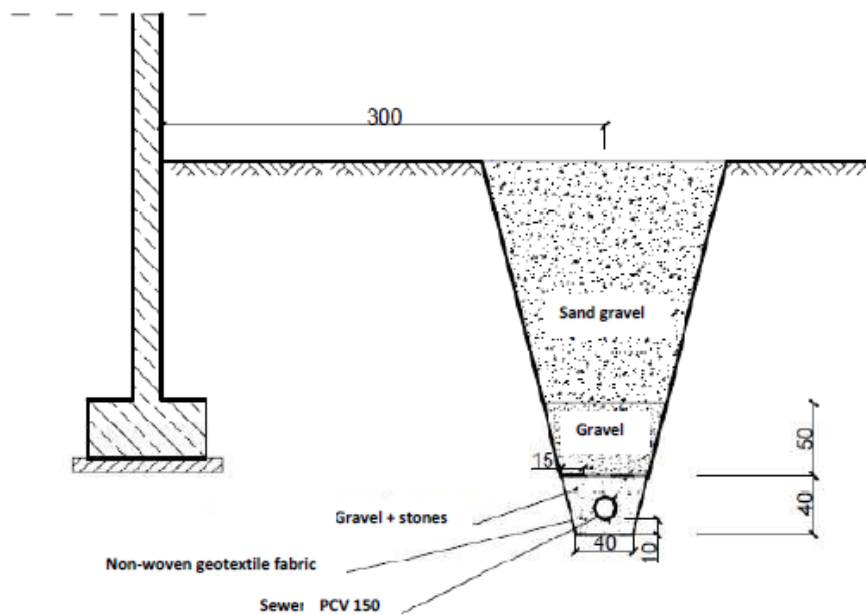


Figure 3.3 French drain

Despite the fact that the recommendations listed above are disseminated by the relevant authorities, they are rarely applied mostly because of the additional costs of these actions and the lack of awareness of flood danger and flood protection.

Structural construction materials used in Poland

The most popular structural construction materials used in Poland are reinforced concrete, steel and wood.

The most common approach for the construction of multifamily buildings and office buildings is to use reinforced concrete. Reinforced concrete columns, slabs and beams are constructed in two different technologies: as prefabricated elements in production plants and as elements produced at a building site (Stopka, 2009). For auxiliary constructions, such as roofs or elevator structures, steel sections are used (hot-rolled or cold-formed).

Wood is used as the main/supporting element in swimming pools, sport halls etc in the form of glued girders. It is also commonly used in single-family buildings. However, the most popular building technology in single-family building construction is the traditional technology: use of various elements for each construction element. Main walls are built out of bricks and blocks. Ceilings are built out of monolithic concrete elements in different technologies and roofs are usually wooden (in some cases steel).

Building foundations are concrete or reinforced concrete constructions, with different protective insulations (BudowaPlus.pl, 2007).

Water resistance of buildings

The group of materials which are water resistant includes: concrete, glass, metal and ceramics. Materials not water resistant are: gypsum and wood. Structural building construction is mostly resistant to water as wooden construction technologies are not as often used. However, wood and gypsum are very popular as finish materials (wooden floors, wall panelling, gypsum or carton-gypsum, walls and ceilings, wooden stairs, etc).

It is possible that many aspects will change and new acts and directives will be formulated in the near future because of the enormous damage caused by floods that have occurred in Poland in 2010 and earlier, in 1997. It became clear to the government and responsible authorities that additional protective measures such as special requirements concerning construction materials and techniques need to be implemented to avoid flood damage.

Germany

The German Bundesministerium für Verkehr, Bau und Stadtentwicklung published a flood protection manual (BVBS, 2008) which includes, among a comprehensive description of flood protection products, a list of construction materials and their suitability with regard to flood water. The materials are rated as being suitable, moderately suitable or unsuitable. In addition to the table, which is quite detailed in terms of materials but does not relate suitability with water level, this publication mentions that wood should not be used in basements or ground floors. It is not straightforward to extract structural materials from the list as they are categorised as building materials, slabs, floors, walls, outer layers, plaster, paint, wall coverings, windows, window sills, doors and stairs. However, the following structural materials can be given as suitable:

- Concrete slabs
- Concrete
- Cement

- Plastic (depending on type)
- Metal (depending on type)
- Wood (moderately suitable)
- Bricks.

France

in France there is currently no guidance available concerning flood resilient materials and the only effect of water in French building regulations is the buoyancy force on fuel/gas tanks and underground building infrastructure. General advice is given in the French flood prevention plans with regard to replacing existing materials with less water sensitive materials but a list of these materials does not yet exist. A recent publication (CEPRI, 2009) was put into practice after the February 2010 floods from a review of 80 documents from different countries. In line with British guidance (CLG, 2007) three different strategies are suggested for adaptation to flood risk: avoidance, resistance and allowance of flood water into the property. For each strategy, Annex 4 of this publication gives several measures, some of them material-based such as filling in any cracks, coating external walls with impermeable products or the use of PVC materials, for example. The measures are quite extensive and relate both to the height of flood water and the flood duration. Two different flood levels are considered: 1m (above which the aim to avoid water entry may cause structural problems) and 2.5m (above which the first floor may be endangered).

Other European countries

In southern Europe the significant seismic risk that most countries are subjected to, coupled with availability of cement materials (and limited sources of iron for steel production) has set reinforced concrete as the preferential structural frame material for both domestic and public/commercial buildings. Pre-cast concrete wall and slab construction has also a wide spread, which offers in principle good resistance to flood waters.

USA

Construction in areas in the USA denoted as “Special Flood Hazard Areas” (or SFHAs) requires protection against damage caused by flood water. The National Flood Insurance Program (NFIP) issues regulations to support this aim, which includes minimum building design criteria that apply to new construction, repair of substantially damaged buildings, and substantial improvement of existing buildings in SFHAs (FEMA, 2008). These areas are defined on Flood Insurance Rate Maps (FIRMs) that are produced by the NFIP. The base flood on which these maps are drawn is the event that has a 1% chance of being equalled or exceeded in any given year (or the 100-year flood). Where community or state requirements exceed those of the NFIP, these should take precedence.

For non residential buildings the lowest floor (enclosed) must be set at a level at least equal to the base flood elevation (BFE) or dry proofed to that level and generally basements are not allowed to extend below the BFE. FEMA Technical Bulletin 3-93 (FEMA, 1993) sets the requirements for these buildings and includes a Certificate Form that reflects the suitability of the building from the following viewpoints: structural (hydrostatic and hydrodynamic) stability of the building including buoyancy and anticipated debris impact

forces, watertightness of the structure and walls together with attendant utilities and sanitary facilities to the floodproofed design elevation.

All materials (to the exception of those used for safety/warning systems or to comply with electricity regulations) used below the BFE need to be flood-damage resistant. This corresponds to Classes 4 and 5 of the regulations (a similar classification had been previously given in US Corps of Engineers (1995):

Class 5 - Materials that can survive wetting and drying, including damage caused by moving water, and may be successfully cleaned after a flood to render them free from most harmful pollutants; can be used outside under long flood exposure

Class 4 – Materials that can survive wetting and drying and may be successfully cleaned after a flood to render them free from most harmful pollutants but are susceptible to moving water damage; can be used in interior spaces.

Notes:

Floodwater is defined as containing pollutants such as sewage, chemicals, heavy metals, or other toxic substances that are potentially hazardous to humans

Moving water is defined as water moving at low velocities of about 1.5m/s or less. Water moving at velocities greater than 1.5m/s may cause structural damage to building materials.

Some materials can be successfully cleaned of most of the pollutants typically found in floodwater. However, some individual pollutants such as heating oil can be extremely difficult to remove from uncoated concrete. These materials are flood damage-resistant except when exposed to individual pollutants that cannot be successfully cleaned.

FEMA's Technical bulletin 2 (FEMA, 2008) gives tables listing a large number of materials considered to be flood-damage resistant (and also those that are not) - of those materials a sample is given below.

Structural materials resistant to moving water (up to approximately 1.5m/s):

- Asbestos-cement board
- Brick (face or glazed)
- Cast stone (in waterproof mortar)
- Cement board/fibre-cement board
- Clay tile, structural glazed
- Concrete (precast or cast-in-place)
- Concrete block
- Plywood (marine grade and preservative treated Borate)
- Recycled plastic lumber (RPL):

- Commingled, with 80-90% polyethylene (PE)
- Fibre-reinforced, with glass fibre strands
- High-density polyethylene (HDPE), up to 95%
- Stone (natural or artificial non-absorbent solid or veneer, waterproof grout)
- Structural Building Components:
 - Floor trusses, steel
 - Headers and beams, steel
 - Wood (Solid, decay-resistant).

Metal materials listed above are not suitable for salt water conditions.

Construction practices with regard to the use of structural materials vary widely within the USA, with steel, wood and concrete being common materials. However, for critical infrastructure, it is reasonable to state that steel is likely to be the main structural material.

It should be noted that the NFIP determines the minimum building code standards but different States can design their own regulations that go beyond these minimum requirements, for example having a higher design flood elevation below which only flood-damage resistant materials can be used (Aerts & Wouter Botzen, 2011).

As part of a study to assess options for floodproofing commercial constructions, a test programme was carried out at the Oak Ridge National Laboratory, Tennessee, which involved testing a variety of wall assemblies at full size (SERRI, 2011). Six test pods of wall assemblies (equipped with sensors) were constructed in an outdoor tank and subjected to three feet (approximately 0.9m) of water (still) for 24 hours – see Figure 3.4. Using the information on the leakage observed and subsequent drying of the test walls, the walls were modified to improve their dry proof performance and then re-tested. The types of construction that were considered viable options included, according to the USACE definition of dry proof construction (permitted accumulation of no more than four inches of water depth during a 24 hour period):

- Concrete masonry blocks with sprayed- and sheet-applied water resistant membranes
- Insulated Concrete Formwork (ICF)
- Metal Structural Insulated Panels (SIPs).



Figure 3.4 Tests of dry proof wall constructions at Oak Ridge National Laboratory, USA (from SERRI project, www.gccds.org)

Australia

The City of Canterbury in New South Wales in Australia (City of Canterbury, 1997) produced a Development Control Plan No. 28 entitled Flood Management and Flood Proofing in 1997, which has not yet been updated. While aimed at regulating residential developments affected by the one in a hundred years Flood Standard for the flood plains of the Salt Pan Creek and the Cooks River and nearby areas, it provides lists of materials for constructions graded as to their suitability in flood prone areas. The buildings should be designed and constructed to withstand the stresses of the highest probable flood. The Council issues flood level information based on the Australian Height Datum to the nearest 100mm, for the 1 in 20 year flood, one in 50 and one in 100 year flood levels.

Classed as most suitable are those materials or products which are relatively unaffected by submersion and unmitigated flood exposure and are the best available for the particular application. Buildings in the affected areas must be built using these materials. Other materials are classed in the second and third preference classes, which will betray respectively minor and marked effects from flood conditions. These types of material will only be considered for approval in constructions if 'circumstances warrant it'. In the fourth category are those materials that are to be avoided, as their serious damage will entail complete removal and replacement if submerged.

The Designated Floor Level (DFL) is the minimum floor level acceptable to the Council when giving consent to an application for development. It will normally be 0.5m above the Standard Flood Level for habitable rooms.

Classed as most suitable structural materials and those as second preference are as follows (Table 3.2):

Table 3.2 City of Canterbury, Australia, list of suitable structural materials

Component	Most suitable	Second preference
Flooring and sub-floor structure	- Concrete slab-on-ground monolithic construction. (Note: clay filling is not permitted beneath slab-on-ground construction, which could be inundated) - Suspension reinforced concrete slab	Timber floor (t&G boarded, marine plywood) full epoxy sealed, on joints
Wall structure (up to the DFL)	Solid brickwork, blockwork, reinforced concrete or mass concrete	Two skins of brickwork or blockwork with inspection openings
Roofing structure (for situations where the DFL is above the ceiling)	- Reinforced concrete construction - Galvanised metal construction	Timber trusses with galvanised fittings

3.1.2 Finish materials

Definition:

Finish materials are defined here as including coverings, finishes and elements that do not provide structural support or rigidity to a building or building component but provide enclosure of spaces and cover surfaces. Examples include wall cladding, floor coverings, and wall and ceiling surface treatments.

Country construction practices and resilience:

UK

“Finish materials” is a category that includes an extremely broad range of materials that are in standard use and also those that are being developed and introduced in the market, particularly for bespoke applications and non-standard buildings - as such, any attempt to classify them in terms of flood resilience will inevitably be incomplete.

Recent years have seen the widespread use of wall-to-wall glass cladding in commercial/public building facades for its aesthetic value as well as lighting-enabling characteristics among other advantages. Note that in this type of application, the glass panels can have a structural function as they can transfer loads to

the structural frame. The traditional reservation to the use of glass in building facades in high flood risk areas, i.e. its fragility with regard to debris impact is not valid in case of critical infrastructure buildings as toughened glass would be specified; a small risk remains of leakage through the sealants and joints with other building materials. Despite its impermeability, standard glass is not a flood resilient material due to its vulnerability to floating debris, which are likely to occur in flash flood situations, and the usually poor sealing specifications.

A laboratory study of various materials undertaken by HR Wallingford (CIRIA, 2006) included the testing of some finish materials in isolation and also as part of wall composites. The materials, when tested in isolation, were measured for their water absorption, seepage rate when subjected to 1m head of water and drying characteristics. The following table (Table 3.3) shows an overall assessment of their resilience characteristics resulting from this study.

Table 3.3 Flood resilience characteristics of finish materials (CIRIA, 2006)

Material	Resilience characteristics*			Overall resilience performance
	Water penetration	Drying ability	Retention of pre-flood dimensions, integrity	
Timber board				
OSB2, 11mm thick (Oriented Strand Board)	Medium	Poor	Poor	Poor
OSB3, 18mm thick (Oriented Strand Board)	Medium	Poor	Poor	Poor
Gypsum plaster board				
Gypsum Plasterboard, 9mm thick	Poor	Not assessed	Poor	Poor
Mortars				
Below DPC (Damp Proof Course) 1:3(cement:sand)	Good	Good	Good	Good
Above DPC (Damp Proof Course) 1:6(cement:sand)	Good	Good	Good	Good

*Resilience characteristics are related to the testing carried out and exclude aspects such as ability to withstand freeze/thaw cycles, cleanability and mould growth

Poland

Wall and Ceiling plasters

Cement plasters are used in rooms that are exposed to moisture but, as this is an expensive material, it is used only where high moisture levels are present. Nowadays, manufactured plaster masses with thickness of 3-6 mm and plasters made of gypsum blends have become very popular. In many cases, instead of plasters, carton-gypsum boards are used. For rooms exposed to moisture (bathrooms, kitchens, laundries), special water resistant carton-gypsum boards are applied (green boards).

Internal Walls

Internal walls are often made of carton-gypsum boards or bricks. As insulating material in bathrooms, toilets and kitchens, special water resistant insulation is used, together with ceramic tiles. In some cases, walls are covered by wooden panelling or wallpapers (only on dry rooms).

Floors

In bedrooms and living areas of single houses and multi-family buildings parquet wooden floors or polished stone tiles are often used. In public buildings the most popular materials covering floors are: ceramic and polished tiles slabs.

Germany

The German Bundesministerium für Verkehr, Bau und Stadtentwicklung flood protection manual (BVBS, 2008) offers the following classification for finish materials (note that the materials below are a sub-list of all the materials given) – Table 3.4:

Table 3.4 Suitability of finish materials with regard to floodwater (from BVBS, 2008)

Building element	Material	Suitability		
		Suitable	Moderately suitable	Unsuitable
Floor coverings	Natural stone (e.g. granite, dolomite)	✓		
	Sandstone, marble			✓
	Tiles (depending on type)	✓	✓	
	Epoxy	✓		
	Wood (including laminated, parquet and solid wood)			✓
	Cork			✓
	Carpet			✓
	Vinyl			✓
Plasters	Gypsum			✓
	Cement, hydraulic lime	✓		
	Water repellent plaster	✓		
Paint	Mineral paint	✓		
	Dispersion paint			✓
Wall coverings	Wallpaper			✓
	Tiles	✓		
	Wood			✓
	Cork			✓
	Textiles			✓
	Gypsum board			✓

Other European countries

In countries such as Portugal, internal walls are usually made of hollowed bricks joined up with cement mortar. Cement-based renders are usually applied on the inside face of the walls followed by a chalk-based wet plaster skin. Various types of cladding (for exterior walls) are currently in favour for new public buildings (polished stone, synthetic cladding) but ceramic tiles were traditionally used as an exterior revetment (and still are). Although these materials are essentially impermeable to water, the lack of an effective damp proof course, often results in humidity rise along the walls, which would be worsened in times of flood.

USA

In FEMA's Technical bulletin 2 (FEMA, 2008) finish materials are classified in terms of flood-damage resistance as follows – see also Appendix 1. A sample is given next:

Materials resistant to moving water (up to approximately 1.5m/s):

- Glass blocks (for use in walls/ceilings)
- Steel (panels, trim, tiles) with water-proof adhesives for walls and ceilings

Materials resistant to moving water (up to approximately 1.5m/s):

- Ceramic and porcelain tiles with mortar set
- Concrete tiles with mortar set
- Glass (sheets, coloured tiles, panels)
- Metals, ferrous (not for salt water conditions)
- Partitions, free-standing
- Paint

Unacceptable below flood elevation

- Carpeting
- Ceramic and porcelain tiles with organic adhesives
- Corkboard
- Linoleum
- Mastic flooring , formed-in-place
- Metals, non-ferrous for walls/ceilings
- Wall coverings (wallpaper, vinyl, cloth types)

- Wood floor coverings.

Australia

According to the City of Canterbury code for Flood Management and Flood Proofing (City of Canterbury, 1997), the following finishes are regarded to be most suitable and second preference under flood conditions (Table 3.5):

Table 3.5 City of Canterbury, Australia, list of suitable finish materials

Component	Most suitable	Second preference
Floor covering	• Clay tile • Concrete, precast or insitu • Concrete tiles] • Epoxy, formed-in-place • Mastic flooring formed-in-place • Rubber sheets with chemical-set adhesives • Silicone floors formed-in-place • Vinyl sheets with chemical-set adhesive	• Cement/bituminous formed-in-place • Cement/latex formed-in-place • Rubber tiles, with chemical-set adhesive • Terrazzo • Vinyl tiles with chemical-set adhesive • Vinyl tiles, asphaltic adhesives • Loose rugs • Ceramic tiles with acid and alkali-resistant grout
Wall and ceiling linings	• Compressed cement or plasterboard • Brick, face or glazed, in waterproof mortar • Concrete • Concrete block • Steel with waterproof applications • Stone, natural solid or veneer, waterproof grout	• Brick, common • Plastic wall tiles • Metals. Non-ferrous • Rubber mouldings and trim • Wood, solid or exterior grade plywood fully sealed

	• Glass blocks • Glass • Plastic sheeting or wall with waterproof adhesive	
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3.1.3 Insulating materials

Definition:

Insulating materials are those that prevent or minimise the transmission of heat or sound. Examples include cavity wall insulation and corkboard.

Country construction practices and resilience:

UK

In the UK a variety of insulating materials are used and these can be divided into conventional and natural insulation (Sustainable Build, web site):

- Conventional Insulation

These materials are made from petrochemicals and include:

- Fibreglass
- Mineral wool
- Polystyrene
- Polyurethane foam
- Multi-foils.
- Natural Insulation Materials

There are many different types available, including:

- Sheep's Wool
- Flax and Hemp
- Cellulose (a recycled product made from newsprint and other cellulose fibre; available in blown-in, quilts, boards and batts)
- Wood Fibre (made from wood chips compressed into boards or batts using water or natural resins as a binder).

- Expanded Clay Aggregate (small fired clay pellets used in foundations).

Various types of wall insulating materials commonly used in the UK were tested by HR Wallingford as part of an investigation of flood resilient construction (CIRIA, 2006, CLG, 2007). They were tested as part of wall composites (subjected to 1m head for three days on the external face of the wall and one day on both sides) and included:

- Mineral fibre in batts (inside wall cavity)
- Expanded mica (inside wall cavity)
- Rigid PU (inside wall cavity)
- Polystyrene external insulation on a proprietary multi-layered solid masonry wall.

The main conclusions from the tests were:

- Mineral fibre in batts used in cavity wall insulation became totally soaked in contact with cavity water and fragile to handle; it appeared to hinder drying of walls and remained wet after three months following the test;
- The blown-in insulation material tested (expanded mica) absorbed water (450% weight gain) and slumped by about 4% of height; compared with mineral fibre in batts, it was only marginally better in terms of promoting drying of the internal wall face (surface values); the expanded mica material was found to still retain 50% more weight than in dry state after 3 months;
- Rigid PU foam (for part-fill insulation) also absorbed some water but retained structural integrity and was considered to offer better flood resilience performance than the other types tested.

The following rating for these materials was provided in this study in the following table (Table 3.6):

Table 3.6 Flood resilience characteristics of insulating materials (CIRIA, 2006)

Material	Resilience characteristics*			Overall resilience performance
	Water penetration	Drying ability	Retention of pre-flood dimensions, integrity	
Cavity insulation				
Mineral fibre	Poor	Poor	Poor	Poor
Blown-in	Poor	Poor	Poor	Poor
Rigid PU foam	Medium	Medium	Good	Medium

* Resilience characteristics are related to the testing carried out and exclude aspects such as ability to withstand freeze/thaw cycles, cleanability and mould growth

Poland

Thermal insulating

In Poland the following insulating materials protecting against heat loss are used:

- mineral insulation material: stone wool or glass wool
- styrofoam
- insulating foil
- fiber glass
- polyurethane foam insulation.

The most popular from the list above are mineral wool and styrofoam.

Anti moisture insulation

All new building foundations in Poland are protected against moisture and water by special insulation (vertical and horizontal). Some old buildings are not insulated at all or are wrongly insulated and there is no protection against water damage.

In Poland, insulation is used in rooms vulnerable to water impact such as: bathrooms, laundries, etc. The most popular are anti-moisture liquid foils. On top of a foil, ceramic slabs are often placed.

Special insulating materials such as liquid bitumen-based materials (asphalt paints or solutions), foils, HDPE (high density polyethylene), EPDM membranes, bentonite panels are also applied in new building basements (Kerntopf-Ślusarczyk and Traczyński, 1997). Vertical insulation is usually applied in walls up to 0.3m above soil level. Horizontal insulation usually is applied in two places: on continuous footing and in basement walls below basement ceiling. When basement ceiling is located below soil level, insulation is applied additionally 0.3m above soil level. Horizontal insulation applied on continuous footing should be connected with basement floor horizontal insulation (Nowakowska, 2009).

USA

FEMA's Technical bulletin 2 (FEMA, 2008) gives a listing of insulation materials used in floor and wall/ceilings and their classification in terms of flood-damage resistance – see also Appendix 1:

Materials resistant to moving water (up to approximately 1.5m/s):

- Sprayed polyurethane foam (SPUF) or closed-cell plastic foams

Unacceptable below flood elevation:

- Inorganic – fibreglass, mineral wool: batts, blankets or blown
- All other types (cellulose, cotton, open-cell plastic foams, etc).

Australia

Only one type of insulation rates as most suitable in the City of Canterbury code for Flood Management and Flood Proofing (City of Canterbury, 1997): this is described as 'foam or closed cell types'. 'Reflective insulation' is classed as second preference.

3.1.4 Apertures

Definition:

Under the "apertures" category the following are considered here: door and window frames. It is well established by numerous case studies that these apertures can offer a preferential route for floodwater ingress into a building and in response to this a number of different guards have been developed to protect these apertures. Although many types of these flood guards can be effective at keeping the water out, they require fixing supporting elements to the walls and to be deployed in times of a flood. There is scope for development or increased use of existing designs of apertures that are fully sealed and thus provide the required flood protection without any additional means.

Country construction practices and resilience:

UK

Flood ingress through unprotected wooden doors used in domestic buildings has been recorded in most flood situations if not in all, which has prompted the development of a variety of flood guards. A Publicly Available Specification (PAS 1188) specifies the testing of these products in static conditions as well as under wave and current action (BSI, 2009); a national test rig and system of certification (as a joint effort of the UK Environment Agency, HR Wallingford and the British Standards Institute) have been set up.

It is expected that fully sealed PVC, glass or steel doors will provide a barrier to water ingress but to our knowledge, there has been no testing to substantiate this assumption. The vulnerability of fully sealed doors (and windows) will probably reside in the interface between the frame and the walls.

Poland

In Poland, the most popular types of window nowadays are those made of PVC. They have very good thermal parameters, are very durable and water resistant. They are recommended to be used in flood-prone areas.

Next to PVC windows, wooden windows are also very often used in the country. They are popular in single-family houses, while in multifamily and public buildings they are rarely used. They are less resistant to weather conditions, need more maintenance as they are made of a water absorbent material. Wooden windows should not be used in flood-prone areas (Wierzelewski, 2008).

After the flood in 2010, PVC windows in houses which were under water were cleaned, disinfected and it was not necessary to replace them. Wooden windows needed to be removed and replaced (Papliński, 2010).

Germany

Information on the suitability of various types of window and door is given in the German Bundesministerium für Verkehr, Bau und Stadtentwicklung flood protection manual (BVBS, 2008); an extract of that publication is given below (Table 3.7):

Table 3.7 Suitability of aperture types with regard to floodwater (BVBS, 2008)

Building element	Material	Suitability		
		Suitable	Moderately suitable	Unsuitable
Windows	Wood (depending on type)		✓	
	Plastic/synthetic	✓	✓	
	Aluminium	✓		
	Steel	✓		
Window sills	Marble, sandstone			✓
	Natural stone (e.g. granite, slate)	✓		
	Wood (depending on type)		✓	
	Aluminium and other metals	✓		
Doors	Timber frames and timber doors			✓
	Metal frames	✓		
	Stainless steel doors			

USA

Doors are classified in FEMA (2008) as follows:

Materials resistant to moving water (up to approximately 1.5m/s):

- Epoxy, formed-in-place

Materials resistant to moving water (up to approximately 1.5m/s):

- Metal
- Fibreglass

Unacceptable below base flood elevation:

- Wood (solid, lightweight panel construction, hollow).

Australia

The City of Canterbury code for Flood Management and Flood Proofing (City of Canterbury, 1997) categorises apertures as follows (Table 3.8):

Table 3.8 City of Canterbury list of suitable apertures

Component	Most suitable	Second preference
Windows	• Aluminium frame with stainless steel or brass rollers	• Epoxy sealed timber waterproof glues with stainless steel or brass fittings • Galvanised or painted steel
Doors	• Solid panel with waterproof adhesives • Flush door with marine ply filled with closed cell foam • Painted metal construction • Aluminium or galvanised steel frame	• Flush panel or single panel with marine ply wood and water proof adhesive • T&G lined door, framed ledged and braced • Painted steel timber frame fully epoxy sealed before assembly
Nails, bolts and hinges	• Brass, nylon or stainless steel • Removable pin hinges	

3.2 Discussion

The main findings from the review are presented in Section 3.4.1. At the start of the review of construction materials and practices there was an expectation that the search would lead to a wealth of information on flood resilience for critical infrastructure and a number of case studies that would illustrate how this

information has been implemented in practice. The reality was quite different, with a scarcity of design guidance for non domestic buildings and very limited national or local regulations.

This finding was by itself, nevertheless, useful as it highlighted the gaps in current knowledge and in the regulatory approach in Europe. The United States are leading the way in this field, with guidance documents which rate building materials according to their ability to resist flood water dating back to over 15 years ago. German guidance also includes material classification and the UK has also taken important steps in the classification of materials and construction components (walls and floors) based on test protocols developed specifically for flooding waters. However, these test methods have not been embedded in any regulation nor have the materials/components.

3.3 Assessment of stakeholder acceptability of new flood resilient technologies

A short questionnaire was designed to assess stakeholder acceptability of new techniques for flood resilient buildings and presented to participants at the first workshop of the project that took place in Madrid in April 2010. It was intended to gather basic information on:

- the extent of use of flood resilient building techniques (avoidance, resilient materials/components, new technologies such as floating houses) and whether this was covered by legislation
- measures to minimise water entry in basements
- acceptability of new technologies/materials without the backing of legislation
- the likely role that costs will play in the uptake of new technologies.

A total of 13 responses were collated during the workshop and included eight from stakeholders and interested parties:

- Rijkswaterstaat – Expertise network Waterveiligheid, NL
- City of Dordrecht, NL
- STOWA, NL
- Veiligheidsregio Rotterdam-Rijnmond, NL
- VRV, CZ
- City Hall Prague, CZ
- US Army Corps of Engineers, USA
- SMARTTEST, UK.

Table 3.9 summarises the responses obtained.

Table 3.9 Summary of responses to stakeholder questionnaire on stakeholder acceptability of new techniques for flood resilient buildings

Question 1. Use of flood resilient building techniques			
	Awareness	Application in case studies	In general use
<u>Avoidance measures</u> (e.g. raising ground level, perimeter walls, waterproofing walls up to structurally safe level)	4 (stakeholders) 2 (partners)	3 (stakeholders; UK and NL) 2 (partners)	7 (stakeholders; CZ, NL, USA) 3 (partners)
<u>Resilient building materials/components</u> (e.g. concrete walls and floors, sealed doors/windows, impermeable flooring such as ceramic tiles, water proof building services)	2 (stakeholders) 2 (partners)	2 (stakeholders; UK and NL) 2 (partners)	3 (stakeholders; CZ and NL) 1 (partners)
<u>New technologies</u> (e.g. floating homes and bridges, Modern Methods of Construction such as composite wall panels that include flood resistant insulation, prefabricated components and water resistant plaster)	5 (stakeholders; UK, USA and NL) 3 (partners)	2 (stakeholders; UK and NL) 3 (partners)	1 (stakeholders; NL) 2 (partners)

Question 2. Is building flood resilience part of current legislation in your country? Yes/No

If **Yes**, please specify which types of resilience and which legislation (e.g. Planning legislation, Building Regulations) and which Government Ministry covers this.

In Czech Republic (CZ): Building Regulations; Ministry for Local Development (not certain)

In Netherlands (NL): Delta Law – Ministry V&W

National Water Plan - Ministry V&W – Multi Level Safety

In United Kingdom (UK): Planning – Policy/Guidance (e.g. PPS 25)

Building Regulations – Standard 3.3 (Scotland) in part covers resilience

Building guidance for standard and modern methods of construction (walls, floors, materials); looking to incorporate in Building Regulations.

In Poland (PO): It is forbidden to build houses in areas of high flood risk, i.e. close to rivers.

If **No**, are there any current initiatives to include it? Please provide details and which Government Ministry would deal with this issue

NL: V&W (?) Initiatives: Climate Proof & planning

VROM

USA: No and no current initiatives that respondent is aware of..

UK: Pitt Review Recommendation

Ministry dealing with Building Regulations is DCLG

Norway (N): No current legislation; ministry responsible: partly covered in area of planning procedures

Don't know: 2 (stakeholders).

Question 3. Flood water ingress into basements is a major issue. Is there any legislation/standard/norm in your country covering the flood resilient design of basement entrances?

If **Yes**, please specify the legislation/standard/norm and which types of resilience (e.g. sealed doors, installation of guards)

Norway (NO): Minimum elevation of basement is 0.9m above sewer; below this level pumping is required

If **No**, are there any current initiatives to include it? Please provide details

NL: No, to the knowledge of the respondents

No: in Dordrecht inner dyke "no problem" so no policy

Outer marshes: to be developed: political no man's land

UK: No; Initiatives: see Pitt Review but not specific

USA: No and no current initiatives

PO: Likely NO (to be confirmed)

Don't know: 3 (stakeholders)

Question 4. How do you rate the likelihood of acceptance in your country of new technologies (and non-traditional materials) that offer flood resilience without National legislation?

	Likelihood		
	Low	Medium	High
By building designers/ architects		7 (stakeholders; CZ, NL, USA, UK) 4 (partners)	1 (stakeholders; NL) 1 (partners)
By contractors	3 (stakeholders; NL, UK) 2 (partners)	4 (stakeholders; CZ, USA, NL) 3 (partners)	1 (stakeholders; NL)
By Planning Authorities	1 (stakeholders; UK)	6 (stakeholders; CZ, USA, NL) 4 (partners)	1 (stakeholders; NL) 1 (partners)
By clients	2 (stakeholders; NL, UK) 3 (partners)	4 (stakeholders; CZ, NL) 1 (partners)	2 (stakeholders; NL, USA) 1 (partners)

Question 5. What is the likelihood that cost will influence adoption of new materials/technologies?

	Likelihood		
	Low	Medium	High
		2 (stakeholders;	6 (stakeholders; NL, CZ)

		USA, UK)	2
		3	(partners)
		(partners)	

3.4 Conclusions

3.4.1 Conclusions from the review of flood resilient construction and materials

The findings from the review are summarised below:

- This review was aimed at critical infrastructure buildings, defined as those buildings where essential services are housed; if they were to fail due to flooding, this would severely affect our urban societies. The functionality of these buildings during flood events will depend on three parameters: the fabric of the building (i.e. how it is built), the measures used to minimise the risk of flooding (i.e. where it is built) and the measures adopted to ensure it can operate effectively (i.e. reliance on external suppliers of services and goods). The present report concentrated on the first of these points, i.e. materials and construction practices.
- The review of materials and construction practices covered some European countries in more detail: UK, Germany, Poland. The review revealed that the USA is probably the best source of guidance and this was therefore included in considerable detail.
- Most guidelines on urban flood resilience mention the benefits of using resilient building materials as a way to limit damage and speed up the recovery process. The depth of flood water is a key parameter in the definition of the materials. Guidance in France also includes the flood duration.
- Materials in this report were categorised according to their function, following loosely the classification given in Technical Bulletin 2 of FEMA (Federal Emergency Management Agency), which administers the US National Flood Insurance Program:
 - structural
 - finish
 - insulating
 - apertures (e.g. doors, windows).
- Most classification systems rate the materials according to suitability in a qualitative manner and it is not always clear what the basis for the rating is. It appears that the only testing carried out that simulates exposure of building materials and components to a flood depth (rather than humidity) was conducted in the UK (CIRIA, 2006). This study, however, concentrated on traditional domestic construction and under static conditions. The US regulation (FEMA, 2008) provides a list of structural materials that are resistant to moving water (up to approximately 1.5m/s).

- In general terms, concrete, cement, toughened glass and ceramic materials are considered water resistant, with plastic and metal and even wood being considered acceptable depending on type and conditions (e.g. metal not suitable for salt water flooding).

The following gaps in knowledge were identified:

- 1 – The adequate choice of building materials can be an effective means of minimising the impact of floods but currently there is no regulation at European (or at national) level.
- 2 – No approved testing protocols are available at European level. The standard testing of materials measures absorption rates rather than seepage and, as materials are not subjected to the hydrostatic (and/or hydrodynamic) forces that occur during flooding, the measured behaviour is not necessarily a true depiction of the materials/components response to floodwater.
- 3 – Limited testing has been carried out on building materials (involving mostly materials used for domestic buildings) and there is a need to understand the behaviour of a wide range of materials, wall and floor components, insulation and apertures.
- 4 – Examples of application of resilient and resistant materials either for new buildings or retrofits are very limited and are mainly confined to basements.

3.4.2 Conclusions from the stakeholder assessment of acceptability of new technologies

The stakeholder questionnaire (see Section 3.3) involved only a small number of respondents, but nevertheless allowed some useful conclusions to be drawn from the responses. It should be noted that the views expressed are those of the individuals involved rather than official national statements.

Flood resilient building techniques

- Avoidance measures (e.g. raising ground level, perimeter walls, waterproofing walls up to structurally safe level) are in general use in countries such as the Czech Republic, Netherlands and USA and have been applied in case studies also in the UK and the Netherlands.
- Resilient building materials/components (e.g. concrete walls and floors, sealed doors/windows, impermeable flooring such as ceramic tiles, water proof building services) are in general use in the Czech Republic and the Netherlands, and have been applied in case studies also in the UK and the Netherlands.
- New technologies (e.g. floating homes and bridges, Modern Methods of Construction such as composite wall panels that include flood resistant insulation, prefabricated components and water resistant plaster) are only in use in the Netherlands but most stakeholders are aware of them.

Existence of building flood resilience legislation

- Of the countries in the survey, only the Czech Republic, Netherlands and UK (Scotland only) appear to consider building resilience in their Building Regulations or in planning policies.

Flood water ingress into basements

- Legislation/standards do not appear to exist with regard to prevention of flood water ingress into basements (apart from sewer ingress prevention).

Acceptance of new technologies

- In the view of the respondents, without legislation to enforce them, new technologies still have a medium likelihood of acceptance by building designers/architects, by contractors, planning authorities and by clients. This is an encouraging finding given the timeframe usually associated with the publishing of new legislation.

Cost was mostly considered to have a high likelihood of influencing the adoption of new materials/technologies (a medium likelihood was suggested by the stakeholders representing the UK and the USA).

4 Cost-benefits of building resilience measures

4.1 Introduction

The Cost Benefit Analysis (CBA) approach, in its general term, attempts to quantify feasible costs and benefits of the proposed alternatives of a project in terms of the claims they make on and the gains they provide to beneficiaries involved (Brent, 2003). Comparison of the total expected costs of each intervention against the total expected benefits helps determine and justify the alternative interventions to rank and prioritize them if their benefits outweigh the costs, and by how much (USAID, 2011).

Selection of the approach to be applied for assessing the costs and benefits depends upon the objectives of the respective CBA as well as the data sources at hand (Mechler, 2005). Regardless of the CBA type to be used and the purpose of conducting it, any CBA analysis comprises of defining the desired outcomes (objectives) and alternative options (interventions), identifying and estimating significant costs and benefits, and time period of realization. All of the cost benefit evaluation methods make use of costs, however they have different approaches to assess and justify benefits.

This study presents the steps necessary to conduct a cost-benefit analysis for flood resilience measures according to a standard methodology employed by Commonwealth of Australia (Commonwealth-Australia-6, 2006). The proposed method can be used to analyse the outcome of different resilience measures activities. It aims to offer a transparent and accessible method which does not include the indirect impacts of a project on the economy. Rather, the costs of mitigating adverse flood impacts are counted for CBA.

In the context of flood resilient buildings, benefits are defined as flood damages avoided. Therefore, the benefit of an intervention, for increasing flood resilience, equals the flood damages without implementing the intervention ("do nothing" or status quo) minus the flood damages caused after implementing that

intervention. The term resilience is used here to cover a range of measures including resistance, resilience and avoidance. The measures to enhance resilience considers both retrofitting, and rebuilding/relocating of existing critical buildings. Damages avoided include direct physical damages to the building fabric and its susceptible contents due to flooding which reflects the best estimates of the damage costs to estimate the incremental cash flow (IFAC 2008). The reduction in damages to any structure is accomplished by computing the shift in the depth-damage curves before and after implementation in addition to estimating the loss of life reduction (this latter aspect is not covered in this project). The costs of construction, operation and maintenance (O & M) associated with the retrofitting (for old buildings), and relocation/rebuilding (of new buildings) are taken into account to be compared with the prevented damage costs (benefits) for each intervention.

A flood resilient intervention or measure is technically sound if the flood damage with the measure will be less than the flood damage without the measure. This means that the monetary benefits of implementing the measure are greater than the implementation costs, and then the ratio of benefits to costs must exceed unity demonstrating that the project will make a positive impact on the economy. It should be noted that all the benefits and costs, expressed in monetary terms, must be adjusted for the time value of money by computing their present values.

Eventually, the net present value of benefits (discounted benefits minus discounted costs), and the benefit to cost ratio (B/C ratio) are used to select the alternative that should be executed. However, all competing alternatives must have a B/C ratio greater than one. The alternative with the highest net benefit value is the one that should be chosen even if that alternative may not be the one with the greatest B/C ratio (Medina, 2006).

Besides that, each of the alternative options will impact on a number of individuals, groups and organizations. Hence, it is important to indicate who will benefit and who will pay the costs associated with different interventions when undertaking a CBA analysis. In the case of critical buildings (or hotspots), one needs to consider a broad set of interested parties. These can include residents and business owners affected by disruption in services provided by that building, public sector agencies that must respond and fund the recovery process, as well as the general taxpayer that will bear some of the repair costs of the damaged critical buildings and their installations (Kunreuther et al., 2001).

The subsequent sections discuss the components that need to be addressed when conducting a cost benefit analysis.

4.2 Objectives and alternative options

As defined by HM Treasury (2011), the first essential step to conduct in any kind of cost benefit analysis is to state the project's objectives and desired outcomes clearly. Furthermore, this step includes a definition of the objectives to be achieved by the project and identification of the beneficiaries engaged. Within the scope of the FloodProBE Project the general aim is "providing cost-effective solutions for flood risk reduction in urban areas." Accordingly, this study reviews relevant literature to introduce different adaptive measures for increasing the resilience of new and existing critical buildings (hotspots) against flood water as mentioned in Section 1.2. Moreover, it is the primary objective that the critical buildings should retain the functionality during the flood event whilst the final selected alternative should be cost

efficient (minimising the costs) as well as cost effective in providing higher resistant level (lowering flood risk).

In addition to the objectives, alternatives should also be clearly distinguished in sufficient detail to be analytically judged for elimination of the alternatives that are not feasible. In the context of flood resilience, any alternative is described as a combination of adjustments and/or incorporation of features to buildings that eliminate or reduce the potential for flood damage (FEMA, 1993). Accordingly, building greater flood resilience into critical buildings can be achieved through:

1. Anticipatory or pro-active interventions (into new buildings or existing buildings through retrofitting); this type of intervention is often referred to as planned adaptation.
2. Opportunistic interventions in conjunction with autonomous renewal or upgrading of existing buildings; this type of intervention is often referred to as mainstream adaptation.
3. Reactive interventions during repairing activities of damaged buildings after the flooding.

The present guideline focuses mainly on the anticipatory interventions. They consist of flood proofing of individual buildings and municipal infrastructure and adapting the building activities to the risk. Both situations of either retrofitting of existing (old) buildings or relocation (rebuilding) of present buildings to newly flood proofed ones should be considered as potential alternatives to be evaluated. This can be done by avoiding contact with floodwater or by making the building resilient to potential damage caused by floodwater. The main strategies for flood proofing considered here are: using elevated configuration (building on column or on mound), dry proofing the building (sealing by doors or guards, airbrick covers), wet proofing the building (e.g. ceramic tiles for flooring, flood resilient doors, windows and frames), and using relocating or rebuilding the present buildings to flood proofed ones (i.g. floating or amphibious buildings). Extensive description of different possibilities for flood proofing can be reviewed in Section 2.2 of this report. However, Figure 4.1 depicts some sketches of three of these measures including an elevated, dry proofed, and wet proofed structure.

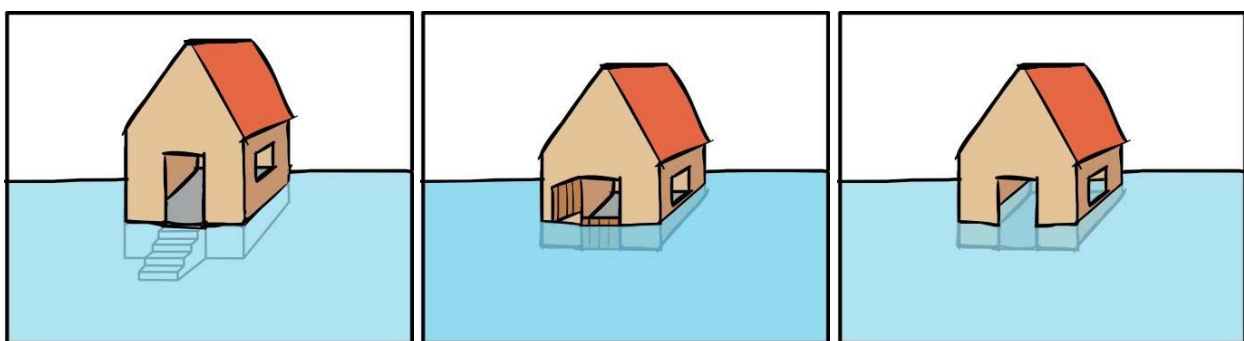


Figure 4.1 Elevated, dry proof and wet proof dwelling adopted from (Wolthuis, 2011)

An important decision to be made is the selection of the best alternatives for the feasibility study. The CLG guidance (2007) has provided a table that summarises the framework for selecting the alternatives. That table has been improved for Modern Methods of Construction (MMC) and included in Garvin (2012). Table 4.1 shows the suggested measures for each depth and duration of flooding which has been prepared

for residential buildings, but not specifically for critical buildings. It also does not have any suggestion for selection of amphibious or floating buildings, however it suggests relocation and raising of buildings for flood depths higher than 1m.

Table 4.1 Strategies for flood-resilience construction of residential buildings (based on CLG, 2007 and Garvin, 2012)

<i>Type of flood protection</i>	<i>Design water depth/ duration of flood</i>	<i>Approach</i>	<i>Mitigation measure</i>
Resistance/ Resilience	0.6 - 1 m 4 - 24 hr	Allow water through the property to avoid risk of structural damage (water entry strategy)	Flood-resilient material and designs up to 1m in depth. Access to all spaces to allow drying and decontamination. Design to drain water away after flooding
	0.3 - 0.6 m < 4 hr	Allow water to enter the building above 0.3 m. Alternatively, a full structural assessment is necessary for the performance to at least hydrostatic pressure up to 0.6m depth, to keep water out to that depth	Materials with low permeability up to 0.3m. Materials with low permeability up to 0.6m if building structurally robust. Flood-resilient material and designs to 0.6 m if entry allowed. Flood products for opening up to 0.6m.
	< 0.3 m < 4 hr	Attempt to keep water out (water exclusion)	Low-permeability material and construction. Flood products for opening up to 0.3 m .
Avoidance	> 1m > 24 hr	Remove building/development from flood hazard	Relocate building to alternative site. Land raising (lifting the building above the flood depth). Landscaping. Raised thresholds. Raised basement/foundations. Hybrid construction with resilient ground floor. Barriers and demountable barriers near to the property.

Additionally, as mentioned in FEMA guideline for Non-Residential Flood proofing, some other factors should be considered in advance of determining the appropriate flood proofing alternatives. For instance, if available warning time is short for a flood prone site which can be surrounded by rapidly rising, high-velocity floodwaters, then the site is inappropriate for a flood proofed building. This means that the flood warning system must be capable to adequately provide sufficient lead time to evacuate a flood prone building when flooding threatens. Another critical parameter to be considered is the safe access to a flood proofed building. Furthermore, a site that has been flooded frequently may not be appropriate for a dry-flood proofed building because of the cumulative wear-and-tear on a building's external components as a result of recurring inundation (FEMA, 2008).

4.3 Estimation of costs

Most likely, the cost items are direct monetary costs to structurally retrofit or replace some components of critical buildings or to relocate/rebuild the whole structure. Furthermore, those costs can be represented by one-time costs of utility relocation/rebuilding, and periodic costs of maintenance (including replacement and cleanup). In other words, there is incremental cost for building higher resilience that can be classified as the cost of investigating the flooding risk for the status quo and each defined alternative; the capital cost of construction for each intervention (e.g. demolition of the structures, restoration of the land); and the maintenance costs consisting of periodic inspection, preventive maintenance, and repairs throughout the useful life of the assets (i.e. additional construction).

Some specific cost items that have been developed in Gersonius et al. (2008) and in Floodproofing Info #1-10 - STC (2012) for each type of flood proofing alternative are listed in Table 4.2. The provided unit cost estimates are for preliminary planning purposes only based on nationwide averages listed in Floodproofing Info #10 (STC, 2012).

Table 4.2 Cost items and unit costs that may occur in different flood proofing measures

Flood proofing type	Specific costs	Unit Costs
Wet flood proofing	The major costs of this measure involve rearranging utility systems (e.g. relocating electrical facilities and delivery points), installing flood vents, replacing materials that are not flood-resistant, acquiring labour and equipment to move items, and cleanup when floodwaters recede. Major disruptions to structure occupancy may occur during and after floods.	Unfinished basement: 76 cm height (above basement floor): €9.35 per square metre of house footprint 152 cm height (above basement floor): €19.22 per square metre of house footprint 304 cm height (above basement floor): € 55.05 per square metre of house footprint Crawlspace: 76 cm height (above lowest adjacent grade): €7.27 per square metre of house footprint 152 cm height (above lowest adjacent grade): €17.91 per square metre of house footprint
Dry flood proofing	Dry flood proofing may be less costly than other methods of protecting flood-prone structures. Project costs depend largely on the building size, depth of protection, types of material used, and number of openings. Some typical costs are the cost of coating the facades, cost of using material with a low permeability and the cost of installing temporary barriers	Sprayed-on cement (above grade): €18.18 per square metre Waterproof membrane (above grade): € 6.08 per square metre Asphalt (2 coats below grade; not including cost of excavation): € 6.08 per square metre Perimeter drainage: € 65.13 per linear metre Plumbing check valve: €495 lump sum Sump pump (with backup battery): € 795 lump sum Metal flood shield: €399.9 per square metre Wood flood shield: €124.65 per square metre Sprayed-on cement (above grade): €18.17 per square metre
Raising structure (building on stilts or building on mounds)	The cost to lift the building on steel beams and extend or replace the foundation will depend on the size of the structure, type of construction, and amount of elevation. Additional project costs include: disconnection/reconnection of utility lines, elevation of service equipment, temporary housing during construction, and removing/storing belongings. Additional	76 cm raise: Wood frame building with basement or crawlspace: €93.50 per square metre Wood frame building with slab-on-grade foundation: €259.7 per square metre Masonry building with basement or crawlspace: €192.17 per square metre Masonry building with slab-on-grade foundation: €259.7 per

	expenditure may be required to bring the building into compliance with building codes. If the structure has been substantially damaged by flooding, part of the cost may be eligible for Increased Cost of Compliance flood insurance coverage.	square metre <u>114- to 304-cm raise:</u> add €4.15 per square metre for each additional 0.38cm of elevation <u>Above 304 cm:</u> add €5.45 per square metre Wood frame with brick veneer on walls: add 10 percent These costs include foundation, existing utilities, and miscellaneous items. Large buildings (3 or more stories and those with footprints more than 361 square metre) and those with complex shapes are technically more difficult to elevate and may thus be more costly. <u>Displacement costs:</u> Additional expenses will be incurred to remove and store contents and for temporary living quarters during construction, which may last 2 to 3 weeks.
Relocating the structure including: Preparing the new site Moving the building Restoring the old site	Cost is a major concern associated with building relocation. In addition to the cost of moving the structure are the expenses associated with purchase and preparation of the new site, installation of utilities, construction of a new foundation, and restoration of the old site. Arrangements must also be made for temporary housing and storage of belongings. If electrical, plumbing, heating, or other systems do not meet current building code requirements, they will need to be brought into compliance. If the structure has been substantially damaged by flooding, part of the costs may be eligible for Increased Cost of Compliance flood insurance coverage.	<u>Relocation costs:</u> Wood frame building with basement: €176.6 per square metre Wood frame building with crawlspace: €150.6 per square metre Wood frame building with slab-on-grade foundation – €280.47 per square metre Masonry building with basement: €270.1 per square metre Masonry building with crawlspace: €176.6 per square metre Masonry building with slab-on-grade foundation: €337.6 per square metre Wood frame with brick veneer on walls: add 10 percent <u>Restoration of old site:</u> €62.3 per square metre of building footprint These costs include off-site relocation (less than 8 km) and new site development for a 144.4 square metre building. <u>Displacement costs:</u> Additional expenses will be incurred to remove and store contents and for temporary living quarters during construction, which may last 3 to 4 weeks.

4.4 Estimation of benefits

The benefits associated with the investment in building greater resilience for critical buildings are essentially the avoidance of flood damage by reducing the impact of flooding on the property and economic activities affected. The economic value of flood damage is estimated by replacement costs of rebuilding (Wagemaker et al., 2008). These benefits accumulate over the lifetime of the critical buildings and are discounted for comparison to the incremental cost incurred at the inception of alternatives. Furthermore, benefits of a damage reduction strategy are equal to the differences in expected annual damages before implementing an alternative (do nothing case) and the damages after implementing that alternative. For a technically sound alternative intervention, the expected damages caused with the resilience measure should be less than the damages without it with a positive net benefit value.

Many items of flood damage loss are functions of the nature and extent of the flooding, including its duration, velocity and the contamination of the flood waters by sewage and other contaminants (Penning-Rowsell et al., 2010). The indirect flood damages to critical buildings can include loss of health care, electricity, shelter, water and sewage treatment capacity as well as the need for emergency response,

temporary relocation, and post-flood cleanup. However, most flood damages are direct tangible damages and include structural damage to buildings, loss of contents in those buildings, damage to infrastructure, and damage to special or unique facilities (Medina, 2006). Those direct damages result from the physical contact of flood water with damageable property and its contents and they may adversely impact the functionality of critical buildings.

In order to properly assess the benefits of flood resilient building all tangible and intangible prevented damages should be included in the analysis. However, current practice generally includes the direct tangible damages only and fails to consider the intangible damages. The main reason for this fallacy is that these intangible damages are very difficult to assess. Consequently, CBA tends to underestimate the benefits.

4.4.1 Estimation of the "do nothing" case

Normally, the leading alternative in cost benefit analysis is the "do nothing" situation or the status quo which is the reference point for evaluating the relative performance of other alternatives. The status quo refers to the current flooding risk threatening the system without implementing resilience measures. This is necessary because costs and benefits are always incremental to what would have happened if implementation of the alternatives had not gone ahead.

Messner et al. (2007) define a four step framework for flood damage evaluation of the status quo. The first step is to determine a fitting approach for damage assessment. This approach is dependent on the scale of the study, objectives of the study, and data availability for that scale. The second step is to identify the damage categories to be considered. Based on the objectives of the study, and the resources available, a variety of tangible and intangible (direct and indirect) damages can be considered for the assessment process. The third step is the major task in which flood damages are evaluated. This includes determining the flood characteristics by performing hydrodynamic simulations, preparing the land use data including the types and numbers of critical assets in the study area, estimating the value of the classified assets, and assessing the damages caused to them for each flooding scenario. Finally, the fourth step, integrates all the information collected in previous steps in order to calculate the expected damages.

Regarding the objectives of the FloodProBE project, this study only considers the direct tangible damages which are monetary losses directly attributable to flooding as a result of the actions of floodwaters on properties and structures. A classification of such kind of damages has been provided by Gersonius et al. (2008) including a list of potential damage groups as damages to the building fabric, internal walls, ceiling, covering, and any installation services (e.g. electrical installation). The examined approach for damage assessment is by developing the stage-damage, depth-damage or frequency-damage curves based on flood simulation results. Respectively, simulation of flood characteristics can be done by application of 1D/2D hydraulic models which simulate flooding characteristics by converting rainfall data into runoff information. The modelling process is performed for individual flood incidents of varying severity and probability of occurrence. The generated output information represents development of flood characteristics such as water depth and extent, flow velocity and duration, and load of contaminants over time. However, the area and depth of flooding is the most important information needed for the physical damage assessment process. By application of GIS to depict the land use data (location, number, type and elevation of the assets), it is possible to determine the depth of flooding at each hotspot building as well as

the extent of flooding to be used for the calculation of damages. Thereafter, direct damages associated with the physical impacts of flooding are generally estimated by what is referred to as unit damage functions or stage-damage functions.

Stage-damage functions are considered essential components of flood damage estimation models to provide information on a specified relationship between flood characteristics (usually depth) and the extent of economic damage for each type of building considered. Normally, the damage function is a function of inundation depth, duration, fresh or salt water and velocity, which governs the damage characteristics (Wolthuis, 2011), and it must be an increasing function, which means that as the inundation grows, also damages rise. However, there are other factors such as structure resistance variables, for example type of building, precautionary measures as mentioned in Gersonious et al (2008), which are not taken into account in most of the current depth-damage curves. Besides that, some damages can be avoided during a flood event by appropriate action from the people who live in the floodplain. Such efforts should not be included in damage assessment (Genovese, 2006).

Damage functions can be differentiated into relative damage functions, showing the damaged share of the total value, and absolute damage functions, indicating absolute damage amounts as a function of inundation depth. Damage functions can be either derived from real flood damage data (survey data) or synthetically, i.e. by expert estimation for either standardised property type or for the specific properties located in the study area. Both absolute and relative damage functions can be used at all scale levels (Messner et al., 2007). In any case, the replacement, residual, repair or relocation values (Wolthuis, 2011) can be used for monetisation or 'pricing' of the structural damages (Jonkman et al., 2008) to critical buildings. Replacement costs represent the potential expenses for replacement of the dwelling, content, infrastructure, etc. at the price it can be bought at the capital market. Residual values count for depreciation (Hoes, 2006). The direct physical damages are determined by means of a maximum damage amount per damage object (each type of critical building).

Since flooding damages the structure and its contents, the floodplain inventory for critical buildings must include a topographic survey of first floors as well as characterisation of the type of property: one storey or multi-storey, with or without basement, detached or attached. Certainly, the specific installed facilities that can be damaged such as electrical installations must also be identified. However, if data is insufficient, contents are typically estimated as a fraction of the replacement value.

The results of damage functions computed for different flood depths and flooding probabilities are sketched in stage-damage or depth (elevation)-damage curves. For the development of such curves, building inventory, lowest-floor elevations, and flood characteristics are combined to produce the graphs showing the accumulated damages for all assets that would occur if the flood waters reach different depths (or elevations). Figure 4.2 shows the typical shape of these curves. Because each flood depth in Figure 4.2 is associated with the probability of the rainfall event that caused it, the depth-damage curves can be transformed into damage-frequency curves by assigning the exceedance probability to the corresponding damages.

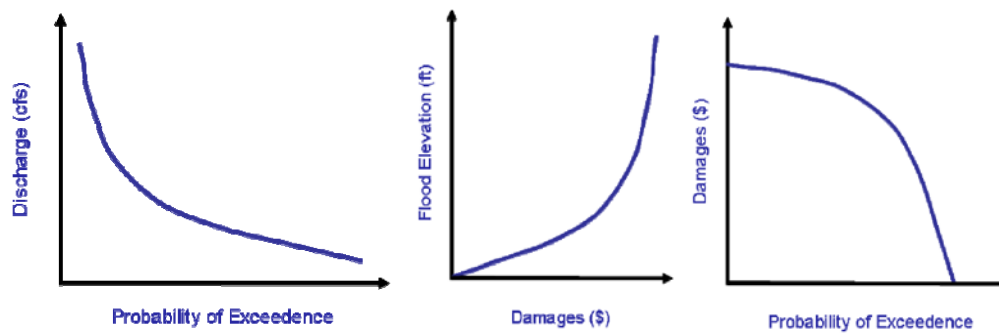


Figure 4.2 Sample representation of graphs that can be produced as a result of applying damage functions

Eventually, all the information gathered and generated in previous steps is applied to compute the absolute annual direct damages. The final outcome is a single direct, tangible damage value in monetary units that has been obtained from the area below each damage-probability curve for each flooding scenario considered. The summation of the values of different scenarios is used to compute the net annual benefit of other alternatives in comparison with the do nothing case described in following section.

4.4.2 Damage reduction assessment

Four different categories namely wet flood proofing, dry flood proofing, elevated structures, and relocation/rebuilding of buildings (old and newly developed) are the proposed alternative measures to build a greater resilience in critical buildings. Implementing any of these can directly result in reducing the impacts of flooding on that structure and the services it provides. Therefore, estimating the damage reduction after implementation is used to estimate the benefits of that intervention.

The process of computing damages avoided (benefits) requires developing the damage-frequency relationship for the new situation (after implementing the alternative). Basically, the procedure includes the same sequence of computations explained above for the do nothing condition. Plotting the "do nothing" case vs. the implemented alternative case will clearly show a shift in depth-damage curves as shown in Figure 4.3 for different resilience measures.

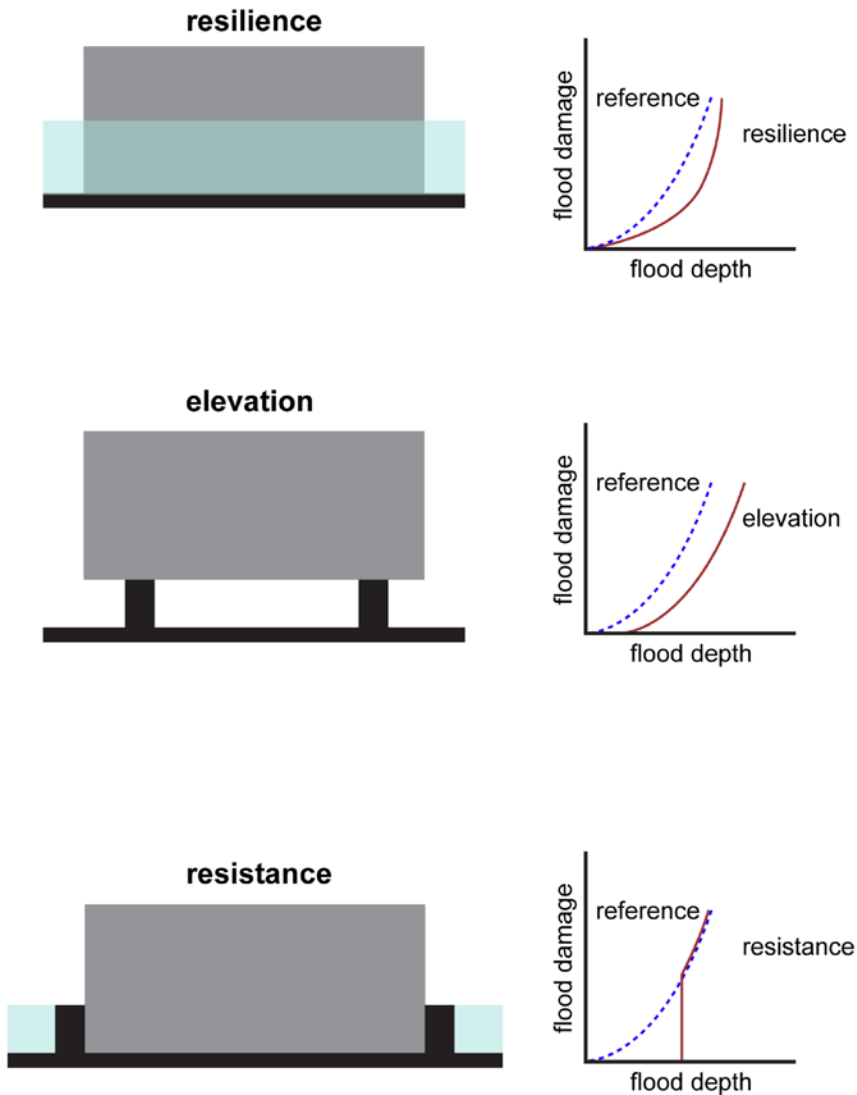


Figure 4.3 Symbolic changes in depth-damage curves for the "do nothing" case vs. implementing some of the resilience measures

Afterwards, the developed damage-probability curves for "do nothing" and "implementing the alternative" are plotted in the same graph to be applied for computation of the annual benefits of that alternative. In other words, the area between the two graphs will be the expected annual benefit of that alternative which by definition corresponds to the cost saved due to implementing that option. As shown in Figure 4.4, the horizontal axis represents probability where the vertical axis contains the damages and the shaded area represents the change in damage caused (or in the flood risk). This change in damages caused depicts the annual benefit of the proposed measure (Wagemaker et al., 2008).

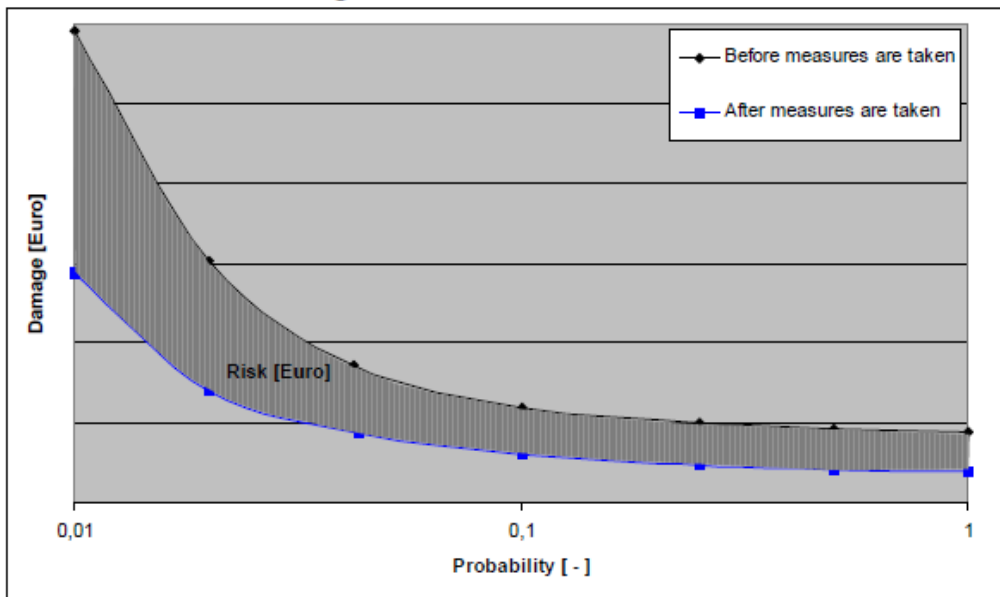


Figure 4.4 Curves showing the annual benefit of risk reduction (by increasing resilience) of implementing a sample alternative (in Wagemaker et al, 2008)

4.5 Decision making criteria

Any decision to select the best alternative option for increasing resilience must be evaluated under cost-benefit criteria to see if it is financially attractive together with being effective in delivering higher resilience. To do that, the valuation process to determine the worthwhile alternative option is conducted by comparing the discounted net present values. If the discounted present value of the benefits exceeds the discounted present value of the costs, then the alternative is acceptable. Put another way, not only the net benefit should be positive but also the ratio of the present value of the benefits to the present value of the costs must be greater than one for a feasible alternative. Eventually, the final selected alternative will be the one with the highest net present value. This is equivalent to the benefit/cost ratio being greater than one and the internal rate of return being greater than the cost of capital.

4.5.1 Net present values

The standard approach to value costs and benefits occurring at different times assumes that a monetary unit is now worth more than it will next year. Therefore, all the costs and benefits incurring in different time periods are converted to their 'present values,' so that they can be compared. The present values are estimated by discounting the sum of annual costs and benefits. The Net Present Value (NPV) takes the present value of the lump sum of the net benefit (benefit minus cost) that is discounted by an appropriate discount rate for the life time of the project. The following formula summarizes the above description in which B_r denotes the annual net financial cost or benefit, and T is the life time of the project.

$$\sum_{t=0}^T \frac{B_r}{(1+r)^t}$$

The net present value (NPV) rule should be the primary basis for recommendation and decision making in every project evaluation. The NPV takes the discounted total benefit minus the discounted total cost. As a result, the benefits outweigh the costs if the computed NPV is greater than zero. Whereby, higher NPV provides greater financial argument for initiating the project (Venton, 2010).

In addition to the NPV which is the primary approach to determine the worthwhile alternative, the benefit cost ratio (B/C) summarizes the relative size of the benefits and cost of a project that must be greater than one.

4.5.2 Benefit to cost ratio

Rules other than the net present value rule can provide useful supplementary information. However, they should only be employed carefully to prevent misleading recommendations. An example is the benefit to cost (B/C) ratio as a variant of the NPV since benefits are divided by costs. If the ratio is larger than 1 meaning that the benefits exceed costs, then that alternative adds value to beneficiaries. The B/C ratio indicates the level of benefit that will be accrued for every €1 of cost. Respectively, a ratio greater than 1 indicates that the project is worth investing in from a financial perspective. Whereas, the ratio less than one depicts a negative return (Venton, 2010). The benefit-cost ratio of a project can be calculated in two ways. The most useful way is by dividing the present value of net recurrent benefits (benefits less operating or other recurrent costs) by the present value of the capital costs (Commonwealth-Australia-6, 2006):

$$\text{BCR} = \text{PV net recurrent costs} / \text{PV capital costs}$$

The other way to calculate the B/C ratio is by dividing the present value of all benefits by the present value of all costs:

$$\text{BCR} = \text{PV benefits} / \text{PV costs}$$

A B/C ratio greater than one is required for an acceptable alternative intervention by application of either methods. Note that the NPV gives an estimate of the absolute size of the net social benefits whilst the B/C ratio summarizes the relative size of the benefits and cost of a project (Wolthuis, 2011).

The decision regarding identification of the feasible flood proofing alternative must also be based on the personal preferences and concerns of the people who will be living with the results on a day-to-day basis. Are there some public preferences? Is there any concern about the accessibility/functionality of the critical building during flooding? Special considerations related to critical buildings? Would someone be available and able to implement protective measures prior to a flood? How much damage is acceptable for each type of critical building? These considerations must be integrated with technical and financial considerations to develop the most appropriate strategy for managing the flood risks in a particular situation.

It should be noted that the sequence of steps presented here should not be regarded as rigid; analysts may often find it necessary to return to previous steps as the nature of the problem they are investigating becomes clearer.

4.5.3 Recommendations

The NPV method is suggested for the financial appraisal. When comparing with other available methods (such as the Pay Back or the Internal Rate of Return methods), as the NPV deals with the long-term value of money, it overcomes the disadvantage of the Pay Back method which is not suitable for very long financing. Besides that, the NPV is preferred over the Internal Rate of Return method (IRR) since NPV can be used for rating mutually exclusive projects.

Figure 4.5 summarises the recommended procedure for a cost-benefit analysis for selection of flood resilient alternatives based on monetary assessment alone. However, it should be noted that factors other than monetary should be included in any option appraisal analysis. These factors include considerations of waste minimisation, carbon emissions reduction, sustainability of natural resources, use of recycling materials. Waste created by the refurbishment of buildings damaged by a flood event is an increasingly important concern in Europe as a result of recent EU Directives that impose heavy charges that effectively limit the amounts of waste to be sent to land fill. Given the urgent nature of flood damage repair, it is not surprising that little attention is currently paid to the separation of materials for recycling but there is scope for better guidance/regulation in this area. Equally, during the refurbishment of flood affected properties, guidance is required on the environmental impact of flood resilient/resistant materials, be it with regard to carbon emissions or sustainability in general. The quantification of these issues should ideally be part of the cost-benefit analysis but current state of knowledge does not permit it. Besides this, each of the alternative options will impact on a number of individuals, groups and organisations and therefore it is important to indicate who will benefit and who will pay the costs associated with different interventions when undertaking a CBA. In the case of critical buildings, a broad set of interested parties is potentially involved: residents and business owners affected by disruption in services provided by that building, public sector agencies that may need to respond and/or fund the recovery process, as well as the general taxpayer that will bear some of the repair costs of the damaged critical buildings and their installations.

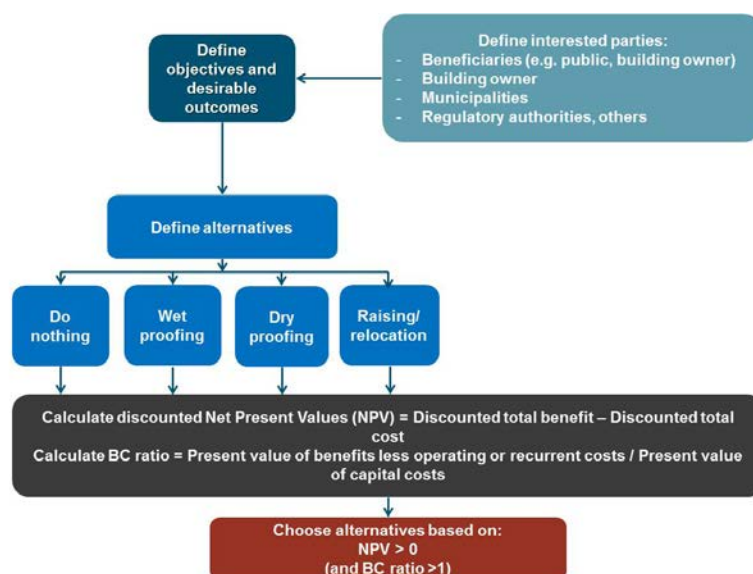


Figure 4.5 Schematic for cost-benefit analysis of flood resilient alternatives

5 Cost assessment of building resilience measures for critical buildings

5.1 The individual building tool

Under Task 2.2 of the FloodProBE project a tool was developed for predicting the costs associated with flooding of individual buildings (D2.2 “Assessment of the vulnerability of critical infrastructure buildings to floods”). The tool estimates the cost of cleaning, repair or replacement of each construction element of the building as a percentage of the new-built cost. This tool was developed to capture the specificity of critical buildings, which have a large variety of elements and therefore do not usually conform to pre-defined categories of construction. The details of the tool are given in the above mentioned D2.2 report.

5.2 Test case

Of the three case studies used to verify the tool in D2.2, case study 1 was chosen to explore the costs of installing measures for dry proofing and wet proofing the building in order to compare the required outlay with the costs of damage if no measures were taken. This comparison would help to make cost/benefit analyses of installing the various options. The building occupant will also take into account in these calculations the value of the stock stored and of the costs of interruptions to the business. However, this exploration of costs refers only to the building itself.

Case study 1 is a retail outlet with warehouse with a total floor area approx. 700 m². It has a U shaped configuration of buildings around a yard area. There is a two storeyed, former dwelling house which has been converted to provide a wine cellar in the lower storey with office accommodation above. This building is of brick construction, with a pitched, tile clad roof, suspended timber intermediate floor and a concrete ground floor. To the rear of this building and bordering the site boundary, there is a single storeyed, brick constructed building with a pitched, tiled roof which accommodates the retail and wholesale trade counter, entrance lobby and offices; along the perimeter at the rear of the site, there is a steel portal framed warehouse, part metal part timber frame-metal profile cladding over concrete block walls with roof cladding with plastic foam insulation boards linings and having a part mezzanine floor, which provides the main storage accommodation on the site. This building backs immediately on to the embankment of the River Don, in Sheffield, UK (see Figure 5.1).



Figure 5.1 Case study 1 Retail outlet with warehouse

According to the UK Environment Agency (EA, website) this flood event was likely to be associated with a return period over 150 years. It had the following characteristics on which the calculations for damage and associated costs of repair and replacement were based (see Table 5.1).

Table 5.1 Case study 1 flood characteristics of predicted flood event

Characteristic	Predicted flood event
Flood depth	0.9m
Flood duration	Up to 24 hours
Velocity and debris content	None
Type of pollution	Hazardous

5.3 Calculations for dry proofing

Assuming a maximum flood level 900mm above ground floor level, in order to dry proof the case study building, it will be necessary to install barriers to all relevant openings, to ensure that the external walls are waterproof up to 1.2m and able to withstand the pressure of water up to 900mm, and to prevent water ingress through drainage by installing non-return valves. Prices for the various measures are based on quotations received from specialist suppliers and installers of flood proofing equipment. The prices are typical installed prices in the UK and do not necessarily represent specific overseas markets or arrangements to supply a third party.

Three dry proofing scenarios are explored (see Tables 5.2, 5.3 and 5.4) :

Scenario I - Using flood-control doors, air brick covers, non-return valves

Table 5.2 Costs for Scenario I

Installation	Number of items	Cost per item (£)	Total cost (£)
Airbrick covers	20	120	2,400
1 metre wide flood-control door	4	1,300	5,200
2.5 metre wide flood-control door (cargo door)	2	3,800	7,600
50mm non-return valves	10	25	250
Builders work in sealing holes and service entries	40	60	2,400

Waterproof sealant on external brickwork	88m ²	10 per m ²	880
Waterproof sealant on concrete walls	100m ²	10 per m ²	1000
Total			19,730

Scenario II - Using demountable door barriers, automatic air bricks, non-return valves

Table 5.3 Costs for Scenario II

Installation	Number of items	Cost per item (£)	Total cost (£)
Airbrick covers	20	120	2,400
1 metre wide demountable door barrier	4	800	3,200
2.5 metre wide demountable door barrier (cargo door)	2	2,500	5,000
50mm non-return valves	10	25	250
Builders work in sealing holes and service entries	40	60	2,400
Waterproof sealant on external brickwork	88m ²	10 per m ²	880
Waterproof sealant on concrete walls	100m ²	10 per m ²	1000
Total			15,130

Scenario III Demountable barrier around the buildings, assuming that there is sufficient space around the buildings to install the barrier

Table 5.4 Costs for Scenario III

Installation	Number of items	Cost per item (£)	Total cost (£)
50mm non-return valves	10	25	250
Demountable barrier around buildings	152m	300 per m	45,600

Associated building works	152m	150 per m	22,800
Total			68,650

5.4 Calculations for wet proofing

Again, assuming a maximum flood level of 900mm above ground flood level, wet proofing will involve replacing all materials and finishes in the existing buildings that will be subject to floodwater with water resistant/resilient materials that can easily be cleaned, dried and replaced without being damaged. This will affect the design of the ground floors, the lower parts of the external walls and internal partitions, the internal and external doors, and some windows. Particular attention will have to be paid to the layout of the services, particularly wired services, to position them above the likely flood level. Other equipment, such as boilers, air-conditioning units etc. will also have to be suitably positioned.

Scenario IV. It is assumed that this flood resilient replacement work is carried out as a repair to the building after flood when the damaged items need to be replaced anyway.

In this case the damaged material is replaced with flood resilient materials and finishes, i.e. the flood event is used as an opportunity for wet proofing the buildings. The additional cost of these compared with simple replacement of existing vulnerable materials is calculated in Table 5.5 below. This is equivalent to the extra cost of specifying suitable wet proofing materials during an identical new-build premises, as the costs of clearing up, demolition and disposal and cleaning up are not part of this calculation.

Table 5.5 Scenario IV Additional cost of flood resilient replacement work is carried out as a repair to the building

Element construction	Additional works required for wet proofing	Current new-build cost (per m ² or m or number) for building as built (£)	Current new-build cost (per m ² or m or number) for flood resilient construction (£)	Square metre, length or number affected	Total additional cost of using flood resilient construction (£)
External brick/block cavity wall with rigid foam insulation	Replace internal plaster with cement rendering, provision of drainage for wall cavity	120	127	66	462
External solid brick/block walls	No change required	35	35	75	0

(warehouse)					
Steel profiled cladding	Replace insulation quilt with rigid foam insulation	97	118	76	1596
Internal stud and plasterboard partitions	Replace partitions with dense blockwork, cement rendered both sides	45	66	30	630
Timber external doors	Replace with steel doors and frames	440	485	4	180
Timber internal doors	Replace with steel doors and frames	220	385	8	1320
Concrete floor, screed	3mm epoxy resin waterproof floor treatment	84.5	104.5	400	8000
Concrete floor, (office)	Ceramic floor tiles	84.5	114.5	200	6000
Steel cargo doors	No change required	2500	2500	2	0
Hot and Cold water supply	No change required	12.2	12.2	200	0
Electric supply office/shop	Move up to min. 900mm above floor level	32.28	33.5	200	244
Electrical supply warehouse	Move up to min. 900mm above floor level	47.75	50.5	400	920
Heating installation	No change required	48	48	204	0
Total					19,352

Scenario V. Flood damage and reinstatement cost for the wet proofed building

This scenario uses the tool to estimate the costs of reinstating the wet proofed building after flooding. This shows the reduced damage and costs compared with the original building containing vulnerable materials and constructions (Table 5.6). The clear-up and clean-up costs are the same (some different percentages appear due to the different new-build costs of upgraded constructions), but the demolition and replacement costs are eliminated, only requiring redecoration of the affected areas after the building is cleaned and dried.

Table 5.6 Costs of reinstating the wet proofed building after flooding

Element construction	Damage repair/Re-placement and drying as % of new-build cost	Addition for hazardous pollution clean-up	Total % new-build cost	Square metre, length or number affected	Current new-build cost in £ (per m ² or m or number)	Actual total cost of re-instatement in £ (costs of reinstatement of non-wet proofed building) ¹
External brick/block cavity wall with rigid foam insulation, internal rendering	5	43	48	66	127	4023.36 (5544)
External solid brick/block walls (warehouse)	62	154	216	75	35	5670 (5670)
Steel profiled cladding, rigid foam insulation	2	50	52	76	118	4663.36 (7784.25)
Internal concrete block and rendered partitions	4	25	29	30	66	574.20 (1404)
Steel external doors	4	10	14	4	485	246.40 (1918.40)

Steel internal doors	6	15	21	8	385	646.80 (2877.60)
Concrete floor, screed	2	10	12	400	104.5	5016 (22646)
Concrete floor, quarry tile finish (office)	2	8	10	200	114.5	2290 (11323)
Steel cargo doors	4	22	26	2	2500	1300 (1300)
Hot and Cold water supply	0	0	0	200	12.2	0 (317.20)
Electric supply office/shop	0	0	0	200	32.28	0 (8586.48)
Electrical supply warehouse	0	0	0	400	47.75	0 (14976)
Heating installation	21	32	54	204	48	2578.50 (2578.50)
					Total	27,008.62 (86,925.43)

Note 1: Refer to Floodprobe D2.2 "Assessment of the vulnerability of critical infrastructure buildings to floods"

Unlike the result of the dry proofing scenarios, where a flood event of the type described will not affect the fabric of the building (apart from some cleaning of the external facades in the case of Scenario I and II), the wet proofing Scenario V does result in considerable costs in order to clear up and clean and redecorate the affected areas. However, in this case, the estimated saving in repair costs gained from wet proofing the building is £59,917 (repairing using resilient materials corresponded in this example to about 30% of the costs of repairing like for like – it should be noted however, that there may be differences in the cost basis).

5.3 Comparative costs of dry and wet proofing options

The costs of the various scenarios are compared in Table 5.7 and these comparisons are relevant to existing buildings in a post-flood situation. It should also be noted that Scenarios I to III can be also applied as preventive measures whereas the costs associated to Scenario IV only relate to repair measures after a flood event. Wet proofing measures do not prevent the ingress of floodwater, so despite the benefits of reduced damage, simplified cleaning up and quicker drying out times, the contents of the buildings are still exposed to the threat. The more frequently the building is flooded, the more cost effective the investment in flood resilient materials will be. This also applies to the investment required for implementation of dry proofing measures. Scenario V illustrates a case where the replacement of flood damaged materials with flood resilient ones shows an immediate saving when compared with replacing like for like; this stems mainly from the lower restoration costs but cannot be taken as general across all situations. The financial benefits of wet proofing measures usually become evident with recurring floods.

For the case study analysed (warehouse type construction and flood with high return period estimated at 150 years and flood depth of 0.9m), Table 5.7 indicates that the costs of wet proofing can be comparable to the costs of dry proofing (except for the case of demountable barriers). We consider that the use of these dry proofing methods for flood depths of 0.9m is at the limit of recommended application due to the risk of structural instability when water is prevented from entering the building. It has also been assumed that there is no leakage into the building from the ground (or from the walls); should this not be the case, the costs associated with these methods could significantly increase.

Several additional factors should be taken into account when considering these different options. Any demountable equipment needs to be stored in a suitably accessible place when not in use. With air brick covers and door barriers, this should not provide a serious problem, as they are light and compact for easy storage. However, in Scenario III, no account has been taken of the costs of storing the perimeter barriers when not in use. These are large installations with heavy components and much material that may be difficult to store nearby, perhaps using valuable commercial space. The costs incurred should be calculated depending on the individual situation.

In addition, demountable barriers require a sufficiently trained workforce to be available at short notice to erect or install the barriers if the danger of flooding unexpectedly arrives. There are also costs incurred during the erection and dismantling of the barriers. Training is required for the erectors if they are company staff, or alternatively expert installers are required who should provide a rapid response service. Automatic barriers provide a solution to both storage and erection problems, but are always more costly, and require considerable associated building work to install them.

Table 5.7 Comparative costs of dry and wet proofing

Scenario	Extra cost over repair cost in £
Original building	0
Scenario I - Using flood-control doors, air brick covers, non-return valves	19,730
Scenario II - Using demountable door barriers, automatic air bricks, non-return valves	15,130
Scenario III - Demountable barrier around the buildings, assuming that there is sufficient space around the buildings to install the barrier	68,650
Scenario IV - Flood resistance replacement work is carried out as a repair to the building after flood (or the extra cost of specifying suitable wet proofing materials during an identical new-build premises)	19,352
Scenario V – Savings in repair costs due to wet proofing	59,916.81

It must be noted that the above calculations must be regarded as indicative only of the scale of differences between the various scenarios. In order to achieve accurate figures it would be necessary to make precise measurements of the buildings and to get comparative quotations for the work according to detailed specifications. It was not within the scope of this project to undertake this detail of investigation.

Furthermore, when critical buildings are affected by floods, “cascading effects” and associated costs will occur which will affect other parts of the critical infrastructure. These have not been considered in the present analysis as they are not possible to estimate without detailed knowledge of the network.

When calculating the cost/benefit of installing flood protection measures, the predicted frequency and severity of the flooding should be taken into account. It is common practice to measure the effect of introducing various flood mitigation measures to calculate annual damages from flooding expressed in units of currency per year. This is a familiar performance indicator used to measure the level of potential damages inflicted by a range of flood magnitudes. These figures can then be used to judge the economic viability of various flood mitigation measures, either at single building level or more generally for groups of buildings or for larger areas. Obviously, the smaller the risk of flooding, the less incentive there is to spend a lot of money on flood resistance measures. However, an additional factor that will influence the decision is the value of the contents of the building, and in the case of infrastructure buildings, the importance of the continuing functionality of the building and its contents in relation to the wider network that it serves.

6 Roadmap for accelerated acceptance of building resilient technologies

6.1 Introduction

With growing populations, climate change concerns and a more encompassing understanding of the various potential sources of flooding, modern flood risk management can no longer rely solely on traditional flood defence schemes – rather it needs to be able to use a portfolio of measures and approaches to minimise the impact of floods on communities.

It has become apparent that flood resilient approaches (flood resilience being defined as “the ability to cope with flooding and the ability to recover from flooding” - Smartest, 2011a), can play an important role in as much as they facilitate the management of flood risk at community scale level, require lower levels of capital investment and speed up the process of recovery from a flood. In the above definition of flood resilience, the emphasis should be placed on the small amount of effort to recover from flooding and therefore the term “flood resilient approach” often applies to measures at the level of a building (or groups of buildings) as opposed to infrastructure measures. Using this definition, the flood resilience measures covered in the FloodProBE project are:

- primarily those applied to the fabric of the building (building materials and construction methods), but also
- flood protection products that are deployed at property level, based on findings of the EC FP7 project Smartest. These products are part of the wider group “Resilient technology” that was categorised in Smartest as follows:
 - Building aperture technology (flood protection to openings within a building, such as ventilation areas, entrance doorways and pipework);
 - Perimeter technology including temporary technology (set away from the building and/or between buildings, with no permanently-installed elements and positioned before a flood event occurs); demountable perimeter flood barriers (provide a semi-permanent barrier to flood water and can include various elements that can be installed when required) and preinstalled perimeter flood barriers (provide a permanent flood protection available on site which can be set when necessary)
 - Building technology (can include permanently positioned technology used to seal building walls, foundations and floors, flood resistant doors and windows, local warning systems that are integrated at the building level, waterproofing and anti-corrosion products).
 - Infrastructure technology (flood protection to infrastructure components such as roads, rail routes, pathways and permanent flood defences; specific products could include innovative surfacing materials that resist the potential wash away of infrastructure elements, automatic barriers, and membrane technologies).

A discussion of the barriers to implementation and potential ways of overcoming them (a “roadmap”) will be outlined.

6.2 Implementation of flood resilient measures

By definition, the integration of flood resilient measures in the larger regulatory and legislative context is far more complex than for traditional flood defences, which often fall under the remit of a single authority/organisation and have the backing of European Directives such as the Floods Directive or the Water Framework Directive. In contrast, flood resilience measures can involve various scales, down from an area to an individual household as well as a number of different stakeholders, from flood expert professionals to manufacturers and property occupiers. To compound the issue, property owners and, to some extent, product/material manufacturers, often lack the organisational backing and do not have a sense of common goal that other stakeholders possess. The alignment of the various scales and the coordinated engagement of the stakeholders are challenges to overcome. This can be considered along two axes of integration: vertical integration (regarding scales of influence) and horizontal integration (regarding the agencies of influence) - Smartest, 2011a.

The sections below draw largely from the above mentioned report, which provides a very useful discussion of the issues associated with implementation of flood resilience approaches, focusing on the building materials and construction processes, as well as flood protection products.

6.2.1 Vertical implementation

Smartest (2011a) defines vertical integration as the “entirety of governance from the EU, to the Nation State, to Local Municipalities to the community”. To this definition one could add the “individual” as this differs from the concept of community and brings a whole new set of challenges. Various spatial scales as well as co-ordination of different policy frameworks need to be considered.

At European scale

The Floods Directive 2007/60/EC provides the most significant basis for implementation of flood resilience. Under this Directive, Member States are required to assess flood risk areas, map their extent and define the assets and humans at risk. Flood Risk Management Plans can then be produced to communicate the risk and propose measures to manage these risks. Whilst the Floods Directive presents an opportunity for innovation and adoption of resilient building materials, construction processes and flood protection products, it does not provide the necessary legislative basis to compel States to support the study or development of these measures.

At National scale

Implementation of resilience at National level requires an understanding of the various processes and procedures in place in each country and how the responsibilities are shared among organisations. There has recently been a trend for transfer of responsibilities from the state to other stakeholders, which can hinder the development of regulation.

At municipal scale

At this level municipal authorities can influence the adoption of flood resilience through the interpretation of national legislation/regulation and by exerting political will for their implementation. In some countries, however, the concept of individual responsibility for flood protection that some municipalities (and States) are promoting is encountering resistance from property owners/occupiers. The provision of flood protection is still seen by many as a responsibility of the authorities, being them the State (through provision of hard defences and compensation for flooding) or the local municipality (through the halting of construction on floodplains, implementation of building regulations, etc).

At society/individual scale

Societal cultural differences as well as individual tastes influence the acceptance of resilience measures in different ways; this is quite evident when considering the use of modern methods of construction or materials. With regard to flood protection products that are to be deployed at a group of houses, the establishment of associations of residents may be required, thus implying a will for collaboration. The benefits of these products in the light of the initial capital expenditure also need to be explained to individual property owners/occupiers as many are still unconvinced they are a worthwhile financial investment.

6.2.2 Horizontal implementation

Smartest (2011a) defines horizontal integration as “the widening of engagement to include all those stakeholders with a potential role to play in enabling the use of FRe” (i.e. flood resilience). It is acknowledged that the wide array of stakeholders creates opportunities but also brings with it difficulties related to the disparity of perceptions and interests. The agencies of influence listed (relevant to flood protection products) are: the Built Environment professionals, the Construction Sector (including contractors and manufacturers), the Insurance Sector and the Flood Protection Products manufacturing sector. In addition to these one could add certification bodies such as CEN, the British Standards Institute, and the various certification bodies that operate in European countries issuing product certificates (e.g. BBA, BSI in the UK).

Built Environment Professionals

This category includes planners, architects, engineers, and flood management professionals among others, and their engagement at an early stage can mean the adoption of measures that would otherwise not be at all considered if they are not enshrined into regulation.

Construction Sector (including the Building Materials Sector and their trade organisations)

This sector can have a key role in the development of innovative construction materials and construction processes that contribute to achieving flood resilience, and, by simply making them available to the general public, can influence public acceptance of different building aesthetics. On the other hand, the construction sector is governed by demand and constricted by regulation and has encountered resistance from the public.

Insurance Sector

The Insurance sector plays a more or less important role in the different European countries but it is clear that it can enable or resist the adoption of flood resilience. In countries with State-provided insurance this can become a disincentive for inclusion of flood resilient measures. Equally, in countries where owners rely solely on private insurance, there could be a compulsion to minimise the impact of floods by the introduction of various measures. For a description of the various types of role of the insurance sector in UK, France and Spain refer to Smartest (2011b).

Flood Protection Product Manufacturers

This sector is responsible for the design, development, marketing, installation and maintenance of flood protection products such as flood guards in building apertures or permanent or temporary barriers deployed away from the building that protect a single or a group of buildings. The main challenge these companies face is one of size/capital versus investment required: these are generally small companies and innovation is currently not sufficiently funded by the State. Products require independent testing and also incur certification costs that can be substantial in relation to the value of the products.

Standardisation and Certification Organisations

These organisations are influential in a dual capacity: they provide the requirement for quality and also the demonstration that a product conforms to particular standards. For example, CEN (the Comité Européen de Normalisation or the European Committee for Standardisation) is officially recognised as the European Standards body. Its thirty national members work together to develop European Standards. Not all standards are mandatory but those for materials and products used in construction and listed under the Construction Products Directive are. However, currently these products are not assessed in terms of their flood resilience characteristics. Given their independence, certification organisations have an important role in building public confidence in resilience products but there are concerns that the costs associated with the certification process are not in line with the market value of these products.

The different types of resilience measure covered in the FloodProBE project (building materials and construction methods, and to a lesser extent flood protection products that are deployed at property level) are not equally influenced or dependent on all the scales discussed above. Table 6.1 provides a qualitative summary of the levels of dependence considered applicable at each scale.

In the assessment presented in Table 6.1 it can be seen that a number of payers have a potential significant role in the roadmap to acceptance of flood resilience measures.

Table 6.1 Implementation of building resilience measures – key players

Resilience Measure	Vertical integration				Horizontal integration				
	European scale	National scale	Municipal scale	Society/ individual scale	Built environment professionals	Construction sector	Insurance sector*	Flood protection products manufacturers	Standardisation/ certification organisations
Construction materials	M	H	H	M	H	H	H to L	-	H
Construction processes	-	M	M	L	H	H	H to L	-	M
Flood protection products	M	H	H	H	M	M	H to L	H	H

Legend:

H – High dependence

M – Medium dependence

L – Low dependence

Notes:

* The Insurance Sector plays different roles in different countries - the “high dependence” rating given here refers to those countries (such as the UK) where the Insurance Sector (private) offers flood cover as a standard feature of household insurance; household insurance is, however, not compulsory. There is currently (running until June 2013) a statement of principles between the Insurance sector and the UK state binding the industry to cover all the population. Private flood insurance also prevails in Germany where natural disaster cover is included as standard, and in the Netherlands only private insurance is given for pluvial and groundwater flooding. France has a mixed State and private insurance system where the Government needs to recognise a flood as a natural disaster in order to cover (and re-insure) for direct flood damage. In Spain flood insurance is provided by a public entity working with the private market, whereas in Greece all types of flooding insurance are provided by private companies. Cyprus also holds a private insurance scheme, with uninsured victims of floods receiving compensation by the government (Smartest, 2011a and 2011b).

With regard to construction materials, the National and Municipal scales take slight prominence over the individual scale. Although society/individual acceptance of new materials is important, this is not sufficient to ensure its adoption in a large scale; this needs to be achieved through regulation (National or European), implemented in architectural/engineering projects and enforced at municipal level through inspection of compliance. For these construction products to be accepted as flood resilient, standards must be developed for their production, testing and certification, and the products certified independently.

Construction processes that help achieve flood resilience in buildings need also be regulated and given the “seal of approval” but, due to their variability, it is harder to see how they can be part of national (or European) regulation. In this case society or the individual will have a smaller input due to a general lack of interest and knowledge (understandable for the wider population), and the non disclosure of construction processes.

With regard to flood protection products, the public/individuals are essential agents for their implementation (as well as the manufacturers and certification bodies, obviously). Across Europe a trend has emerged in recent decades where the State is devolving responsibility for flood protection, establishing public-private partnerships and alerting citizens to their duties as guardians of their own flood safe futures. It is predicted that this devolution will increase in coming years, in line with cost cutting measures that many European countries have implemented as a response to the world financial downturn of 2009-2011 (e.g. UK) – Smartest 2011(a).

6.3 Roadmap to overcome barriers to implementation of building resilience

From the above discussion, it is clear that regulation at National and Municipal scales would be an important vehicle for the wider spread of resilient building materials and techniques; if possible this should be supported by European legislation. Could an EU Directive on Flood Resilience provide the necessary legislative push? European norms covering the definition of flood resilience and building flood resilience as well as testing protocols for materials and construction assemblies would be useful standards for the promotion of flood risk management at building level. However, the high diversity of contexts and needs across Europe is a challenge to overcome.

The following sections present and discuss several vehicles for further dissemination and uptake of building resilience.

6.3.1 Resilience and Building Regulations

Although there is guidance on flood resilient materials and techniques in many European countries (FloodProBE, 2010), the level of uptake of this guidance is not entirely uniform across the countries and even within a country, as it often depends on the local planning authorities perception of their importance in the context of urban planning.

Construction-related rules at national level are often collated in the form of Building Regulations or standards and then enforced by municipalities. Note: in the USA flood resilience guidance is issued by FEMA (Federal Emergency Management Agency). The following table, Table 6.2, summarises information on building regulations in a number of European countries, some of which was drawn from the Smartest project (Smartest, 2011a) as well as from the current project.

The specific case of critical buildings raises some questions regarding the decision to implement building resilience: should this be the responsibility of the building owner (to protect his assets and ensure functionality is not jeopardised during floods) or the State/Municipality (to ensure the public continues to be offered the required level of services that those critical buildings provide)? This debate can be aided by cost-benefit analysis if the benefits from resilience can be clearly (and quantitatively) stated, including non-monetary benefits. As discussed in Section 4.5.3, further research is needed in this area.

Table 6.2 Building flood resilience in the Building Regulations/Standards in various countries

	Building regulations/standards	
<u>Europe:</u>	Current coverage	Future developments
United Kingdom	Building Regulations and Standard 3.3 (Scotland) in part cover resilience; since 2010 a local authority can demand the use of flood resistance materials	The Pitt review noted that a revision of the Building Regulations should be made to ensure all new and refurbished buildings in high flood-risk areas are flood resistant or resilient.
The Netherlands	National and municipal regulations state that buildings should be watertight (from surface and ground)	No developments expected in the near future
France	Regulations cover new build only; no specific guidance on resilient materials or building layout	Guidance is being produced for the refurbishment of existing buildings following floods
Norway	The National Office of Building Technology and Administration publishes regular updates of the Technical Regulations for Planning and Building. The 2010 version (as previous ones) provides general statements only (e.g. buildings for which the consequences of flooding are very important should not be located in flood prone areas or be protected for 1/1000 floods). No specifications with regard to resilient materials apart from general guidance on limiting major material damage. General recommendations on building layout (e.g. elevation of building floor above certain levels and provision of protective walls).	No initiatives known
Poland	No regulation; only recommendations covering location of building entrances above probable flood level, use of waterproof materials in the lower part of buildings, building on embankments or pillars; ensuring sufficient building weight to counteract uplift forces	In the wake of the 2010 (and 1997) floods it is likely that new regulation and directives will be formulated
Spain	The orientation of new buildings must mitigate the blockage effect to floods	No developments expected in the near future
Czech Republic	Flood resilience is part of Building Regulations	-

Germany	Vague requirements on construction and materials to be used in buildings in flood prone areas; only applicable to new buildings or extensions of existing buildings.	There is need for common specifications for resilience measures. "Building passports" with information on the resilience measures they contain have been suggested to ensure maintenance of such measures is guaranteed
Greece	No relevant regulations; British and French regulations used when necessary	Expectations for the formation of a committee to formulate flood regulation in a single source
Cyprus	No requirements for flood resilience in Building Regulations	-
Portugal	No requirements for flood resilience in Building Regulations	No developments expected in the near future
USA	The International Building Code (updated every three years) has been generally adopted across the USA but recommendations on flood resilience are provided through FEMA's Technical Bulletins 2 and 3. The National Flood Insurance Program (NFIP) requires the use of flood damage-resistant materials below the base flood elevation (BFE) for all structures in special flood hazard areas. Technical Bulletin 2, <i>Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas</i> (TB 2), identifies some such materials based on their ability to withstand "direct and prolonged contact" with water without sustaining any damage that requires more than cosmetic repair to restore these materials to pre-flood condition.	A new standard is being prepared which establishes methods to be used for determining the flood damage resistance ratings ("Acceptable", or "Unacceptable") of materials consistent with the intent of the NFIP requirements. The standard addresses the following effects of flooding on materials and assemblies: wetting and drying, exposure to elevated temperature and humidity environments which can produce mould growth, and the restorability of those materials and assemblies. Flood hazards excluded from the standard include: flood borne debris impact, flood velocity, presence of contaminants. The standard is intended to apply to construction materials, assemblies, and components that are elements of the building including but not limited to, items such as sheathing, structural elements, insulations, finishes, windows, doors, vents, and other types of fixed or operable openings.
Australia	The technical document which sets the standards of building work in Australia is the Building Code of Australia (part of the National Construction Code series) and there are variations for the States/Territories. The City of Canterbury Development Plan no. 28 defines classes for materials according to their suitability under floods and designated floor levels above standard floor levels are also given.	Not known

6.3.2 The US FEMA draft standard for Determining the Flood Damage Resistance Rating of Materials and Assemblies

There are currently two main documents issued by FEMA, the US Federal Emergency Management Agency, which are relevant for the assessment of building flood resilience:

- Technical Bulletin 3-93 *Non-Residential Floodproofing - Requirements and*

Certification for Buildings Located in Special Flood Hazard Area in accordance with the National Flood Insurance Program

Construction in areas denoted as “Special Flood Hazard Areas” (or SFHAs) requires protection against damage caused by flood water; these areas are defined on Flood Insurance Rate Maps (FIRMs), produced by the National Flood Insurance Program

- Technical Bulletin 2-08 *Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas*

For non residential buildings the lowest floor (enclosed) must be set at a level at least equal to the base flood elevation (BFE) or dry proofed to that level.

All materials (to the exception of those used for safety/warning systems or to comply with electricity regulations) used below the BFE need to be flood-damage resistant. This corresponds to Classes 4 and 5:

Class 5 - Materials that can survive wetting and drying, including damage caused by moving water (up to 1.5m/s), and may be successfully cleaned after a flood to render them free from most harmful pollutants; can be used outside under long flood exposure

Class 4 – As above but susceptible to moving water damage; can be used in interior spaces.

With a start in 2009, FEMA and its consultants, backed up by an international panel of experts that included a member of the FloodProBE team, has been developing a standard for evaluating the flood damage resistance of building materials and assemblies (e.g., walls, floors, and ceiling assemblies). A Working Group (wk35237FDRM) was formed in 2011 to produce an ASTM standard (ASTM International was formerly the American Society for Testing Materials).

The objective of the standard is to set out procedures for rating the flood damage resistance rating of building construction materials and assemblies (ratings are: “Acceptable” and “Unacceptable”). The standard has been developed from procedures in FEMA’s Technical Bulletin 2, which is recognised in the USA as the basis of evaluation for flood damage resistant materials requirements. Building materials such as sheathing, structural elements, insulations, finishes, windows, doors, vents, and other types of fixed or operable openings are covered by the standard. The testing parameters considered are:

- water type (freshwater and salt water)
- exposure duration

- drying duration

and the draft standard indicates how the preparation and testing should be carried out and the evaluation rating criteria.

The performance of materials/assemblies is evaluated under the following categories based on a comparison before and after immersion, drying period and cosmetic repair (as appropriate):

- strength
- dimensional stability
- absorption
- drying
- ability to be cleaned and restored.

The draft standard also includes descriptions of testing for elevated temperature and humidity.

The resistance against debris impact, flood velocity, wave action, presence of contaminants and other adverse factors are not covered in this standard, and it states that the testing conditions are not to be construed as being a true representation of conditions during flood events.

All specimens must achieve an “acceptable” rating in order for the material/assembly receive such rating.

The specification for immersion of test specimens varies according to the type of specimen:

- vertical test specimens for wall assemblies (e.g., walls and foundations) are immersed to 50 percent of the height of the assembly but not less than 4 ft (1.2m approximately; specimen size is 2.4m by 2.4m)
- horizontal test specimens (e.g., girders, beams, sub-flooring and floor/ceiling assemblies) are fully immersed to a depth of 25 mm below the surface of the water.

The ability to be cleaned is assessed through testing for immersion and at elevated humidity and temperature, in an environmental chamber configured to provide continuous exposure of the test specimens to the air at not less than 95% to 98% relative humidity at a temperature not less than 32.5°C for a 14-day exposure period. After the exposure period, the material is dried in controlled laboratory air at 24°C ($\pm 3^\circ\text{C}$) and 50% ($\pm 5\%$) relative humidity until the moisture content of the specimen returns to that of “before” exposure condition, or for a maximum of 21 days, whichever occurs first.

The draft standard follows the flood damage resistance ratings as defined in Technical Bulletin 2, using an either “acceptable” or “unacceptable” rating (see Table 6.3).

Table 6.3 Flood damage ratings (from FEMA's Technical Bulletin 2)

Flood damage Resistance Rating	Material Class	Material Class Description
Acceptable	4, 5	These materials can survive wetting and drying and exposure to elevated humidity and temperatures and may be successfully cleaned and refinished after these exposures.
Unacceptable	1, 2, 3	These materials are unable to survive wetting and drying and exposure to elevated humidity and temperatures and be successfully cleaned and refinished after these exposures.

6.3.3 Evaluation of the effects of environmental contaminants in flood water

Discussions held during the drafting of the standard described in Section 6.3.2 highlighted the need to evaluate the effect that contaminants in floodwater may have on building materials. Current and draft FEMA guidance does not take into account the chemistry of floodwater that would typically be found during flood events; this is perfectly justifiable for pragmatic reasons (i.e. testing with contaminants increases the variables and hence time/cost) and is also due to the lack of consensus in this area. To address this gap, FEMA (underpinned by a panel of independent experts) is undertaking screening tests to determine a consensual representative water composition to be used in testing.

The research comprises two phases, the first of which involves testing on small samples, to be followed by full-scale testing of full-size materials and assemblies. The test floodwater is freshwater with varying levels of the following contaminants (a control sample is also used in the tests):

- Bacteria (to represent sewage/compost)
- VOCs (to represent petroleum/gasoline)
- Fungi (to represent mould growth)

Work is in progress (FEMA, 2012) and modifications to the originally agreed conditions are being proposed in what concerns immersion of the specimens, drying and evaluation points.

6.3.4 Discussion

Both the draft ASTM standard and the research programme on the simulation of contaminated floodwaters undertaken under the umbrella of FEMA, USA, are important initiatives to advance the uptake of flood resilience at building level. Through these initiatives, undoubtedly a better understanding will be reached of the impact that floodwaters have on the performance of building materials and assemblies

which will enable informed choices to be made when reinstating properties after floods or designing new ones.

Despite the clear benefits of having testing standards, it should not be forgotten that the ASTM proposed testing method does not fully reproduce the conditions that materials and assemblies experience during floods since they are immersed in water and not subject to an external pressure. As demonstrated in tests carried out at HR Wallingford (CIRIA 2006), the seepage rate is a relevant parameter that is variable in time and requires the test protocol to subject materials and assemblies to a water pressure (which is not achieved in immersion tests). The two philosophies are quite different but both have their merits: the ASTM method allows a more expedite and less onerous testing of samples thus enabling classification of a wide range of products; the HR Wallingford method is arguably more realistic but also more time consuming and onerous. The development of standards at European level should benefit from the American guidance whilst considering how best to reproduce real flood conditions as much as possible.

7 Conclusions

Resilience at property level can be achieved by the use of adequate construction materials and methods of construction, layouts and flood protection products, combined with careful site considerations that minimise the potential for exposure to floodwater. The provision of safe access to the building is also of paramount importance – this is dealt with in other deliverables from this project. Qualitative guidance on building flood resilience exists throughout Europe but it is suggested that the development of standards and regulation at European or national level would be an important (and necessary) vehicle for the wider spread of resilient building construction.

The present research has :

- Identified requirements and development of concepts for critical (or hotspot buildings), i.e. buildings on which the functioning of urban societies rely in times of flooding
- Defined methods for flood proofing of buildings and their applicability with regards to design depth and duration of flood
- Produced a review of the state-of-the-art of building resilience materials across and outside Europe which has provided an insight on the current guidance on building flood resilience and identified a number of gaps (described below)
- Defined the steps necessary to conduct a cost-benefit analysis of building resilience measures and identified other relevant factors to be included in the analysis as well as gaps in knowledge (described below)
- Assessed the costs associated with incorporation of different types of flood resilient building measures using the individual building tool developed under WP2. Five scenarios were considered based on a real case study, three dry proofing scenarios and two of wet proofing. The savings in repair costs due to wet proofing compared with repair costs if no resilient measures were in place were found to be of the order of 30% (for the particular case analysed). However these are

indicative costs that have not taken into account important factors such as the frequency of flooding, which will necessarily impact on upgrade decisions, and the “cascading” effects resulting from damage to critical buildings within a critical infrastructure network.

- Outlined a roadmap for implementation of resilience measures at building level which included the identification of key players across two levels of implementation (horizontal and vertical implementation) and the need for standardisation and regulation. Current initiatives regarding the development of standards have also been described and critically discussed. The implementation of flood resilience measures in critical buildings can be aided by regulation but raises questions of who should be responsible for it: the building owner (to protect his assets and ensure functionality is not jeopardised during floods) or the State/Municipality (to ensure the public continues to be offered the required level of services that those critical buildings provide)? This debate can be aided by cost-benefit analysis if the benefits from resilience can be clearly (and quantitatively) stated, including non-monetary benefits.

The following gaps were identified from the review of building resilience materials and construction practices:

- The adequate choice of building materials can be an effective means of minimising the impact of floods but currently there is no regulation at European (or at national) level
- No approved testing protocols are available at European level. The standard testing of materials measures absorption rates rather than seepage and, as materials are not subjected to the hydrostatic (and/or hydrodynamic) forces that occur during flooding, the measured behaviour is not necessarily a true depiction of the materials/components response to floodwater.
- Limited testing has been carried out on building materials and there is a need to understand the behaviour of a wide range of materials, wall and floor components, insulation and apertures.
- Examples of application of resilient and resistant materials either for new buildings or retrofits are very limited and are mainly confined to basements.

The following gaps were identified with regard to cost-benefit analysis of building resilience measures:

- Cost-benefit analysis should include non-monetary factors such as waste minimisation, quantification and reduction of carbon emissions, recycling and sustainable sourcing of materials
- Social issues should also be considered through an evaluation of who will benefit and who will pay the costs of different interventions. A broad set of parties should be identified (for example residents and business owners, public sector agencies that must respond and fund the recovery process as well as the general tax payer).
- A framework is required for developing a full Cost Benefit Analysis that takes into account the “cascading effects” associated with flood damage of critical buildings (within critical infrastructure networks). WP2 of this project has established some basis for assessing vulnerability and indirect impacts of flooding but more research is required in order to translate vulnerability into costs and establish the indirect benefits of resilient construction.

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Appendix

Questionnaire - Assessment of stakeholder acceptability of new techniques for flood resilient buildings



Questionnaire for stakeholders

at Madrid Workshop 26-27 April 2010

FloodProBE Task 4.3 - Assessment of stakeholder acceptability of new techniques for flood resilient buildingsObjective of task:

This task is aimed at producing a **roadmap** to overcome barriers to implementation of flood resilience materials and techniques for **new and retrofitted buildings** that are part of the **critical urban infrastructure** (e.g. hospitals, buildings that house communications, fire services, ambulance centres, railway stations, public shelters, electricity substations, water and sewage treatment plants, etc).

Please fill in to the best of your knowledge and insert your name, affiliation and contact information below.

Name:.....

Affiliation and country:.....

Contact information:.....

.....

Question 1. Use of flood resilient building techniques (please tick)			
	Awareness	Application in case studies	In general use
<u>Avoidance measures</u> (e.g. raising ground level, perimeter walls, waterproofing walls up to structurally safe level)			
<u>Resilient building materials/components</u> (e.g. concrete walls and floors, sealed			

doors/windows, impermeable flooring such as ceramic tiles, water proof building services)			
<u>New technologies</u> (e.g. floating homes and bridges, Modern Methods of Construction such as composite wall panels that include flood resistant insulation, prefabricated components and water resistant plaster)			

Question 2. Is building flood resilience part of current legislation in your country? Yes/No

If Yes, please specify which types of resilience and which legislation (e.g. Planning legislation, Building Regulations) and which Government Ministry covers this

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.....

.....

.....

If No, are there any current initiatives to include it? Please provide details and which Government Ministry would deal with this issue

.....

.....

.....

Question 3. Flood water ingress into basements is a major issue. Is there any legislation/standard/norm in your country covering the flood resilient design of basement entrances?

If Yes, please specify the legislation/standard/norm and which types of resilience (e.g. sealed doors, installation of guards)

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.....

.....

If No, are there any current initiatives to include it? Please provide details

.....

.....

.....

Question 4. How do you rate the likelihood of acceptance in your country of new technologies (and non-traditional materials) that offer flood resilience without National legislation? (please tick)

	Likelihood		
	Low	Medium	High
By building designers/architects			
By contractors			
By Planning Authorities			
By clients			

Question 5. What is the likelihood that cost will influence adoption of new materials/technologies? (please tick)

	Likelihood		
	Low	Medium	High

Thank you for your time!

Can we contact you for a follow-up call or visit? YES/NO