The role of building materials in improved flood resilience and routes for implementation

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Abstract

This paper reports on work developed under the EC FP7 project FloodProBE “Technologies for the cost-effective protection of the built environment”. Across and outside Europe, urban flood resilience guidelines acknowledge the benefits of resilient building materials as a way to limit damage and speed up recovery from floods; however most existing classification systems are only qualitative and not transparent. This stems from the very limited data on performance, the inappropriate standard testing of materials with regard to flood exposure and the absence of approved testing protocols at European level. Regulation and practices on building resilience in a range of countries are discussed and outline cost benefit analysis is presented focusing on urban critical infrastructure buildings. A roadmap for overcoming technical barriers to the improved acceptance and implementation of building flood resilience is delineated, including suggestions for new European Norms on flood resilient buildings and materials.

1. Introduction

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 and authorities/organisations 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 (e.g. private hospitals and providers of telephone/internet/mobile phone communications services). 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.

This paper reports on work developed under the EC FP7 project FloodProBE “Technologies for the cost-effective protection of the built environment” which focuses on critical urban infrastructure. This is defined as the networks and building types that are essential for the functioning of urban societies during periods of flooding. Also termed “hotspot buildings”, the building types in question are high value nodes in the critical network that need to be made flood resilient and include: power stations, communication and data hubs, water treatment plants, logistic centres for food distribution, nodes in transportation networks, hospitals, fire fighting stations and other emergency services.

Of the range of resilience techniques available, the work described here concentrated on building materials and construction processes – other flood resilience techniques such as flood protection products have been extensively covered by other EC funded projects, e.g. SMARTeST (www.floodresilience.eu).

2. Overview of existing building resilience guidance

Maintaining the functionality of critical buildings during flood events will depend on three main parameters: the construction of the building (i.e. how it is built a), the measures taken to minimise the risk of flooding to the building (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 and access).

A review of existing building resilience guidance was carried out with a focus on Europe, concentrating on the first of these parameters, i.e. materials and construction practices. Some European countries were covered in more detail (UK, Germany, Poland) and, as the review revealed that the USA is probably the best source of guidance, US guidance was therefore included in considerable detail (Escarameia, 2010). Other aspects have been considered also within the FloodProBE project and are discussed by de Graaf *et al* (2012).

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 classification of the materials. Guidance in France also includes the flood duration and US guidance covers the effect of flood water velocity.

In the review, materials were categorised according to their function, following loosely the classification given in Technical Bulletin 2 of FEMA (2008), which administers the US National Flood Insurance Program: structural materials, finishes, insulation and 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 simulated exposure of building materials and assemblies to a flood depth (where the pressure of water is acting on the test units, rather than simple immersion in water) was conducted in the UK (CIRIA, 2006). These HR Wallingford laboratory tests concentrated on traditional UK domestic construction and covered only static water 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).

When the review commenced 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 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. 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 flood waters. However, these test methods have not been embedded in regulation nor have the classification of materials/assemblies. The following gaps in knowledge were identified:

- 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 a true depiction of the materials/components response to floodwater.
- 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 wider 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.

3. Determining cost-benefits of building resilience measures

3.1. Principles of Cost-Benefit Analysis

The steps necessary to conduct a cost-benefit analysis (CBA) of different building flood resilience measures have been developed, according to standard methodology employed by Commonwealth of Australia (2006). These are given in Figure 1.

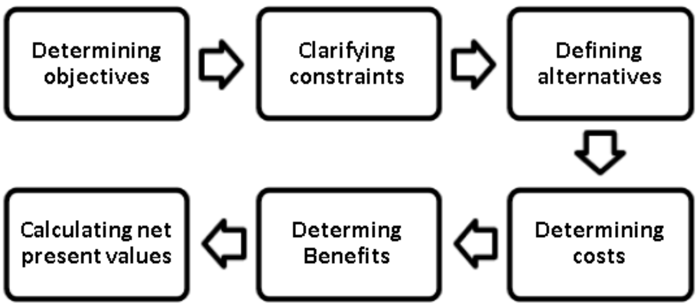

Figure 1: Steps in a Cost-Benefit Analysis

Comparing the expected costs of each option with the expected benefits helps to determine and justify the alternative options to rank and prioritize those alternatives where benefits outweigh the costs. In the context of flood resilient buildings, benefits are defined as flood damage avoided; therefore, the benefit of an intervention, for increasing flood resilience, equals the flood damage caused without implementing the intervention ("do nothing" or status quo) minus the flood damage caused after implementing that intervention.

Many items of flood damage loss are a function of the nature and extent of the flooding, including its duration, velocity and the contamination of the flood waters by sewage and other contaminants, as pointed out by Penning-Rowsell *et al* (2010). The indirect flood damage 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, in standard CBA most flood damage is considered to be direct tangible damage and includes structural damage to buildings, loss of contents, damage to services, and damage to special or unique facilities. This direct damage results from the physical contact of flood water with damageable property and its contents. In order to properly assess the benefits of flood resilient building construction both tangible and intangible prevented damages should be included in the analysis but current practice generally fails to consider the intangible damage. The main reason for this shortcoming is that intangible damage is very difficult to assess. Consequently, CBAs tend to underestimate the benefits.

3.2. Estimation of costs and benefits

The benefits associated with 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 that depend on these buildings. The economic value of the flood damage is estimated by rebuilding/replacement costs.

Normally, the leading alternative in a cost-benefit analysis is the "do nothing" situation or the status quo which is the reference point for evaluating how well other alternatives perform. The status quo refers to the current vulnerability of the system without resilience measures in place. The assessment is usually carried out by defining damage functions computed for different flood depths and flooding probabilities. These are sketched in depth (elevation)-damage curves. For the development of such curves, building construction and contents inventory, lowest-floor plans and 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).

A damage reduction assessment will include consideration of the various options available for flood resilience, amongst which are the judicious choice of building materials and construction layouts (others include elevated structures, relocation/reconstruction of buildings). The process of computing damages avoided (benefits) requires developing the damage-frequency relationship for the new situation (after implementing the alternative) to estimate the damages caused after the flood resilience intervention is implemented. This requires the same approach as for the without-project (“the do nothing”) condition. Plotting the "do nothing" case vs. the implemented alternative case will show a shift in depth-damage curves (see Figure 2).

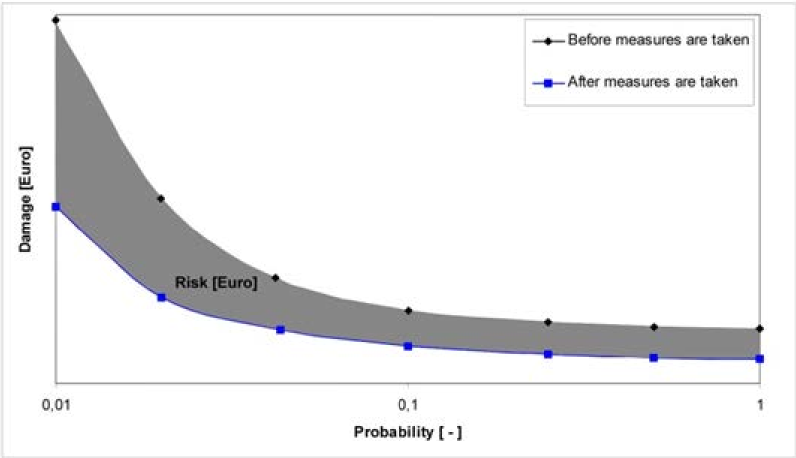

Figure 2: Illustration of the benefit of damage reduction by increasing resilience (adapted from Wagemaker et al, 2008)

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. If the result is greater than zero, this indicates that the benefits outweigh the costs: the higher the value, the greater the financial argument for initiating the project. In order to compare different projects, in addition to NPV it is also helpful to calculate the benefit-cost ratio (B/C). The NPV is calculated by subtracting the present value of the costs from the present value of the benefits; the B/C ratio divides these values. As so, the NPV gives an estimate of the absolute size of the net social benefits. The B/C ratio summarises the relative size of the benefits and cost of a project.

Herein, the NPV method is suggested for the financial appraisal. As NPV deals with the long-term value of money, it overcomes the disadvantage of the Pay Back method that 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.

3.3. Considerations on current CBA

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.

4. Roadmap for implementation of building flood resilience

4.1. General considerations

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.

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, from an area down 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.

4.2. Implementation of resilience measures

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) 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 should add the "individual" as this differs from the concept of community and brings a whole new set of challenges (Escarameia, 2012). Tables 1 and 2 identify the key players and the levels of dependence on them along the vertical and horizontal axes.

Table 1: Implementation of building resilience measures (vertical integration) – key players

Resilience Measure	European scale	National scale	Municipal scale	Society/individual scale
Construction Materials	M	H	H	M
Construction Processes	-	M	M	L

Table 2: Implementation of building resilience measures (horizontal integration) – key players

Resilience Measure	Professionals built env	Const sector	Insurance sector*	Standardisation/ certification organisations
Construction Materials	H	H	H to L	H
Construction Processes	H	H	H to L	M

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 a ‘statement of principles’ between the Insurance sector and the UK state binding the industry to cover all the population, subject to Government funding on flooding. 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). It should be noted also that many public/critical buildings have special arrangements in place with regard to insurance that differ from the general rules for domestic or commercial properties – for example owners of large numbers of buildings (such as Municipalities) have their own insurance policies. Therefore critical buildings will often need to be assessed on a one to one basis.

4.3. Resilience and Building regulations

Although there is guidance on flood resilient materials and techniques in many European countries, the level of uptake of this guidance is not entirely uniform across the countries or 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. Table 3 summarises information on building regulations in a number of European and non-European countries, some of which was drawn from the SMARTeST project (Smartest, 2011a).

5. Conclusions

A comprehensive review was undertaken of resilience building materials guidance 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 application of the outlined cost-benefit analysis in conjunction with a tool for the estimation of flood damage of individual buildings that has also been developed under the FloodProBE project 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.

The picture depicted in Table 3 indicates that regulation at National and Municipal scales would be an important vehicle for the wider spread of resilient building materials and techniques; however, it is also important to stress that, in the case of critical buildings, it is not clear which of the two has the main interest in safeguarding buildings against flood impact: the owner of the buildings or the State? No doubt, views will vary across Europe and will be dependent on the political environment. 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.

Table 3: Building flood resilience in the Building Regulations/Standards in various countries (as of early 2012)

Country	Current coverage	Future developments
United Kingdom	Building Regulations and Standard 3.3 (Scotland) cover resilience partly; since 2010 a local authority can demand the use of flood resistance materials	Government advised to revise Building Regulations to ensure all new and refurbished buildings in high flood-risk areas are flood resistant or resilient. However, current trend is to move away from regulations
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	Technical Regulations for Planning and Building are published by the National Office of Building Technology and Administration. The 2010 version (as previous ones) provides general statements only (e.g. location of important buildings outside flood prone areas or protection for 1/1000 floods). No specifications with regard to resilient materials. General recommendations on building layout (e.g. elevation of building	No known initiatives

Country	Current coverage	Future developments
	floor above certain levels and provision of protective walls).	
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, Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas (TB 2), identifies some such materials based on their ability to withstand “direct and prolonged contact” with water without	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,

Country	Current coverage	Future developments
	sustaining any damage that requires more than cosmetic repair to restore these materials to pre-flood condition.	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.	

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