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Design and Technical

UK's first amphibious house.
Can-float Amphibious Building

Richard Coutts, Baca Architects
Robert Barker, Baca Architects

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> This is a very interesting and timely project that very clearly demonstrates the importance of research to design. The wider discussion of flooding, an important topic, well-presented and the project is an intriguing way of meeting planning regulations by building "underground" in a flood risk area. The exemplar design is a very useful piece of research that is unique to the UK and useful in pushing specific boundaries of amphibious design. That the research component is taken through to a full build adds value to the research that is also concluded with rigour and reflection.
>
> 2016 Judging Panel

"The sea is barely wrinkled, and little waves strike the sandy shore. Mr. Palomar is standing on the shore, looking at a wave. Not that he is lost in contemplation of the waves. He is not lost, because he is quite aware of what he is doing: he wants to look at a wave and he is looking at it. He is not contemplating, because for contemplation you need the right temperament, the right mood, and the right combination of exterior circumstances; and though Mr. Palomar has nothing against contemplation in principle, none of these three conditions applies to him. Finally, it is not 'the waves' that he means to look at, but just one individual wave: in his desire to avoid vague sensations, he establishes for his every action a limited and precise object."

from Mr Palomar, by Italo Calvino

UK's First Amphibious House. Can-float Amphibious Building

Richard Coutts Baca Architects
Robert Barker Baca Architects

An amphibious house is a building that rests on the ground on fixed foundations but, whenever a flood occurs, rises up in its dock and floats there buoyed by the floodwater. In the last 20 years, the ten worst international flood events alone claimed over 50,000 lives, affected one billion people and resulted in damages in excess of $165 billion. Higher frequency storm events over the past decade and the failing of recently constructed flood defenses in Cumbria have exposed a growing uncertainty in weather patterns and a weakness in relying on traditional flood defenses alone. In 2009 the Authors published The LifE 'Long-term Initiatives for Flood-risk Environments' Project for Defra marking a fundamental shift from traditional flood prevention towards a non-defensive approach; based on 'Making Space for Water' – working with natural processes to provide space for water to expand during times of flood. This paper examines if Amphibious Architecture may provide a long-term failsafe solution to UK flooding. It examines Amphibious Architecture in the context of best practice approaches to masterplanning to reduce flood-risk and climate change. It also considers amphibious design alongside other property level approaches to reducing flood-risk and reviews the design of the UK's first Amphibious House located in the middle catchment of the River Thames. The proposition was a real site, with a client and budget. The authors had to determine: what an Amphibious House would look like? How it would function in static and flood positions? How services would be connected? and how to make it acceptable to Planning and Building Control in the absence of any UK precedent? During construction the house was tested when the amphibious base was completed, to assess the integrity of the hull, water-tightness, balancing, and the running gear. It was tested again on completion to rebalance the system. Practical completion was achieved in spring 2015 and the client is now enjoying their aquatic lifestyle. The author's offer thanks to the Client for their contribution to flood mitigation and this new architectural typology.

Section 1. Amphibious House

Introduction

Water plays a vital role in shaping our built environment, as it has for centuries. We depend on it, use it and live with it – as a consequence we must also respect it.

Flooding is a result of the natural weather cycle. Annual flooding may bring benefits to some areas through siltation and nutrient and water replenishment. Until recently, in developed countries flood defences and planning have managed to reduce flood risk from more frequent storm events and it has been only the extreme events that cause flooding. While flooding has been present throughout human history, natural disasters appear to be occurring with greater frequency and intensity around the globe.

Climate change and urbanisation are increasing the risk of flooding. There are more people living in coastal and flood-risk areas than at any time in history, and this number is continuing to rise.[1] Water supply and flooding are likely to become two of the greatest challenges to mankind in the 21st century.

According to the latest climate research[52], there is a lag in the climate system that means we are currently experiencing the effects of past emissions and that the effects of current emissions are yet to manifest. Therefore, even if global emissions were capped now, the effects of climate change would continue to be felt for many years to come.

In the last 20 years, the 10 worst international floods alone claimed over 50,000 lives, affected over 1 billion people, claiming over 50,000 lives and causing more than $165 billion of damage.[4] Flooding is exposing the vulnerability of 19th- and 20th-century designed towns and cities. As we will continue to live near water for transport, sustenance and pleasure, we need to address how to manage the threat.

In the UK there are currently over 5 million properties at risk of flooding with over 10,000 new properties built in flood-risk areas every year. This represents about 17% of the total property in the UK. The annual cost of flood damage is estimated to be £1.1 billion and this is expected to rise . The 2013/2014 floods were believed to cost small UK businesses £830m.

Whilst the insurance companies are required to pay out to repair properties there is no incentive to build back better and therefore the risk of flooding is unchanged.

This paper examines Amphibious Architecture in the context of best practice approaches to masterplanning to reduce flood-risk and climate change. It also considers amphibious design alongside other property level approaches to reducing flood-risk and reviews the design of the UK's first Amphibious House located in the middle catchment of the River Thames.

Flood risk

"If a tree falls in a forest and no one is around to hear it, does it make a sound?" The same is broadly true of flooding: "If a river floods its banks but no one is in there to be flooded, does it cause a problem?"[65].

Flood risk is a combination of probability and consequence. This is the likelihood of a flood occurring in any given year and the impact of that flood. If a flood occurs in the wilderness, where no one is affected, the consequence and therefore the risk could be considered to be low. Typically, the closer a site is located to a river, or the closer one is to the sea, or if the land forms a natural depression, the higher the likelihood of being flooded. Likewise, as the land rises up the river valley, out of the sea or up from a depression, the probability of flooding decreases.

The probability of flooding is described as the percentage probability of a flood occurring in any given year, such as 5%. This is also described as 1 in 20 years, which indicates the likely 'return period' for a similar-sized flood. The return period

	Very low flood risk	Low flood risk	Medium flood risk	High flood risk
Less vulnerable uses: • Shops and restaurants • Offices • Industry and warehouses • Agriculture and forestry • Water and sewage treatment	YES	YES	YES	NO
More vulnerable uses: • Residential house and flats • Residential institutions, hotels and prisons • Hospitals, health centres • Hotels, bars and nightclubs • Holiday lets or short let caravans	YES	YES	MAYBE [1]	NO
Highly vulnerable uses: • Basement flats • Caravans and mobile homes for permanent residence • Police, fire and ambulance stations • Telecoms centres needed during a flood	YES	MAYBE	NO	NO
Water compatible uses: • Flood defences • Docks, marinas and ship building • Water-based recreation • Amenity open space • Outdoor sports and recreation grounds	YES	YES	YES	YES
Essential infrastructure: • Essential transport links • Primary electricity sub-stations • Sewage and water treatment works	YES	YES	MAYBE	MAYBE

[1] Cells indicated as maybe correspond to use to which are required to pass the exception test in England

Table 1. Appropriate uses based upon flood risk, based upon UK planning guidance

can be misleading as a 5% probability flood could occur three years in a row and then not again for 60 years.

The probability of a flood also reflects the magnitude. For example, a 1% (1 in 100 year) flood will be bigger than a 5% (1 in 20 year) flood; but it is less likely to occur (Figure 1.1). However, climate change is affecting the magnitude of floods and confusing this method of understanding – in the future a 5% probability flood could be more extensive, perhaps equivalent to a current 2% flood.

Historically, engineers have focused on reducing the probability of a flood occurring through flood defences. However, as changing weather patterns decrease the predictability of flooding, there needs to be a shift towards reducing the consequence. Traditional approaches to defending land from flooding are becoming more costly and less effective. New flood defences can have a detrimental effect on land up- and downstream by forcing flood water elsewhere and therefore need to be carefully considered. Management of flood risk to reduce the effects of flooding, rather than just reducing the exposure and vulnerability to flooding, may be a more sustainable approach. This requires a shift in thinking towards embracing the natural water cycle and designing with water.

Typically, the closer the site is to the source of flooding (such as river or sea), the greater the hazard. Where this is a residential population (particularly dense, informal settlements) or where there is essential infrastructure (such as hospitals or nuclear power stations), the consequence and therefore the risk is increased. One approach to reducing risk is to reduce the vulnerability. Table 1 indicates the type of land uses that may be considered appropriate for different flood-risk areas. The land uses are grouped according to vulnerability, and probability of flooding is described in terms of risk from very low to high, which corresponds to flood zones 1 to 3b (described later).

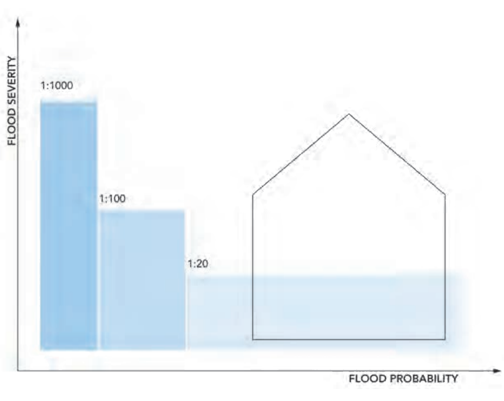


Figure 1.1
Illustration to show flood probability versus severity

Sources of flooding

Flooding can occur from various sources. The main causes of flooding are outlined below, with the likely sources along different parts of the catchment indicated in the image key overleaf.[59]

River flooding results when water overtops the riverbank. This occurs when the runoff after a rainstorm overwhelms the capacity of the river or artificial channel to discharge the water. The land around the river that is flooded is known as the floodplain and can extend for hundreds of

Figure 1.2
Sources of Flooding

metres, sometimes kilometres. This is the most well-recognised source of flooding.

Coastal flooding results when seawater is driven on to the land by storms, tsunamis and high tides. Typically, flooding occurs when meteorological events, such as hurricanes or storms, combine with strong winds and low pressure to raise sea levels sufficiently to overwhelm or breach the sea defences. In low-lying areas this can be devastating.

Surface water flooding results when excessive rain cannot be absorbed into the ground and runs off hard (or waterlogged) surfaces too quickly to be discharged. It is becoming more prevalent in urban areas, where green space has been built over and drainage systems are old and lack sufficient capacity to cope with big storms.

Sewer flooding occurs when too much rainwater enters the sewers, causing the drains to become surcharged and spill over the land. In many towns foul and surface (rain) water are drained into combined sewers, exacerbating the problem. Contaminants can cause health risk to people and pollution of water channels, damaging local ecology.

Groundwater flooding results when the below-ground water rises above ground level. This typically occurs in winter months or the rainy season and flooding can last for several months, until the water level subsides in the summer months or dry season.

Flooding can occur from failure of artificial systems, such as a dam failure, a burst water main or an embankment collapsing. If a collapse or

Figure 1.3
River (fluvial) flooding

Figure 1.4
Coastal (and tidal) flooding

Figure 1.5
Surface water (pluvial) flooding

Figure 1.6
Sewer flooding

Figure 1.7
Groundwater flooding

Figure 1.8
Flooding from artificial structures

breach occurs, this can result in fast-flowing water in unexpected locations, catching people unaware.

Flood zones

Flood zones are used to indicate areas of high to low flood risk, typically based upon probability of flooding. These provide a simple, high-level indication of areas that are liable to flooding within a given return period. Many countries publish flood maps online; when used in conjunction with planning guidance these can help identify potential flood threats to development so that they can be planned accordingly.

Figure 1.9 indicates the flood zones in Ashford, Kent, from several years ago. These flood zones indicate the areas that could have been at risk of flooding from rivers or the sea but ignored the presence of defences. The map also indicates the location of flood defences and the areas that would have benefited from them.

Flood zones are generally based upon river and coastal flooding. Mapping of other sources of flooding is relatively new. In the UK, the Environment Agency publishes maps – using the most accurate data available at the time – showing areas at risk from surface water flooding (Figure 1.10), failure of man-made structures (Figure 1.11) and river and coastal flooding after flood defences have been taken into account (Figure 1.12). Ideally, these various sources of flooding would be integrated to create a complete flood map; with interactive technology, this may well become an invaluable tool in the near future.

Assessing the impacts of flooding is a continually evolving science. Determining areas that are liable to flood has previously been

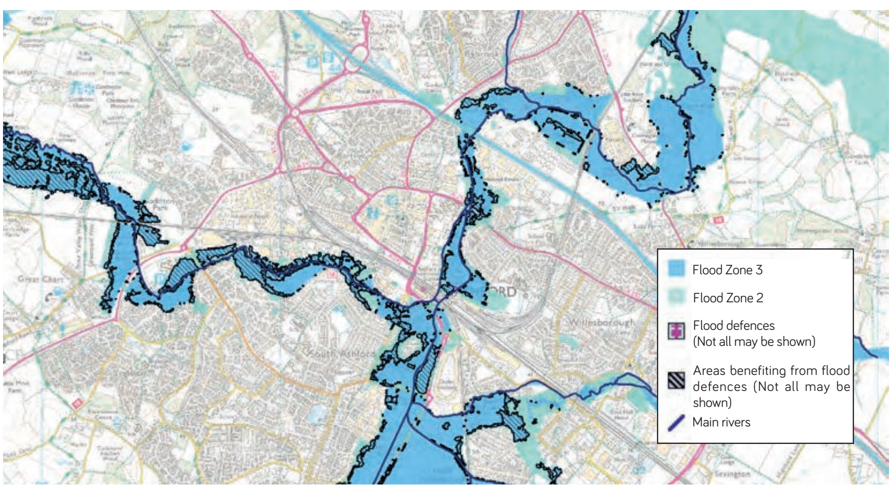


Figure 1.9
Flood Zones, for the purpose of planning (showing Ashford, UK, 2014; data has since been updated)

Figure 1.10
Flooding from surface water (showing Ashford, UK)

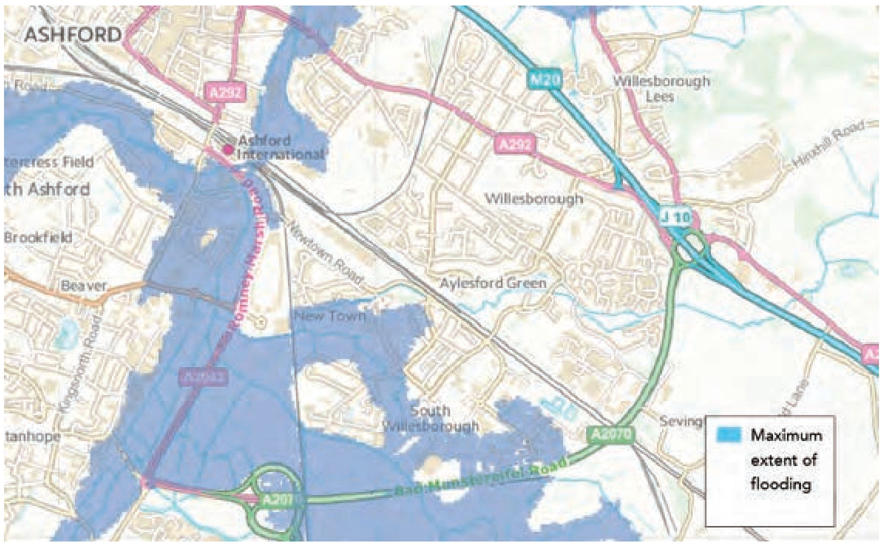


Figure 1.11
Flooding from reservoirs (showing Ashford, UK)

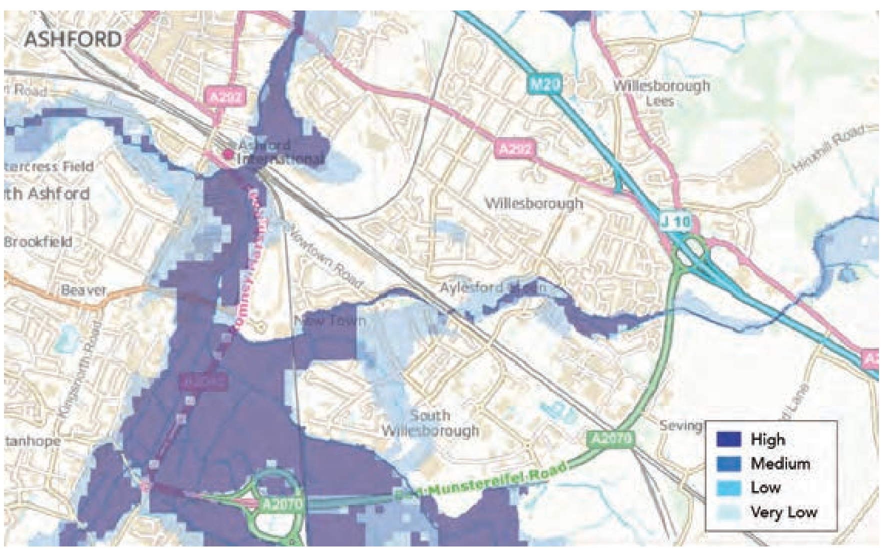


Figure 1.12
Flooding from rivers and sea (showing Ashford, UK)

based on historical records of past events. Flow modelling is now more frequently used but this is calibrated against records of actual floods, where these exist. By inputting climate data it is possible to model the potential extent of future flooding. If climate change increases the severity of storm events we may see an increase in areas at risk from flooding. More extreme weather may also increase the probability of flooding, which in turn may change the flood zones, and so a more detailed understanding of flood risk is essential to guide future development.

Water in architecture

Modern architects have often sought to capture the enigma of water in architecture, pushing the boundaries of the relationship between water and buildings. Architects such as Frank Lloyd Wright and Carlo Scarpa have designed seminal projects heavily inspired by Japanese architecture and landscape design and their affinity with water. Wright designed the landmark private house Falling Water in 1935, surprising the client by building the house partly on a waterfall, rather than facing onto the water (Figure 1.13). The building is renowned for its fluid space and floating cantilevers. The eastern influence, encouraging harmony between man and nature, is evident in the blurring of internal and external boundaries. The design features boulders protruding through floors, stairways leading directly to the stream, a spring-fed swimming pool and ambient water sounds, as well as natural spring water that intentionally drips into the building and is then

Figure 1.13
Falling Water by Frank Lloyd Wright, USA

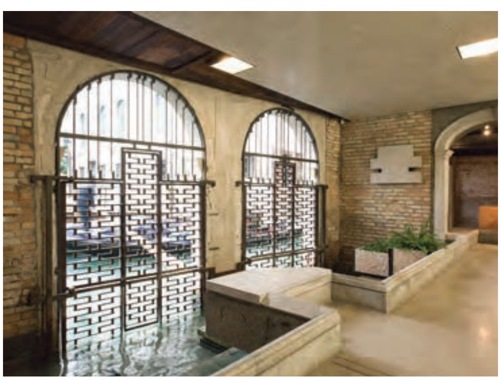


Figure 1.14
Querini Stampalia by Carlo Scarpa, Venice

channelled out. However, this pioneering piece has come at a cost, with structural, humidity and condensation problems, as well as repeated leaks requiring remedial work to safeguard this architectural jewel.[32]

Water is a central presence in Carlo Scarpa's architecture, where it is allowed to flow through canals and channels around and through the buildings, in response to natural water flows, such as the Venetian *acqua alta*.[33] The success of Scarpa's work lies in his understanding of water as a precarious force, caught and defined by land and sky. This is evident in his 1949 renovation of the Venetian palace Querini Stampalia, following flood damage. Floors step up and down, and wrap up walls to define the flood water line, preventing damage from future floods. Enriching pragmatism through architectural artistry, Scarpa uses the tension between presence and absence to create a sense of anticipation. Water is invited through the iron gates into an anteroom in the building to create an audible presence throughout the palace (Figure 1.14).

The steps down to the water reveal the incremental rise of the tide before it gradually creeps across the sloped floor. In the garden, water is directed through spouts, spiralling channels, rills and a bronze-encased pond to capture the sounds of a gently meandering stream. The Brion Cemetery in San Vito d'Altivole near Treviso (built in 1968), is another poetic space that includes interconnecting canals and pools, complete with an 'inaccessible island' set within a pond, symbolising the afterlife.[34] Water has been widely exploited for its symbolic and sensory values, and applied in architecture for emotive purposes. Peter Zumthor explores the emotive and therapeutic qualities of water through light, transparency, temperature and reflection within his Therme Vals, completed in 1996 (Figure 1.15), as well as different states of water: still and animate, liquid and vapour.

Mies van der Rohe integrated pools of water that bring calm and reflection into buildings, such as to the Barcelona Pavilion in 1929. This extends a tradition used by the affluent of many cultures to use reflection to create drama and express power. The lotus pond at the Taj Mahal, built in 1648, doubles the scale of this impressive mausoleum. The ethereal quality created through the ponds and fountains was achieved through a complex system of purs (ropes and buckets pulled by bullocks), canals, storage tanks and copper and earthenware pipes. Louis Khan and Frank Gehry have famously integrated water into their work, using large pools and bodies of water or even just narrow channels, such as that at the Salk Institute (Figure 1.16) to direct the eye to distant views or enhance their compositions.

Some architects have mastered water to create great artistry. Diller Scofidio + Renfro clad the Blur Building in a fine mist to create an inhabitable cloud on Lake Neuchâtel in Switzerland (Figure 1.17). This temporary technical marvel was accomplished through 31,400 high-pressure jets, which were adjusted by computers in response to climatic conditions including temperature, humidity and wind speed and direction, to create a fog that constantly changed in response to the environmental conditions.[35]

Figure 1.15
Therme Vals by Peter Zumthor, Switzerland

Figure 1.16
Salk Institute by Louis Kahn, California

Figure 1.17
Blur by Diller Scofidio + Renfro, Switzerland

Section 2. Aquatecture: Flood-proof Buildings

Introduction

Flood protection to an individual property may be required where it is not possible to reduce the risk of flooding through planning or landscaping measures alone, or where there is a residual risk of flooding. There may also be the need to provide protection to existing and historic buildings, or to key buildings such as hospitals, communication hubs or safe havens.

There are a number of building types and flood-proofing approaches that can be used to protect property from flooding. In this book they are collectively termed 'aquatecture', in reference to their relationship with water. This chapter illustrates these typologies, examines how each works, and reviews where they may be appropriate based upon the flood risk. We also consider where they can be deployed to redevelop sites more safely and comprehensively; and deliver communities that can be sustained and adapted to future climate conditions.

Some of these building types, particularly floating buildings, offer the opportunity to revitalise obsolete waterspaces with what > could be a unique architectural expression of our relationship with water. These forms of aquatecture can help to reduce the risk from flooding as part of a comprehensive integrated masterplan.

Figure 2.1
Flooded properties after Hurricane Katrina in New Orleans (2005)

Flood-proof building typologies

Where buildings are situated in a floodplain they are likely to be at risk of flooding. Even when protected by structural flood defences there will still remain some 'residual risk' of flooding, should these defences fail. Figure 2.1 shows properties in New Orleans, USA, flooded when the levees were breached during Hurricane Katrina. The considered design of buildings can reduce the vulnerability to flood damage and the risk to life and property. Reducing vulnerability is particularly important for existing settlements, which often cannot be relocated, and where the advantages of continuing to occupy the floodplain may outweigh the cost of protecting the buildings.

A building is often the last line of defence in protecting its occupants and their possessions from flooding. Flood protection may be required for insurance and may help to reduce the cost of the premium and/or excess, by reducing the pay-out costs for insurance companies. It may also reduce the perception of risk by occupiers and impact upon their ability to sell their homes in the future.

Figure 2.2
Elevated properties, Cambodia

Different approaches can be appropriate, depending on whether they are added to an existing building or constructed as part of a new building.

Five main approaches to tackling flood risk at a building scale have been identified as follows:

- Flood avoidance. This approach works by locating buildings away from flood-risk areas, or raising buildings above the flood level on stilts or raised land.
- Flood resistance, also known as dry-proofing and water exclusion strategy. This approach seeks to keep water outside the building by blocking pathways for the water to enter and providing a water-resistant building fabric.
- Flood resilience, also known as wet-proofing and water entry strategy. This approach allows the water into a building in a controlled way and relies on the use of internal water-resilient materials and detailing to prevent permanent damage and allow quick recovery after a flood.
- Floating. This approach works by permanently floating the building on water, enabling it to move up and down with the floodwater and preventing people and property from being flooded.
- Amphibious, also known as can-float. With this approach the building is fixed to a buoyant base that rests on the ground but is designed to float when flood waters rise, temporarily creating a floating structure.

A building type for each approach is given in this chapter, as shown below.

Selecting the most suitable measure in any given case will entail a balance of factors, such as its effectiveness in dealing with the risk, environmental impact, character, and cost. With regards to effectiveness, this must take into consideration the nature of the flood risk. This includes the source or type of flooding, the depth, duration, flow rate, and likelihood of carrying debris. It is also important to consider the environmental conditions, such as climate, soil conditions, pollution and seismic activity. In urban situations, flood water is likely to carry debris and contaminants, increasing the risk of damage to some of these building types.[1] Where possible, flood avoidance is generally considered the best option. Elevated properties have been used as a means of avoiding flooding by people around the world (Figure 2.2).

The detrimental psychological effects of flooding and the fear of being flooded again are well documented. Therefore, occupants typically prefer buildings that avoid or resist flood water (if avoiding the risk is not possible). These approaches seek to prevent water entering a building, thus protecting life, property and possessions. This approach may also provide some protection from

Figure 2.3
Resistant home, UK

damage to the exterior of the building. However, flood resistance may only be effective with shallow flood depths or high-quality reinforced construction that can resist hydrostatic pressures[2] or impact of debris. The stilts upon which buildings are elevated must be capable of resisting flood waters, scour to the foundations and the impact of flood-borne debris in order to provide effective protection and stability.

The limited options for existing buildings are typically resistance or resilience, which in either case will provide betterment over traditional construction methods. They can minimise financial costs attributed to flooding and improve the likelihood of survival for occupants by providing safe refuge. Such techniques can reduce the recovery time, allowing people to continue to occupy a building during a flood, or to evacuate and return to a building after a more severe flood. Improvements to the building design may also reduce secondary risks, such as fires, particularly caused by the inundation of electrical systems by flood water or debris, pollution from fuels and other materials leaking into the flood water, health problems from sewage polluting the flood water, and the growth of mould.[3]

Innovations in aquatecture

New technologies such as automatic flood barriers, high-performance structural glazing and waterproof concrete have enabled the design of buildings that can withstand substantial flood levels. Figure 2.3 shows a combined flood-resistant and flood-resilient property with automatic flood barriers at ground level.

These technologies can make existing settlements safer by improving or replacing sub-standard existing buildings, particularly key buildings such as hospitals or safe havens. They can be combined with measures to 'make space for water' to allow better configuration of spaces that surround these buildings; as a result, they can be used to help plan flood-prone areas responsibly.

There are many examples of floating construction including whole villages in Vietnam (Figure 2.5) to floating islands built by the indigenous people of Lake Titicaca in Peru.

Improvements in floating construction methods have increased the longevity and safety of these structures, leading to a rise in popularity. Many new floating proposals have been developed4 or are under way, including floating stadia, car parks, prisons, parks and airports. Figure 2.4 and Figure 2.6 show some of the modern floating properties, including a floating home in the Netherlands and an elegant research centre in the UK.

Figure 2.4
Floating research station, UK

Figure 2.5
Floating village, Vietnam

Figure 2.6
Floating home, the Netherlands

Aquatecture may provide the opportunity to use waterspace productively in planning and to engage with the water in much the same way that a building engages with the landscape.

Elevated buildings

Description
Of all the risk-reducing building typologies, the elevated building is the most common. An elevated building is one in which the floor or the whole building is raised above the predicted flood level. This can be on structural posts or on raised ground. The latter should only be used where flood storage can be maintained and where it does not push flood water elsewhere.

Construction
There are many examples of buildings that are elevated on masonry or stone, or on posts varying from bamboo to reinforced concrete. The posts or walls that are used and the foundations must be designed to resist water pressure, weight of flood water, scour and impact from floating debris. Figure 2.7 shows an elevated building with a raised public foyer and safe haven.

Appropriateness
The ground conditions, nature of the flood hazard (such as depth, velocity and risk of debris), foundations and integrity of the columns or structure must be considered. Because elevated buildings are fixed, they are not adaptable to increased flood levels, unless designed to be raised. Therefore they may not be the best solution where uncertainty in future flood levels exists.

Safe access to the property is typically provided by steps and/or ramps. If the internal floor is over 1m higher than the ground it may have detrimental social impacts, reducing natural surveillance of the street and hindering wheelchair accessibility. In this scenario the solution to infrequent flooding needs to be balanced against the day-to-day benefit to the streetscape, and other building typologies might be considered. If buildings are elevated a storey or more above the ground, then this area may be appropriate for less vulnerable uses such as parking or amenity; it is important however that these do not reduce the space made for the flood water. If the water table is high, the space below the elevated area could be excavated further to create a permanent waterspace that increases flood storage (Figure 2.8).

Other potential benefits
Elevating buildings can have co-benefits in warmer climates. Buildings are often elevated to prevent damage from termites and intrusion of vermin, and to aid cooling; this can be particularly beneficial in timber-framed buildings. Buildings raised on labyrinth walls can provide large areas of thermal mass to regulate the temperature of air flowing into buildings; this can double as structural support capable of resisting flood damage.

Figure 2.7
Elevated building
with water below

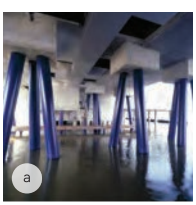
Figure 2.8
Transect through an elevated building

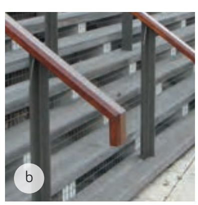
Figure 2.8a
Supporting piers or posts allow flood water through

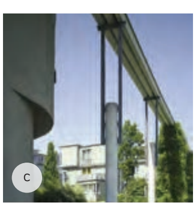
Figure 2.8b
Access ramps and stairs should be permeable to water

Figure 2.8c
Raised services protected from flooding

Figure 2.8d
Raised ground floor and amenity space







Appropriate for different water depths.
Ground use needs careful consideration.

Dry-proof [resistant] buildings

Description

Dry-proofing, or flood resistance, is a measure to make a building resistant to flood damage, either by taking the building out of contact with flood waters or by making the building resistant to any potential damage from flood waters. It is normally used to improve protection to existing buildings. In the absence of structural survey information, it is typically recommended only for locations with shallow flood depths and for short periods of flooding.

Construction

Dry-proofing involves the construction of a building in such a way to prevent flood water entering the building and damaging its fabric; it thus allows occupants some degree of protection from brief periods of flooding. These measures can prevent water getting into a property and allow time for the householder to move valuable possessions to safety. Some of the measures to dry-proof buildings include: flood guards, manual or automatic barriers, waterproof render or linings, infilling cracks, sealing junctions, non-return valves/backflow preventions for drains, and airbrick covers (as indicated in Figure 2.10).

Appropriateness

As it is preferable and more acceptable to raise floor levels above predicted flood levels, dry-proofing is typically applied to existing buildings. With existing masonry buildings, it would typically be used where flood depths are below 600mm to avoid structural implications to the building. There are some examples of properties that are protected against deep flood water, but the pressure of the water on the building requires considerable and costly improvements to the structure, which must resist hydrostatic pressures, scour and potential impact damage from debris.

Studies into the effectiveness of different dry-proofing construction methods have shown that in many cases water still enters the building after a period of time.[5] Therefore, dry-proof technology may not be suitable where flood water is likely to persist for more than a few hours.

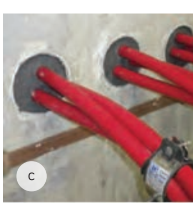
Other potential benefits

Dry-proofing can be used in conjunction with other measures and building typologies to prevent water ingress during frequent flood events. Dry-proofing can also be used away from the building as part of a flood defence, such as to provide protection to a garden, garage or other space. It may also be possible to group several buildings together to minimise the extent of protection required, such as the cluster homes planned for Nijmegen by Baca Architects.

In Dordrecht, the Netherlands, a whole neighbourhood has used dry-proofing measures to protect the properties, particularly the lower floors, which step down from the street. Shops and houses are fitted with channels to secure flood gates, to create a continuous defence. Flood wardens check that the defences can be implemented and ensure empty units are protected. In the event of a flood warning, goods on the lower floors are moved to higher floors or lifted aloft on rigging, creating a local spectacle.

Figure 2.9
Flood protection to property, Germany

Figure 2.10
Transect through a dry-proof building



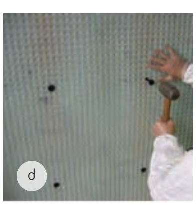


Figure 2.10a
Flood-resistant doors and windows

Figure 2.10b
External door guards

Figure 2.10c
Waterproof junctions to all services

Figure 2.10d
Waterproof wall materials, such as membranes

Appropriate for water depths under 0.6m.
Can be used to protect existing buildings.

Wet-proof [resilient] buildings

Description

Unlike other measures to keep water out of the building, wet-proofing works by reducing damage from water that enters the building. It involves designing the building to cope with and recover quickly from flooding. Wet-proofing seeks to preserve the structural integrity of the building by preventing the build-up of water pressure and using building materials that can survive being waterlogged. The pressure of the water inside the building balances the pressure of the water outside, allowing it to withstand greater flood depths than a dry-proof building.

Figure 2.11
Flood-resilient property for Defra

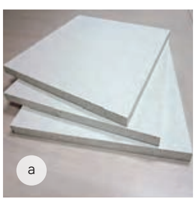
Construction

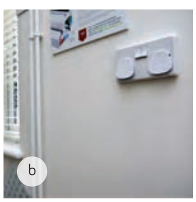
Wet-proofing requires improvements to the fabric of the building, the finishes and the services (Figure 2.12). Solid wall and floor construction can help to prevent moisture being trapped within cavities. Impervious polyurethane may be used in cavities or insulation fitted to either the inside or outside of the wall. Partitions may be fitted with plasterboard horizontally, to allow easy replacement should lower levels be damaged or formed from lime rendered solid construction. Waterproof magnesium oxide board can be used for cupboards. Drains should have non-return valves fitted to prevent sewage coming up through the drains. Electrics should be fitted above flood level, with supply wires distributed from the floor above. Ventilation systems can be used to improve drying times. Detailed guidance varies in different countries, according to local building codes.

Appropriateness

UK guidance states that: “Standard masonry buildings are at significant risk of structural damage if there is a water level difference between outside and inside of about 0.6m or more.”6 Although different forms of construction will perform differently, there is always likely to be a situation where structural damage could be caused. In these situations wet-proofing may provide a viable solution to avoid the risk of collapse. Wet-proofing is more appropriate for reducing risk to existing buildings but it may also be the preferred solution for buildings that are best located at ground level, such as shops or warehouses.

Figure 2.12
Transect through a wet-proof building





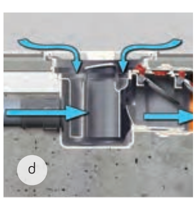


Figure 2.12a
Waterproof boarding used for partitions

Figure 2.12b
Electrics and appliances raised above flood level

Figure 2.12c
Non-return valves fitted to foul drains

Figure 2.12d
Floor drains to allow quick recovery after a flood

Appropriate for flood depths in excess of 0.6m.
Can be used to protect existing buildings.

Other potential benefits

Wet-proofing may be applied to existing properties. It can be used in conjunction with dry-proofing measures, to keep water out during shallow flooding. Internal level changes could be used to locate vulnerable fittings, such as kitchen appliances, above flood levels and provide a refuge for people and possessions. Wet-proofing could provide protection to ground level entrance lobbies of flats that are elevated above. When combined, these measures can make a significant difference to the building's robustness, providing the ability to withstand and recover quickly from a flood, facilitating continuity of daily life and business.

Figure 2.13
Long section showing the wet-proof ground floor and elevated first floor

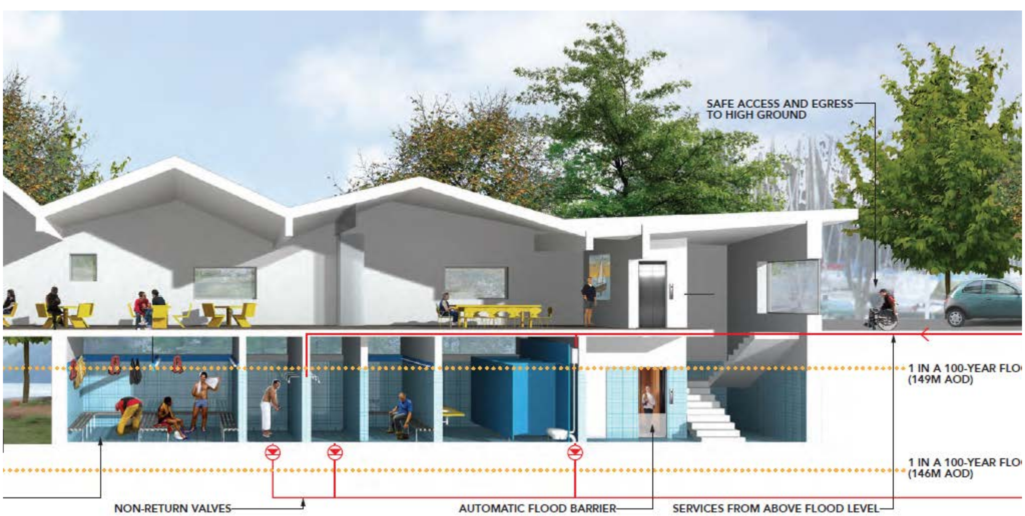


Figure 2.14
Interior view of the club house

Ullswater yacht club

A new yacht club centre has been designed beside a lake in the north-west of England. The building is designed using two flood-proof technologies:

- a wet-proofed ground floor, which contains the changing facilities and storage, is designed to cope with regular flooding
- an elevated first floor, which contains the club hall and offices.

The elevated floor provides access to higher ground at the rear, while the lower ground floor provides easy access to the waterfront.

The lower floor is designed to be able to flood to over 2m in height. The heavy masonry construction is designed to withstand hydrostatic pressure and impact from boats or debris. Non-return wastewater valves, services from the first floor, and an automatic flood guard to the lift provide further protection. The upper floor visually floats above the ground level and the profiled roof is reminiscent of the hills and an unfolding series of sails (Figure 2.13).

This aquatectural design set on a lakeside allows continued access to, and enjoyment of, the water, yet maintains safety for the users and protects the integrity of the building during a flood. The perpendicular orientation screens the car parking, allows views up and down the lake (Figure 2.14), and preserves the open character of the setting.

Floating buildings

Description

A floating building is typically a lightweight structure that rests on a buoyant base or foundation designed to rise and fall with the level of the water. For a building to float, the buoyancy must exceed the weight, as determined by Archimedes' principle. This is the same principle that is used to determine whether a boat will float. The floating building is typically tethered to mooring posts that enable it to move up and down but prevent it from floating away. Floating buildings can tolerate high levels of water variation,

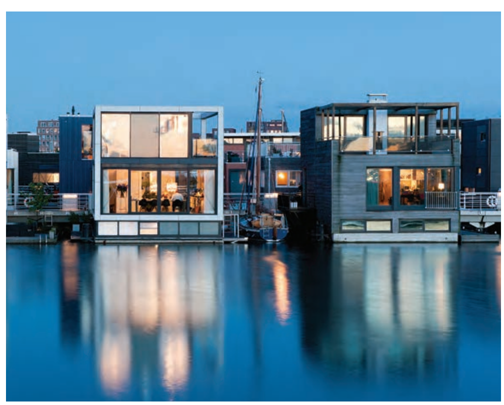


Figure 2.15
Floating homes in the Netherlands

subject to the flexibility of the access and services. The size of the building that can be supported is determined by the weight during live loads versus the displacement of water.

Construction

There are many different types of floating structure. Historically indigenous populations have built floating houses from natural materials, such as straw, bamboo and wood, to form lightweight buildings resting on raft structures. Houseboats have been built with timber, fibreglass, steel and aluminium hulls. More recently, there are modern examples of houses built using polystyrene and concrete rafts, but most are now built with waterproof concrete hulls. This construction provides a good level of stability, durability and minimal long-term maintenance.

Appropriateness

Floating architecture is only normally feasible where water depths exceed 1m. Taller floating buildings require greater water depths (termed 'draft' in marine architecture) to provide sufficient buoyancy for the weight, just as larger boats do. Floating buildings are often mistakenly suggested as a solution to flood risk. Their use as a flood protection measure has to be carefully considered against the flood velocity, due to their inherent instability. After a severe flood it is not uncommon to see boats that have escaped their moorings and been left stranded inland or washed up against structures. If a house weighing in excess of 100 tonnes were to float free from its guides it could cause significant damage. As a consequence, floating architecture is best suited to static bodies of water such as purpose-built docks and inland lakes, where water level variations are predictable and flows are usually low. Man-made harbours could protect communities of floating homes but this should be carefully considered against flood/storm risk. Due to floating architecture's sensitivity to site location it is important that it is supported by clear and robust planning guidance and building codes.

Other potential benefits

In addition to providing buoyancy, water can be used for heat exchange to reduce energy use in the building. The relatively constant temperature of the water can be exchanged with the cold air to warm houses in the winter and vice versa in the summer. When combined with solar panels or wind turbines, a floating building could be a very sustainable proposition.

Floating architecture does not need to be constructed in isolation. Like land-based development, it can be supported by amenity space and complementary uses, such as floating playgrounds, swimming pools, ice rinks and gardens.

The floating village in the Royal Docks

A floating village is planned for London's Royal Docks, which is conceived as a 'Crown' in the docks.7 Built within the waterspace but set away from the dock edge, the Crown is a coherent development. It is also extendable to form a necklace of floating settlements throughout the dock. Like a village, it is semi-autonomous,

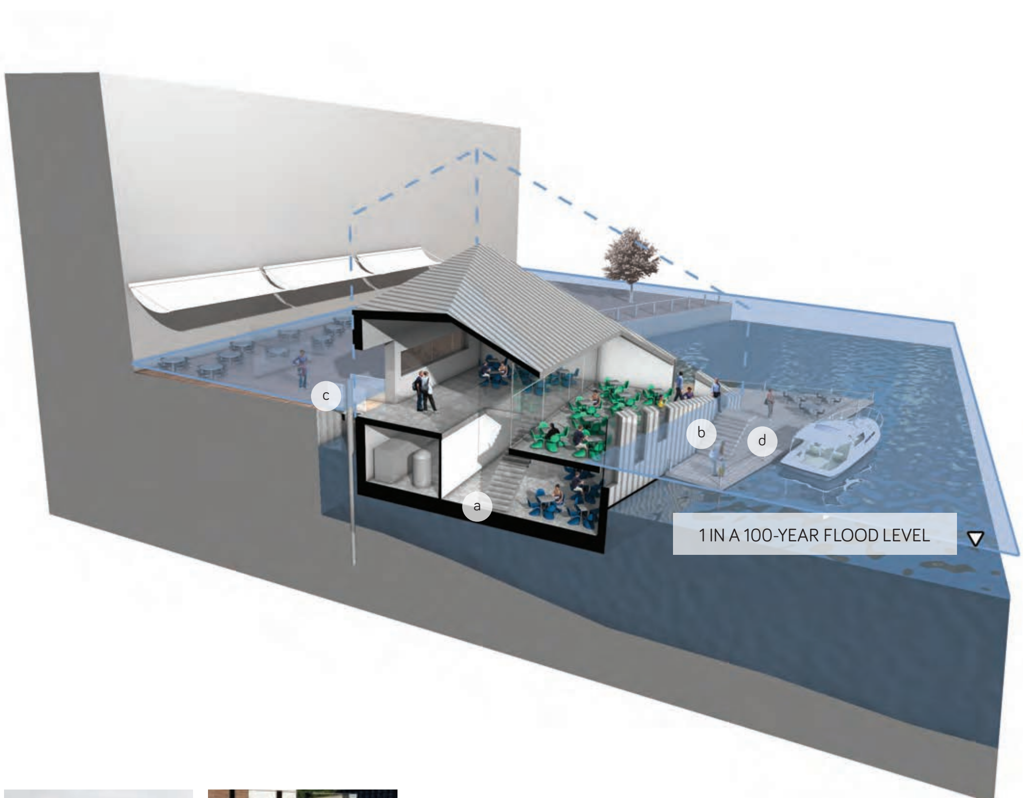
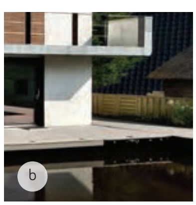
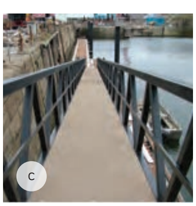


Figure 2.16
Transect through a floating restaurant





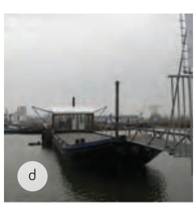


Figure 2.16a
Floating basement

Figure 2.16b
Floating amenity space

Figure 2.16c
Adaptable/flexible access

Figure 2.16d
Mobility and boat access

Appropriate for static bodies of water.
Not suitable in areas susceptible to rapid inundation.

complete with all of the facilities one would expect but, in this case, all floating. It is surrounded by water and organised around a 'village blue', just as a village settlement is an island within the countryside and surrounds a green. It is planned along a water boulevard and water lanes, rather than roads.

Figure 2.17
The floating village as seen from the air

tourist appeal and visiting dignitaries it is best approached by water, particularly in the summer. Vehicular access is restricted to emergency services, recycling and deliveries.

The buildings, roads, paths and public space are all constructed on a floating platform formed from a series of modular concrete pontoons. This system allows the development to be expanded along the waterspace and interspersed with local facilities such as parks, play areas and commercial areas. The services are provided from the dock edge along the two floating causeways and through the floating surface.

A small boat hire operation would run from the Corniche dock edge or from the floating causeway; rowing boats or pedalos could be hired for visitors to make the short journey to the floating village, arriving in the village blue by boat.

Figure 2.18
The village is set around a multifunctional village blue complete with a floating pub

Amphibious (can-float) buildings

Description

An amphibious building rests firmly on the ground but when a flood occurs, the entire building can float, buoyed by the flood water. It is sometimes termed a can-float building. Often the building cannot be distinguished from a land-based building apart from the guideposts or anchoring system. Amphibious buildings can tolerate high levels of water variation, although may be dependent on the flexibility of the access and services.

Construction

This approach uses floating building technology and is often designed to cope with significant water level variation. There are a few examples around the world which use various different construction technologies, including waterproof concrete bases, steel bases and plastic float bases.[8] There are also examples of traditional amphibious properties in Asia. These properties are one- or two-storey single dwelling houses and most sit above the ground level. The earliest modern engineered amphibious homes were built in south Louisiana in the 1980s.[9] Figure 2.18 shows an example from a development of 32 amphibious and 14 floating homes in Maasbommel, the Netherlands.[10] When in 2013 the river flooded, the houses operated as intended, to cope with the rising flood water.[11]

Appropriateness

Amphibious buildings are only feasible where water depths are likely to exceed 1m and dependent on the weight of the building may require much greater depths. This construction may be used where flood depths are too high and water level variation too great for other building types to be considered. They may also be preferable to elevated buildings when ground level access would be an issue or in sensitive locations where the increased height would be an issue.

As with floating buildings, they need to be sufficiently stable to withstand flood flows without tipping over, and they must be securely tethered to prevent a building escaping its moorings. Suitable locations are likely to be near mature rivers, in the middle to lower catchments; in particular where the land levels are relatively flat, so that flood water rises and falls slowly. Amphibious properties are unlikely to be suitable in locations subject to storm surges, hurricanes or tsunamis, where wave action would be likely to cause the building to tip.

Other potential benefits

Amphibious houses combine the accessibility and security benefits of land-based buildings with the flexible response of floating construction. This construction type may be used to create safe havens, particularly in low-lying areas. It may also be used to protect a sensitive part of a larger building, such as an emergency department in a hospital, a communications centre, or a local electricity sub-station, all of which require a high level of protection during a flood.

Different aquatectural typologies are appropriate for different levels of flooding. They provide an opportunity to create new building forms – ones that are designed to manage the threat of water, but also to enjoy the relationship with it. Different types will be appropriate for different situations; in some cases there may be several different measures on one site or even in one building.

Figure 2.19
Transect through an amphibious home

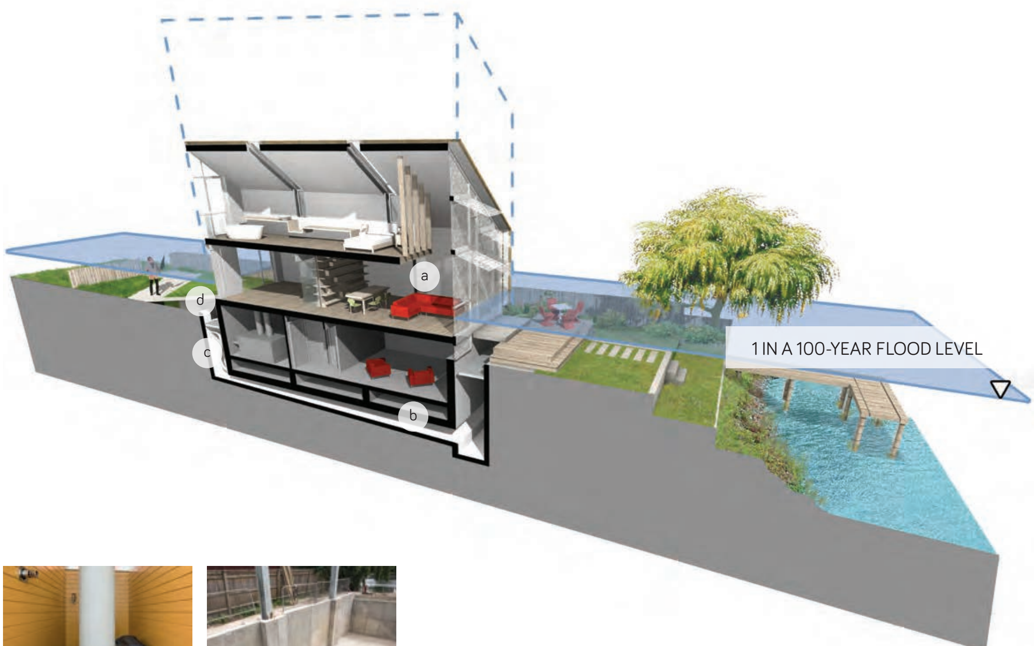


Figure 2.19a
Guides posts and running gear

Figure 2.19b
Impermeable 'can-float' hull

Figure 2.19c
Flexible insulated connections

Figure 2.19d
Flexible access

Appropriate for areas with high flood level variation.
Ground use needs careful consideration.

3. CASE STUDY: Building > Amphibious House

Setting the scene

Lock Island, a small island located on the River Thames in south Buckinghamshire, UK, is home to 15 houses. The houses, which were mostly built before the 1950s, are typically raised about 1m off the ground on timber piles to protect them from flooding[1] At the time of construction they were only built high enoughto protect from regular flooding (1 in 20) rather than extreme flooding. When the owners of one house on the island planned to rebuild their home they discovered that the floor level would need to be raised a further 1.4m above ground level to cope with the predicted extreme (1 in 100) flood level now and in 100 years' time. This would have resulted in a house elevated 2.5m above the ground.[2]

This picturesque part of the town has been designated a conservation area and the local authorities want to preserve its character and scale. These local planning restrictions meant that the replacement building could not be significantly taller, nor significantly increase the building footprint. In summary, the floor of the house needed to be raised up to cope with flooding but the roof could not be raised, nor the building extended, which left very little space in the middle.

The island has no road access and is only accessible by foot across the lock or by boat. Silt in the riverbed limits the depth of water around the island, restricting access to shallow draft boats. This further restricted the design and construction options.

Figure 3.2
Access to the island over the lock

Figure 3.1
Existing riverside elevation of Lock Island

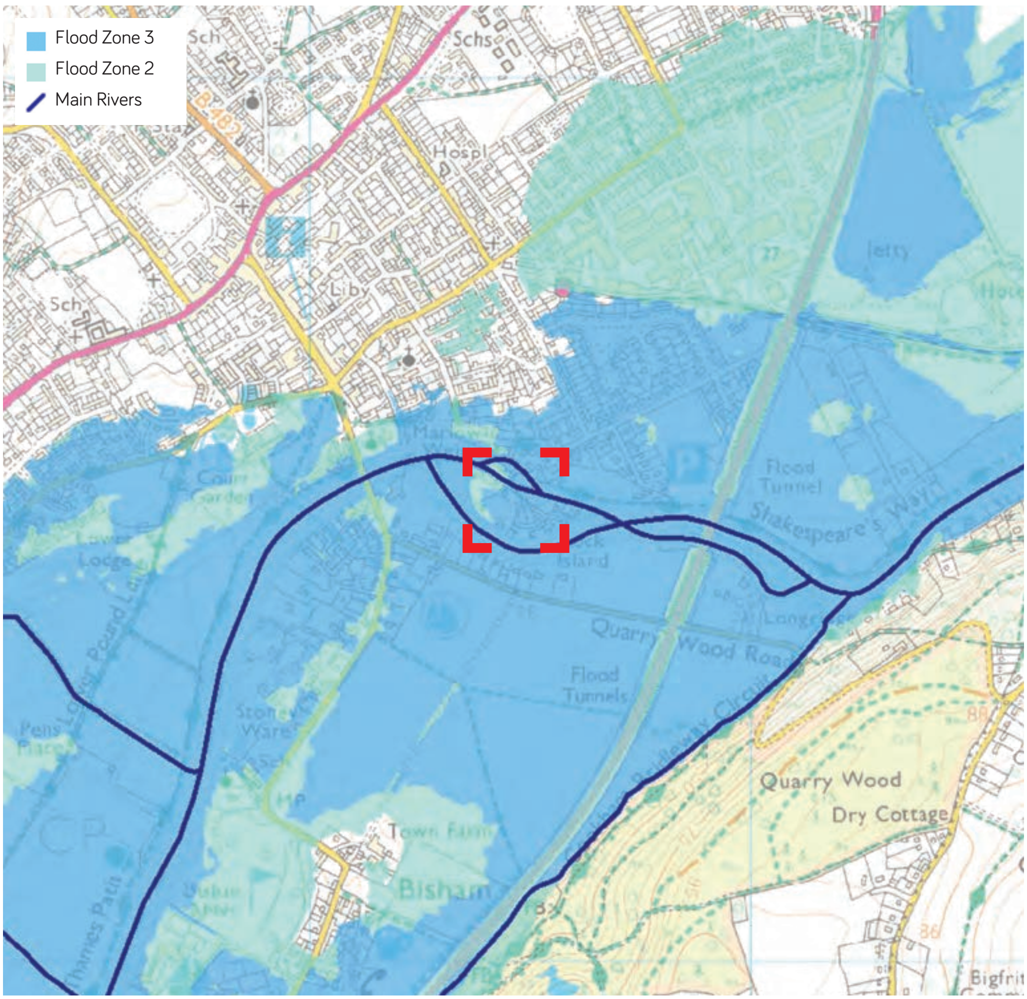


Figure 3.3
EA flood map of Lock Island on the Thames

Figure 3.4
Previous building
on the site

Figure 3.5
Flooding during
construction

Integrated design solution

The solution was an amphibious house – a building that rests on the ground when conditions are dry, but rises up in its dock and floats during a flood. The house itself sits in the ground and the floating base is almost invisible from the outside. The ground floor of the house is raised above the ground by less than 1m rather than by almost 2m as would be required were it not amphibious. This approach meant that a $225m^2$ three bedroom dwelling could be constructed over three floors in place of a single-storey $90m^3$ house without significantly increasing the ridge height.

Figure 3.6
View of the house from the river's edge

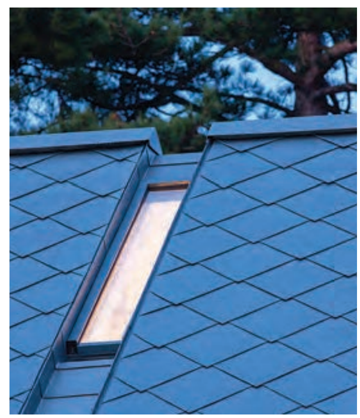


Figure 3.7
Detail of the zinc cladding and rooflight

Figure 3.8
View of the river from the living room

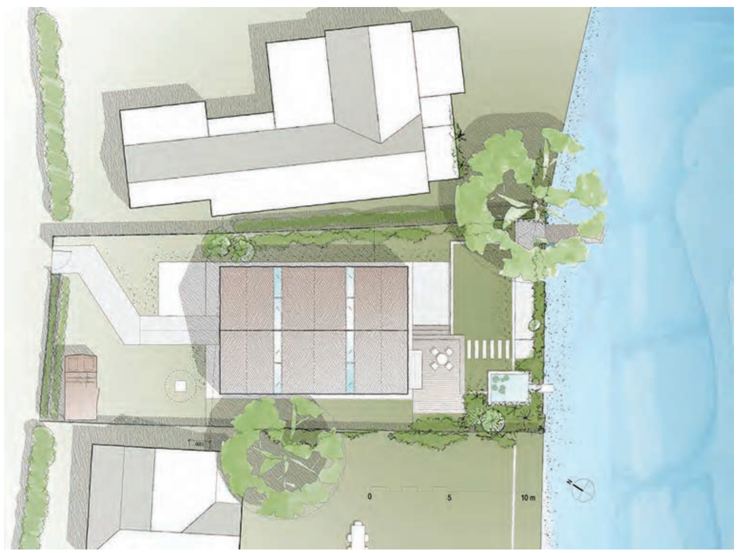


Figure 3.9
The site plan

Planning

The island is accessed from the north, across canal lock gates. A narrow footpath leads to various properties, including the site, which is located on the south side of the island. The site is broadly rectangular with the short edge facing almost due south over the river. The amphibious house is positioned centrally within the site, on the location of the previous house. Any increase in the size of the house could displace water during a flood, increasing risk elsewhere. Therefore, the new house was designed with the same footprint as the previous house.

The local authority planning department required that the height and scale of the building should not be larger than other buildings on the island; that materials should complement the setting; and that flood risk should be reduced. The first two constraints influenced the buildings form and appearance. Flood-risk reduction required both integrated landscape and building approaches; these were set out in a detailed flood-risk assessment, described below.

The site is located in the middle catchment of the River Thames. The river is wide and navigable and requires a large rainfall before 1 in 100 flood occurred, halting construction it floods. Flow gauges installed along the river work for 10 weeks. The flood was predicted help to provide two or more days early warning in advance in local and national press and on of a flood. However, when the site does flood television, radio and the internet, providing it can last for several days.[3] In 2014, a 1 in 50 to ample warning.

Hydroscape

A carefully laid out garden acts as a natural flood warning system. Terraces set at different levels are designed to flood incrementally and alert the occupants well before the water reaches a threatening level, as an ‘intuitive landscape’. The lowest terrace is planted with reeds, another with shrubs and plants. The lawn is located a level above and the terrace is located at the highest point, immediately below the living room. The terraced levels improve recovery by providing dry areas as water levels drop, and the plants help to reduce siltation of the dock.

The limited plant diversity and hardstanding on the previous site was replaced with a variety of plant species and more absorbent surfaces. The Environment Agency required that native plants such as Cornus sanguinea be used along the sensitive riparian zone adjacent to the river.

The concrete river edge was replaced with timber piling, over which planting could grow, to create a softer, more natural river edge with shelter for fish and spawn.

Water and energy infrastructure

The house is orientated almost due south, with the large glazed façade benefitting from solar gain. The heavy concrete hull provides thermal mass, while the timber frame is highly insulated. A mechanical ventilation and heat recovery system (MVHR), combined with a high level of airtightness, reduces heat loss to make an energy-efficient building.[4] Fresh air enters the property via a separate external grille, passes though the heat exchanger and picks up the heat recovered from the stale air. There is no mixing of airflows – only the transfer of heat. MVHR systems improve internal air quality in highly insulated airtight homes.[5]

Without control the solar gain could increase internal temperatures above comfortable levels. Therefore, external louvres have been designed at an angle to provide shade from the sun when it is at its peak, but still allow sunlight through at low level during winter months.

There is no gas or potable water on the island, therefore the house had to be serviced via treated water from a borehole located on the site and mains connected electricity. The shed houses the incoming electricity, water and telephone supplies at high level, before they are routed below ground to the house via flexible connections. The west-facing roof surface has been designed to receive solar photovoltaic (PV) panels in the future. This will allow the building owners to introduce renewable energy that will reduce energy bills and lower the building’s carbon footprint.

Because the house has a floor located below ground level, the wastewater needed to be pumped out of the house. A dual pump system was used so that in the event of a failure the second pump would allow continued use of the toilets.

The wastewater is pumped from the house via a flexible pipe into a package treatment plant buried in the garden, which is weighted down in concrete to prevent it floating during a flood. Package wastewater treatment plants are self contained systems that treat sewage locally. They process solids and liquid, retaining the solids within the unit and treating the liquid to allow water to be safely discharged into the ground or watercourse.[6]

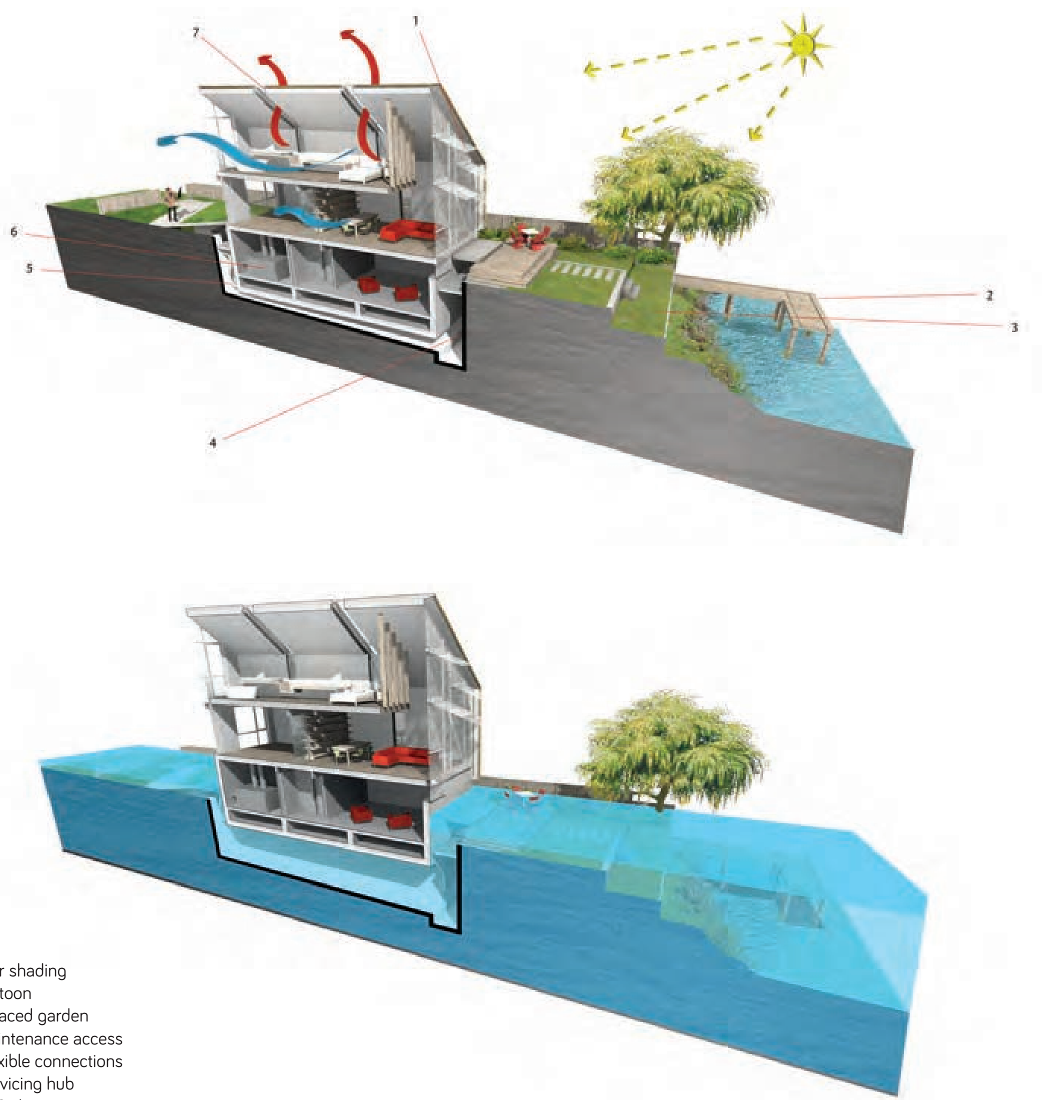


Figure 3.10
=Transect through the house in static and floating position

KEY
1. Solar shading
2. Pontoon
3. Terraced garden
4. Maintenance access
5. Flexible connections
6. Servicing hub
7. Rooflights

Figure 3.11
Construction of the wet dock

Figure 3.12
Construction of the can-float base

Figure 3.13
The can-float base during testing

The system is digitally linked to the house for ease of monitoring and is able to notify owners of capacity or other technical issues.[7]

The flexible service pipes are designed to extend up to 3m, allowing all of the services to remain clean and operational during any flood event. Crucially, this also allows the occupants to return to the property immediately after a flood, maximising the continuity of their daily lives.

The anatomy of the amphibious house

Flood-proof building

The amphibious house contains four key constituent parts:

a. Wet dock and debris control

b. Can-float base and dwelling

c. Guide posts and running gear

d. Flexible utility connections

a. The wet dock (shown in Figure 3.14) is a hole in the ground formed from steel sheet piling, with a reinforced concrete ring beam retaining the top edges of the piles. A permeable concrete slab forms the base of the dock and retains the bottom edge of the sheet piling. The slab is supported by concrete piles driven into the ground and carries the weight of the building during dry conditions.

The concrete ring beam is cast adjacent to the can-float base to create an overlap in the structure and minimise the amount of debris that enters the dock. Some siltation is inevitable; therefore the base is profiled to create a void under the house, which can be flushed out from time to time.

Figure 3.14
3D cutaway model showing the key components

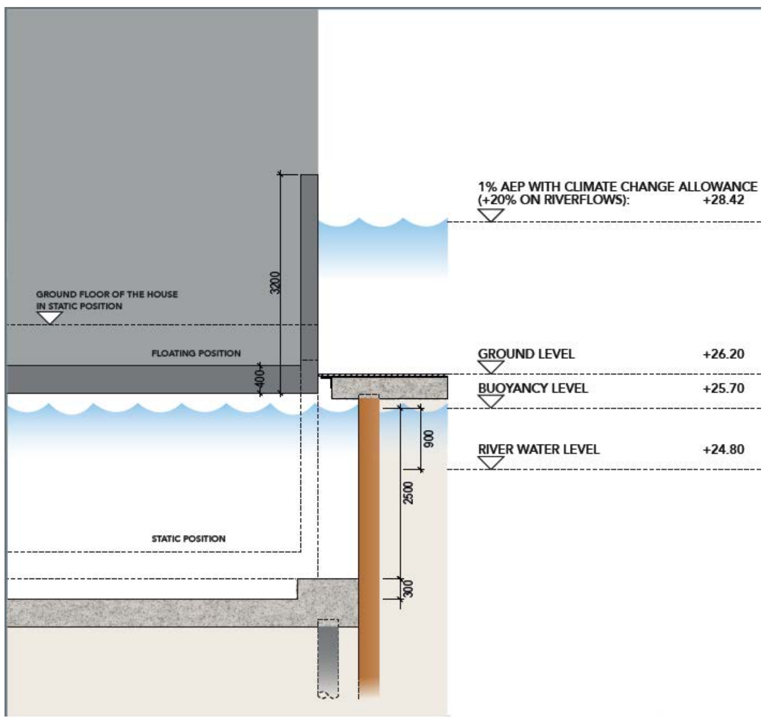


Figure 3.15
Section through the 'can-float' base and wet dock during flood conditions

b. The 'can-float' base functions similarly to the hull of a ship. It provides the building's buoyancy and supports the structural frame of the dwelling. The 'can-float' hull (shown in Figure 3.15) is formed from reinforced waterproof concrete to protect against water ingress. The foundation is designed to be heavy enough to prevent crabbing and impact damage, but sufficient in volume and light enough in mass to provide buoyancy.

c. The dwelling is set between four galvanised steel columns termed 'dolphins'. A bespoke running mechanism is fixed between the house and guide posts to facilitate smooth vertical movement as the house rises and falls. The dolphins hold the house true and level against the river current during a flood.

d. Services connect the house with land. Insulated and flexible pipes run along the side of the house, within the wet dock, to pump wastewater into a treatment tank set in the ground.

How it works

The flotation is designed based on Archimedes' principle , illustrated in Figure 3.16. This states that any object immersed in fluid is buoyed up by a force equal to the weight of the fluid displaced by the object.[8]

The house weighs about 220 tonnes (about 170 cars or 85 Rolls Royces, as illustrated in Figure 3.17), which means a volume of approximately 225m^3 of water is displaced when it becomes buoyant.[9]

The river and ground water are hydrologically linked. During a flood event, as the River Thames rises so will the groundwater on the island. The dock does not fill with water via overtopping of the ground plane but will fill incrementally, gently raising the building as the river level rises, indicated in Figures 3.18 and 3.19.

When the groundwater/river level is just below the ground level the house becomes buoyant. The house will continue to rise up to 2.7m to cope with a 1 in 100 flood event.

The guide posts extend almost 4m above the ground level, up the length of the façade, such that in the event of an even bigger flood the house would still be retained between the posts.

Maintenance

The amphibious house is designed with minimal moving parts, but like any house it requires maintenance, and like a car or a boat it requires testing. The house may not float for several years; therefore it is important to proactively test and maintain the can-float base and flotation system, to ensure that the parts are in good state of preparedness for when a flood occurs.

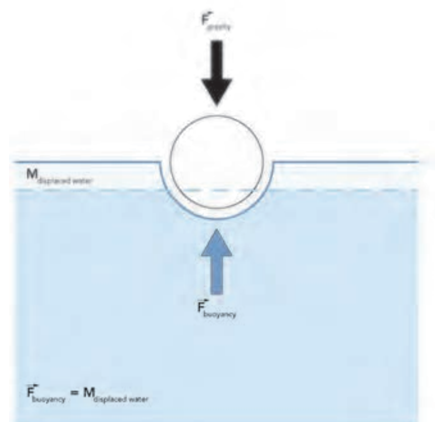


Figure 3.16
Archimedes' principle

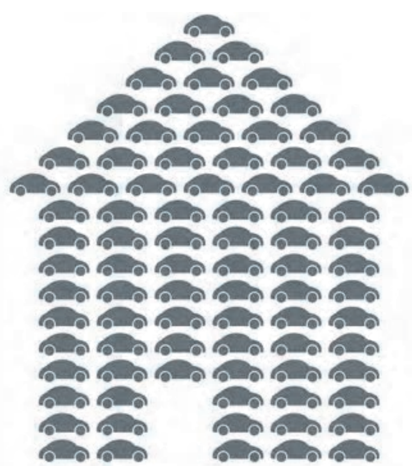


Figure 3.17
Visual representation of the weight of the house

Figure 3.18
Cross-sections of the previous house andthe amphibious house showing the flood level

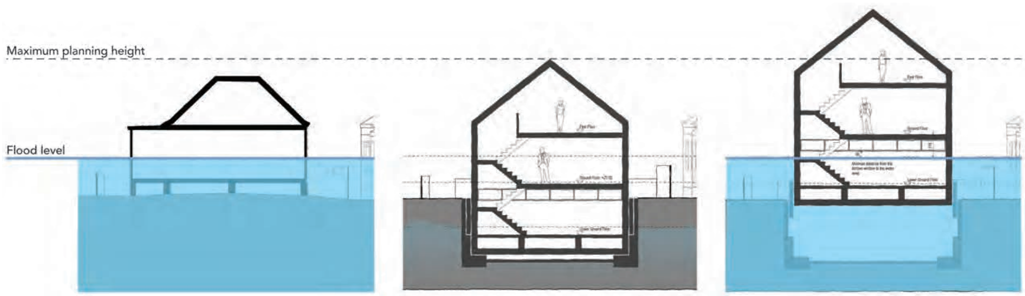


Figure 3.19
Visualisation of the house during flooding

The house has been designed to allow both visual inspection of the key parts and physical testing. During construction the house was tested after the can-float base had been completed, to assess the integrity of the hull, watertightness, balancing, and the running gear. It was then tested again once the upper frame and fit-out was completed to rebalance the system. The first float test is shown in Figures 3.20 to 3.22. Figure 3.20 shows the water being pumped into the access way at the end of the dock to artificially raise the water level. Figures 3.21 and 3.22 show the guide posts.

The wet dock is accessible from both ends of the building. There is a walkway around the entire can-float base to allow visual inspection, replacement of parts (if required), and jet cleaning of the dock to remove siltation. Figure 3.23 shows the access hatches, concealed in the decking.

Once every year the dock will be pumped full of water to repeat the flotation test; the house will be elevated up to 50cm to test the integrity and free movement before the water is slowly released and the building allowed to touch down again.

Figure 3.20
The wet dock can be actively filled with water to float the house

Figure 3.21
The can-float base is built around the guide posts to restrain lateral movement

Figure 3.22
Checks are made during the float test

Figure 3.23
Hatches are built into the decking to access the dock for maintenance

Findings

The challenge of a moving house is in the servicing and utilities and there are a number of obstacles to bringing forward flood-resilient typologies. These include an absence of statutory guidance building standards with regard to stability and buoyancy, as well as approved construction techniques for displacement and hybrid flotation units. Uncertainty of the whole-life performance (and the standards to which they should be built) has raised questions with funders, warrantors and mortgage providers, hampering the realisation of projects.

Two variables impact the whole life-performance of floating and amphibious buildings more significantly than static buildings. Firstly, the wear and tear of movement on connection details, in particular to the external envelope and services, and the potential corrosion from permanent immersion in water. Secondly, the impact of climatic changes such as increased flood frequency, intensity of rainfall, wind loading and overheating.

Like any machine with moving parts, they require regular maintenance and monitoring. Some floating properties in the Netherlands have shown signs of substantial corrosion, listing and abandonment due to poor consideration of the whole life performance. Lack of clear structural standards, poor maintenance and lack of routine monitoring has the potential to result in (avoidable) catastrophic failure.

Part M accessibility

The island on which the amphibious house is located is only accessible via a narrow canal lock that restricts access by wheelchair. The Environment Agency also requires that a flood management plan is in place, linked to an early warning system for evacuate in the event of a flood. Because the case was betterment, the scheme was granted dispensation for wheelchair users.

Nonetheless, our other newbuild schemes including amphibious houses in the Netherlands have been designed to provide continuous access in the event of a flood, in combination with elevated walkways and access points for emergency services.

Amphibious construction is a new phenomenon internationally, and thus there are limited examples. In the US is Brad Pitt s ‘Make it Right scheme in New Orleans following Katrina, while Maasbommel, Holland has 32 units and Thailand has half a dozen units. While the Dutch have produced guidance in respect of stability and buoyancy, these are not fully developed NTAs the Dutch Standardisation Institute’s equivalent of British Standards. An equivalent does not exist in the UK.

To comply with planning and building regulations, standard components from various different construction sectors were tried and tested and appropriated for use on the amphibious house. This was frustrating, time consuming and stifled innovation. There is clearly a vacuum to be filled. An addendum to BR 2015 to incorporate regulations for domestic floating and displacement structures or an equivalent of Robust Details, Part E (Sound resistance) for such building typologies would enable this emerging sector to flourish.

Figure 3.24
Proposed
addition to the
Building 25
Regulations

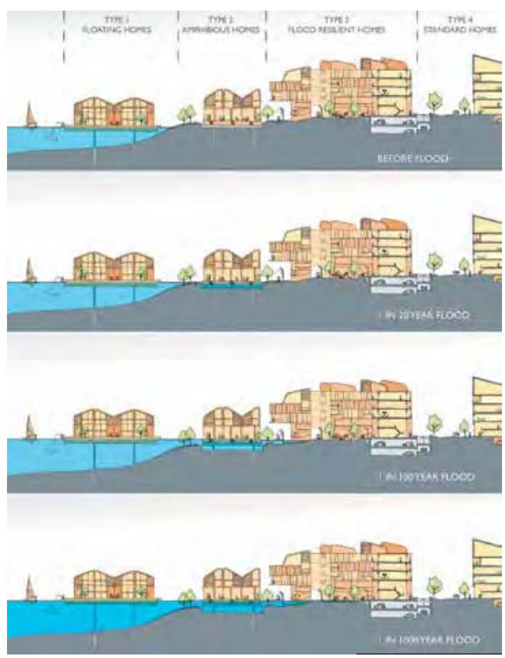


Figure 3.25
Baca Architects
proposals for
a floodproof
Pilot scheme
Dordrecht,
Netherlands

Figure 3.26
View of the house from the river

Lessons learned

Amphibious construction brings together standard components from the construction and marine industries to create a 21st century solution to flooding. It is slightly more expensive than other solutions, due to the two foundation systems (dock and hull); however it is ideally suited to areas of high flood risk, those where there is uncertainty in future flood levels, and historical or sensitive landscape settings where other solutions would be unacceptable.

Where multiple houses or large buildings could be combined together on large can-float bases there would be greater economies of scale. The costs of the dock construction and hull and number of guide posts would all be reduced.

This type of building solution should always be considered in the context of the wider neighbourhood. Where possible it is preferable to locate residential buildings in lower-risk areas but where this is unavoidable an amphibious building may be a viable proposition for areas of greatest flood depth. Amphibious construction may also be used for supporting infrastructure such as walkways and roads to facilitate safe access and egress to wider development. It could also be used in critical buildings or facilities in which flooding would cause serious disruption, such as intensive care units, critical energy services, or emergency services. Integration between amphibious and other construction types could create new architectural typologies through cross-programming.

Dissemination> Recent publications

The UK's first amphibious house is leading the way in flood-resistant design, as **Richard Coutts** explains

Rise of the new

The house is been built on an island in the Thames

Currently, there are more than five million UK properties at risk of flooding and rising sea and river levels could threaten many more over the next 100 years, with a major cost impact on homes and businesses.

One innovative solution may be amphibious construction, with homes resting on fixed foundations but able to float up in the event of flooding. The UK's first amphibious house has been built on a small island in the River Thames in Buckinghamshire, classified as Flood Zone 3b, the functional floodplain.

The initial option of a floating property with the adjacent garden in the river course was not favoured by the Environment Agency. An elevated building would sit high enough to avoid an extreme flood but would be divorced from the garden.

An amphibious house solves these issues by allowing occupants to enjoy their garden, only rising to avoid floods when necessary.

Construction starts with a wet dock formed from steel sheet piling and a reinforced concrete ring beam retaining the top edges of the piles. A permeable concrete slab forms the base of the dock and retains the bottom edge of the sheet piling. The slab is supported by concrete piles driven into the ground and carries the weight of the building during dry conditions.

The concrete ring beam is cast adjacent to the can-float base to create an overlap in the structure and minimise the amount of debris entering the dock. Some siltation is inevitable, so the base is profiled to create a void under the house, which can be flushed out from time to time.

Buoyancy fix

The can-float base functions similarly to the hull of a ship. It provides the building's buoyancy and supports the structural frame of the dwelling, formed from reinforced waterproof concrete to protect from water ingress. The foundation is designed to be heavy enough to prevent crabbing and impact damage, while sufficient in volume and light enough in mass to provide buoyancy.

The dwelling is set between four galvanised steel 'dolphins'. A bespoke running mechanism fixed between the house and guideposts will facilitate smooth vertical movement as the house rises and falls. The dolphins hold the house true and level against the river current during a flood. Flexible services connect the house with the land. Insulated and flexible pipes run along the side of the house within the wet dock to pump wastewater into a treatment tank.

Designed to cope with the predicted extreme (1 in 100) flood level now and in 100 years' time, the contemporary dwelling comes complete with open living space around a double-height space overlooked by the gallery master bedroom. The glazed south-facing facade gives panoramic views of the river and an attractive and functional riverside garden.

High-performance insulation and double-glazing reduces heating demand of the house, with a heat recovery ventilation system adds to energy savings. External louvres shade the building from the southern sun.

The riverside garden includes a number of terraces stepping down to the water's edge, which will incrementally flood when the river rises up its banks, containing the floods in predetermined spaces. This allows residents to be more conscious of their natural environment and in turn raises their awareness of flood risk. An 8m buffer zone, required by planning, provides ecological continuity and protects the character of the riverside setting.

> “The base is designed to be heavy enough to prevent crabbing and impact damage and light enough to provide buoyancy

Overcoming obstacles

The challenge of a moving house is in the servicing and utilities, and there are a number of o bstacles to bringing forward flood-resilient typologies.

These include an absence of statutory guidance building standards with regard to stability and buoyancy, as well as approved construction techniques for displacement and hybrid flotation units. Uncertainty of the whole life performance (and the standards to which they should be built) has raised questions with funders, warrantors and mortgage providers, hampering the realisation of projects.

Two variables impact the whole life performance of floating and amphibious buildings more significantly than static buildings. The first is the wear and tear of movement on connection details, in particular to the external envelope and services, and the potential corrosion from permanent immersion in water. The second is the impact of climatic changes such as increased flood frequency, intensity of rainfall, wind loading and overheating.

Like any machine with moving parts, such buildings require regular maintenance and monitoring. Some floating properties in the Netherlands have shown signs of substantial corrosion, listing and abandonment due to poor consideration of the whole life performance. Lack of clear structural standards, poor maintenance and lack of routine monitoring has the potential to result in (avoidable) catastrophic failure.

The Thameside house is designed to allow both visual inspection of the key parts and physical testing. During construction, the house was tested after the can-float base had been completed to test the integrity of the hull, watertightness, balancing and the running gear, then again once the upper frame and fit-out was completed, to rebalance the system.

The wet dock is accessible from both ends of the building and a walkway around the entire can-float base allows visual inspection, replacement of parts (if required) and jet cleaning of the dock to remove siltation should it occur.

Once a year, the dock will be pumped full of water to repeat the flotation test; the house will be elevated to 50cm to test the integrity and free movement, before the water is slowly released and the building allowed to touch down again.

Part M accessibility

The island on which the amphibious house is located is only accessible via a narrow canal lock that restricts access by wheelchair. The Environment Agency also requires that a flood management plan is in place, linked to an early warning system for evacuate in the event of a flood. Because the case was betterment, the scheme was granted dispensation for wheelchair users.

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Amphibious construction is a new phenomenon internationally, and thus there are limited examples. In the US is Brad Pitt's Make it Right scheme in New Orleans, built following hurricane Katrina, while Maasbommel in Holland has 32 units and Thailand has half a dozen units. While the Dutch have produced guidance in respect of stability and buoyancy, these are not fully developed NTAs – the Dutch Standardisation Institute's equivalent of British Standards. An equivalent does not exist in the UK.

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In future, we envisage large communities that are holistically planned with improved preparedness for flooding and climate change. Dwellings will be low carbon, and organised around multifunctional landscapes that will help control surface water flooding or act as large flood storage areas. New communities will be made up of flood-resilient dwellings located on the highest ground, with amphibious homes in the transitional zones between development and the natural environment.

The planning system, supported by common standards, has a critical role in delivering this vision with the potential to provide safe development, simultaneously address land availability and act as a catalyst for emerging construction industries.

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Further +info

Related competencies include Construction, technology and environmental services

Talks and Seminars

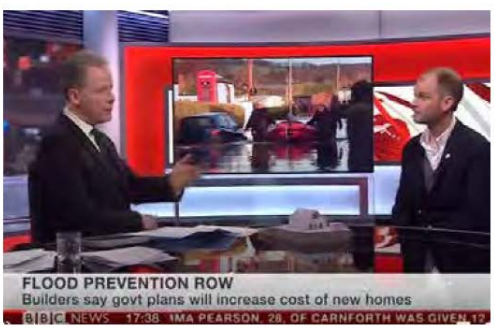
Ecobuild fringe in partnership with Aco 2016 Presenting the UK's first Amphibious House

NLA New Ideas for Housing Hosted at the GLA

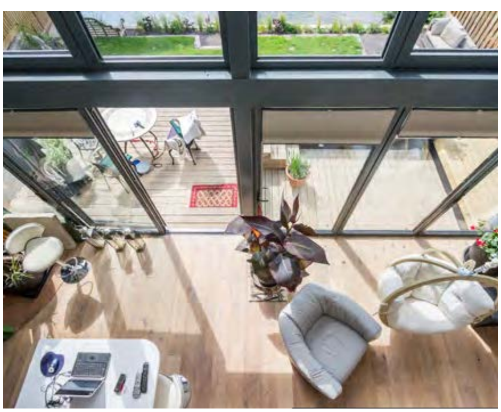
'London's Water'
Pecha Kucha
Event at
Kingston Upon
Thames University
9th June 2016

Alan Vallance
RIBA Interim Chief
Executive talking at
Danish Embassy
Baca prepared
slides on the
LifE project,
Amphibious house
and UK flood
innovations
16th June 2016

Dissemination> Media



"The amphibious house promises delight, beauty and practicality in the everyday, but it is in the event of a flood that it will prove itself phenomenal!"



Conclusions

Urbanisation through expansion and densification of floodplains is contributing to increased flooding and multiplying the number of people exposed.[1] Climate change is increasing the frequency and severity of flooding; global warming is melting ice caps and increasing sea levels.[2] The number of floods over the last 20 years in which existing defences have failed or come close to being overtopped has been a wake-up call to many nations.

With floods occurring in spite of flood defences, a shift from flood prevention to flood-risk management is not only logical but essential. Risk management requires better understanding, better planning, better design and better communication.

This must be supported by flood resilient construction to better cope with the uncertainty of extreme flood levels.

There are several different building typologies to cope with flooding, each with its own merits. Floating and amphibious buildings can cope with dramatic water level variations without impacting on the public realm and streetscape. The space between elevated buildings and the ground can be used to cool buildings, park cars or create sheltered outdoor space. Key buildings can be designed to form local nodes or energy centres, and built to higher standards to provide safe havens in extreme events.

Aquatecture promotes building techniques that are co-designed with the landscape that surrounds and supports them; different techniques aim to anticipate, avoid and protect from flood waters as required. In conjunction with the landscape, new buildings can also help to reduce flood risk to surrounding areas by making space for water beneath and around them. Floating developments may be a solution to revitalise post-industrial waterscapes or to create vibrant waterfronts for emerging cities.

For these properties the water is the landscape that creates new opportunities for architectural expression.

While every case is different and there are always exceptions to the rule, some generic guidance can be determined as follows:

- Dry-proof and wet-proof designs are typically used for existing buildings.
- Dry-proof designs are normally only effective for shallow flood depths and short flood durations.
- Wet-proof designs can tolerate higher flood depths but possessions may be affected and the property will need time to dry out after flood water has receded.
- Elevated buildings can be designed to cope with a range of different flood levels, with higher flood depths requiring greater structural solutions. Where there is uncertainty in flood levels, elevated buildings may not be the best solution.
- Floating buildings should not typically be used near potentially fast-flowing water or where there is wave action, such as along the coast.
- Floating architecture is only feasible where water depths tend to exceed 1m. Taller floating buildings tend to require greater water depths to provide sufficient buoyancy, just as larger boats do.

- Amphibious buildings can provide solutions for areas with high water level variation and in particular where there are access issues or sensitivity about the height of buildings.

Building types may not be mutually exclusive. Dry- and wet-proofing techniques can be combined to create a building resistant to frequent flooding and resilient to extreme flooding. The ground floor of elevated buildings can be dry-proofed to maintain level access on the ground floor. A house could have a wet-proof entrance hall and living spaces and an amphibious bedroom area that will always be safe.

There is an opportunity for these techniques to be integrated with energy-saving technology, with the use of energy piles, heat exchange and labyrinth cooling. There is also an opportunity to mitigate flood-risk by articulating the surroundings, using stepped and textured landscaping as an intuitive warning system. Rusticated or robust materials used below the flood level could provide a reinterpretation of the piano nobile, perhaps called the *piano inundatio*.

Floating buildings can provide one solution to redeveloping static water bodies such as docks and lakes. They can support a vibrant mix of uses (from hotels to parks) to reinvigorate different waterspaces and support adjacent land uses. They can also provide a catalyst for wider regeneration.

By embracing these various forms of construction, people have managed to live with significant seasonal or occasional flooding, enabling them to benefit from the proximity to the water. Using these building types in modern architecture and planning can improve living with water: reducing disruption to lives and businesses, and reducing the physical, social and financial losses of flooding.

With the next generation of UK amphibious housing Baca Architects hope to develop a lower cost prefabricated solution and a highly robust coastal flooding solution, to demonstrate its wider applicability and to resolve blighted coastal locations respectively. Figure 19 illustrate some of the prefabricated properties we are developing, which can be delivered by lorry and craned onto floating bases, or onto can-float bases to form amphibious properties. Like other prefabricated houses, these proposals should improve the quality of workmanship, potentially providing their own guarantee and therefore bypassing the need for a bespoke building warranty. Through modularisation they have the potential for widespread application of amphibious construction, particularly on new development or regeneration sites.

In conclusion, Amphibious Buildings have an important part to play in the flood-risk reduction of the UK, particularly in sensitive historic sites. However, their application is always likely to remain marginalised or of a small scale bespoke nature until standardisation of construction details can be used to obtain building warranties and with this major funding. The Thames Amphibious House, is one of these bespoke solutions, which at least now demonstrates that amphibious construction is technically feasible to tackle UK flood-risk.

The table opposite provides guidance on which building type is appropriate based upon site and flood characteristics.

Table 2
Flood proof options table, with elements adapted from World Bank and USACE

		Elevated property on structural walls	Elevated property supported on posts or columns	Dry flood-proofing/ resistance	Wet flood-proofing/ resilience	Floating construction	Amphibious construction
Flood characteristics							
Depth	Shallow (<0.3m)	✓	✓	✓	✓	✕	✕
	Fairly shallow (0.3m – 0.6m)	✓	✓	✓*	✓	✕	✕
	Moderate (0.6-2m)	✓	✓	✕**	✓	✕	✓*
	Deep (>2m)	✓	✓	✕	✕	✓*	✓
Velocity	Slow (<1m/s)	✓	✓	✓	✓	✓	✓
	Moderate (1-2m/s)	✓	✓	✕	✕	✕	✓
	Fast (>2m/s)	✕	✓	✕	✕	✕	✕
Character	Subject to rapid/ flash flooding	✓	✓	✕	✕	✕	✕
	Subject to ice and debris flow	✓	✓	✕	✕	✕	✕
Site characteristics							
Location	Coastal floodplain	✓	✓	✓	✓	***	***
	Riverine floodplain	✓	✓	✓	✓	*	*
Soil type	Permeable	✓	✓	✕	✓	✕	✓
	Impermeable	✓	✓	✓	✓	✓	✓

* subject to site conditions/details
** flood depths above 0.6m can damage the structural integrity of buildings
*** only in protected areas where sudden fluctuations in levels are controlled

Glossary

Accretion: The process of growth or increase, typically through gradual accumulation of additional layers. The accretion of flows would be when different rivers merge to increase the total flow

Alleviation: In the context of flooding this refers to reducing the severity of flood risk

AOD: Above Ordnance Datum – measure of height above standard datum level

Aquatecture: Water-based or water-related architecture

Aquifer: A body of permeable rock that can contain or transmit groundwater

ATES: Aquifer Thermal Energy Storage uses the temperature difference between an underground temperature store (in this case an aquifer) and a building above ground to heat and cool the building

Attenuation: To reduce or hold back the volume and flow of floodwater

Biomass: The biodegradable fraction of products, waste and residues from agriculture (including plant and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste

Blue infrastructure: Infrastructure relating to water supply and water management. Defined by Dr Ken Yeang as hydrological management, the 'closing' of the water cycle, water conservation and management, grey water reuse, rainwater harvesting, etc

Blue/green infrastructure: Landscaped water management measures such as Sustainable Drainage Systems (SuDS)

Brownfield land: Common name for previously developed land. Previously developed land is that which is or was occupied by a permanent structures and associated permanent land uses

Catchment: The catchment, drainage basin or watershed of a river is the area of land from which rainfall eventually drains into a river

CFMP: Catchment Flood Management Plan

CLG: Communities and Local Government is the UK government department, which sets policy on local government, housing, urban regeneration, planning, fire and rescue

Climate change: Any long-term significant change in the 'average weather' that a given region experiences

Code: Code for Sustainable Homes. The Code is intended as a national standard to guide industry in the design and construction of sustainable homes. The Code measures the sustainability of a home against nine design categories: energy, pollution, water, health and well-being, materials, management, surface water runoff, ecology and waste

Defra: Department for Environment Food and Rural Affairs. Defra has overall policy responsibility for flood and coastal erosion risk in England

Dry-proof: Measures employed in buildings to keep water out

EA: The Environment Agency is the UK government agency concerned with mainly rivers, flooding, and pollution. It is responsible for flood risk and for managing flood defences, river channels and shorelines in England and Wales

Ecological flood mitigation: Flood mitigation techniques based on use of natural systems or mechanisms

FCERM: Flood and Coastal Erosion Risk Management

Flood-proof: Designed to withstand a flood Fluvial flooding: Flooding from rivers

FRA: Flood Risk Assessment

FZ: Flood Zone is an area of land with a designated probability of flooding

GIFA: Gross Internal Floor Area is the area measure of all floors and circulation spaces within a building

Green infrastructure (or ecoinfrastructure): Refers to a network of open spaces and nature corridors that can be used to manage flood risk, provide wildlife corridors and amenity space instead of civil engineered infrastructure. Defined by Dr Ken Yeang as nature's utilities, which includes ecological corridors and networks that link existent and new open spaces and provide habitats for fauna and flora, for natural resource management and integrated urban food production systems

Grey infrastructure: Defined by Dr Ken Yeang as 'cleantech' ecoengineering systems such as sustainable energy systems, transportation/movement systems, natural sewage systems, materials and recycling systems

GSHP: Ground source heat pumps exchange heat between the ground and a building to heat and cool the building

HCA: Homes and Communities Agency

Hydrology: The branch of science concerned with the properties of water, especially movement in relation to the land

Hydroscape: A landscape that is formed from water or is heavily dependent on regular water inundation, such as a wetland

ITS: Interseasonal thermal storage uses an underground storage area to store heat gained from the sun in the summer. A heat pump then transfers this heat from the store to a building in the winter time when it is needed

LAP: Local Area for Play

LEAP: Local Equipped Area for Play

LifE: Long-term Initiatives for Flood-risk Environments

Making Space for Water policy: UK government strategy for flood and coastal erosion risk-management

Managed Coastal Realignment: A form of soft engineering to improve coastal stability and to reduce maintenance of flood defences

MHWN: Mean high water neap tide level

MHWS: Mean high water spring tide level

Micro-tidal: Applied to coastal areas in which the tidal range is less than 2m. Wave action dominates the processes active in micro-tidal areas

MLWN: Mean low water neap tide level

MLWS: Mean low water spring tide level

MSW: Making Space for Water

MUGA: Multi-use gaming area

NEAP: Neighbourhood equipped area of play

ODN (Ordnance Datum Newlyn): Level above or below standard datum level

Passive cooling: The act of keeping a building cool without mechanical or active cooling measures, such as air conditioning

Pilotis: Structural columns used to support a building above ground or water

Pluvial flooding: Flooding from rain

PPG: Planning Policy Guidance

PPS: Planning Policy Statements replace the former Planning Policy Guidance with national policy on spatial planning

PV (photovoltaic): A solar PV is a large area panel that transforms solar energy into electricity by the photovoltaic effect

Rain garden: A garden which takes advantage of rainfall and storm water runoff in its design and plant selection

Rainwater harvesting: The accumulation and deposition of rainwater for reuse on site, rather than allowing it to run off

Ramsar: Ramsar sites are wetlands of international importance designated under the Ramsar Convention

Red or human infrastructure: Defined by Dr Ken Yeang as sustainable human ways of life and societal activities

Renewable energy: Energy generated from naturally renewable resources, such as wind, sun and water. This also includes crops such as willow

Resilient: Able to withstand or recover quickly from the effects of flooding

Resistant: Offering resistance to the effects of flooding

Reticulation: A pattern or arrangement of interlacing lines resembling a net

Return period: The period in which an event, such as a high spring tide, is expected to recur, normally given in years

Rill: A shallow channel cut in the ground by running water

Riparian: A riparian zone or riparian area is the area between land and water along a river or stream

RO (Renewables Obligation): Requires licensed electricity suppliers to source a specific and annually increasing percentage of the electricity they supply from renewable sources

'Room for the River' project: Dutch government strategy to increase the capacity of the rivers to cope with higher water discharge rates and achieve co-benefits

Safe haven: A place of refuge or security, as may be used in an area at risk of flooding SFRA: Strategic Flood Risk Assessment

SSSI: Site of Special Scientific Interest

SUDs: Sustainable drainage systems. Designed to manage rainfall on developments in a way that mimics natural drainage, reducing or without the need for piped underground drainage

Swales: A low or hollow place, especially a marshy depression between ridges

Tidal flooding: Flooding from the sea or tidal parts of the river/estuary

Topography: The arrangement of the natural and artificial physical features of an area

Wetland: Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6m (defined by the Ramsar Convention)

Wet-proof: Measures employed in buildings to prevent water ingress from causing long-term damage

Zero carbon: Providing all energy needs from renewable resources on site, such as wind, tidal and solar power

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