Floating architecture in the landscape: Climate change adaptation ideas, opportunities and challenges

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Abstract

Opportunities exist for radical strategies, driven by spatial planning, to adapt our urban fabric to climate change. Floating developments are one such innovation. This phenomenon and its ideas are driven by a variety of societal forces, including by population pressure, rapid urbanisation, the resulting need for additional housing inventory, by urban adaptation strategies to counter fluvial flooding and sea level rise, plus interests in urban landscape renewal. We reflect on seventeen projects in five countries and note that, to date, it is inner city harbours or industrial areas in decline that are being targeted for floating communities. These can add renewal, recreational and landscape value, while simultaneously expanding the existing urban housing stock.

Introduction

As the debate concerning climate change has shifted from an emphasis mainly on mitigation to a discussion of combined mitigation and adaptation strategies (IPCC, 2013), so the role of urban planning grows in significance and its effect on possible future urban landscapes increases proportionately (see Meyer et al., 2010). However much of the recent discussion on the subject of climate change and urban planning focuses on avoiding development in risky areas (e.g. Davidse et al, 2015), minimising the impact on infrastructure (e.g. Carter et al., 2015) and run-off mitigation strategies such as green roofs and sustainable urban drainage systems (SUDS) (Landscape Institute, 2014). With the exception of some emphasis on resistant and resilient building design (e.g. Blakely, 2007; Mathews, 2011), few strategies have emphasised more radical alternatives. Nevertheless over the past two decades, floating architecture has been receiving increasing attention in certain architectural circles (e.g. Lisa, 2013; Waterstudio.nl, 2015; Baca Architects, 2015; Stopp and Strangfeld, 2017), particularly in response to the vulnerability to increased flooding in densely-populated urban areas (Anderson, 2014).

The concept of floating houses, or living on water, is not a new technology *per se*; people were living in houseboats or floating settlements in Europe as far back as the 17th Century (Kloos and De Korte, 2007) if not before. However, whereas houseboats are constructions that are designed as a boat first - adjusted to accommodate permanent living - the concept of floating houses is based on the traditional purpose of a house as a structure in which to live, but designed to float on water (De Graaf, 2009). Despite its mobility, a floating house is not designed to navigate, nor be self-propelling.

We can here differentiate between amphibious and floating houses (Figure 1). Both are designed to adjust to variations in water levels, and are therefore suitable for flood-prone or tidal areas (Barker and Coutts, 2016). Floating houses are designed with permanent water in mind, whereas amphibious housing is proactive, constructed to operate in dry land conditions as well as during flood events (De Graaf, 2012; Anderson, 2014; Barker and Coutts, 2015). Baca Architects in London have been UK pioneers of both approaches.

This paper focuses on recent developments in this field by providing an overview of current stakeholders and ongoing projects as a platform for an analysis of both current typologies and the impediments to this type of development in the future. We recognise that there are numerous initiatives of this type occurring globally and, as a result, such an overview will never be complete, although we reflect on seventeen projects in five countries (Table 1) but with most examples taken from the Netherlands where this development has been most rapid (Ambica and Venkatraman, 2015). As with Strangfeld and Stopp (2014), we focus on developed countries (e.g. Engineers without Borders Australia, 2014), not least because they generally represent significant innovation there compared to situations in countries such as Bangladesh where floating domestic buildings are commonplace. This is because we wish to analyse and understand the barriers to such innovation in developed countries (cf. Van Herk et al., 2015), as well as the potential landscape and urban planning gains (Barker *et al.*, 2009), thereby complementing Strangfeld and Stopp's (2014) narrower but useful emphasis on construction methods and technologies.

This is not a report on methodologically rigourous research, rather a discursive exploration of ideas, opportunities and challenges. Much of this analysis has a normative slant, given our judgement that the technologies involved have potential which needs to be realised as well as limitations that must be recognised.

The societal drivers

The discussions related to floating houses have raised issues of urban renewal, climate change adaptation, flood resiliency and addressing housing needs (e.g. Mees et al, 2013). A variety of societal drivers influence the opportunities for such floating developments (Stopp and Strangfeld, 2010); these are discussed below.

Global population pressures

Population expansion is particularly prevalent in coastal urban areas and in major river corridors. Large urban areas near rivers and in coastal floodplains (Olsen *et al*, 2000) have all been expanding and urban populations now exceed rural populations (UNFPA, 2007). These urban populations will continue to expand: worldwide more than 70 million people move from rural areas into cities every year (UNFPA, 2007). In 2003 some 23% of the world's population were located within 100 kilometres of the coast (Small and Nicholls, 2003). By 2030, this coastal population is expected to have increased by 50% (Adger *et al*, 2005).

Such rapid urbanisation, in our case in coastal and riverine environments, is creating ever more densely-populated urban centres, pressurising city and regional governments to re-assess their current housing stock and the available room for future expansion. The combination of land scarcity and the intention to convert at least some impermeable urban surfaces into permeable open green space - to increase urban water storage and reduce urban flooding (Foka, 2014) – is requiring new forms of urban living to be considered, including floating homes. A more multi-functional approach towards urban floodplain and open water use, for flood water storage plus recreational, residential and other adaptive purposes, might greatly enhance urban resilience for our cities of the future (De Graaf, 2009). The alternative of 'sterilising' such water-related areas, prohibiting development there on the grounds of flood risk, is no longer a wise strategy.

Sea level rise leads to increased vulnerability

Global warming leading to significant increases in flood risk is especially clear in coastal areas (IPCC, 2013; Muis et al. 2017). The pressure on available urban space is likely to lead to large numbers of people occupying areas vulnerable to sea level rise and more extreme weather events (Anderson, 2014). The consequence is an extensive build-up of wealth and infrastructure in densely-populated coastal flood-prone areas. In developing countries the lowest income groups may have little alternative but to settle in flood-risk areas. In addition to the undesirability of introducing such trends in developed countries, we should avoid the inefficient non-use of such risky areas and provide residential developments there to the highest modern and cost-efficient standards.

The need for alternative energy resources and self-sustaining communities

Floating houses have the potential to operate to some extent as stand-alone units – reducing peak pressures on traditional energy network / electricity grids – by using the water as an energy resource through processes of evaporation, heat exchange or simply running water through wall spaces for cooling (Stopp and Strangfeld, 2010).

Coastal and floodplain areas provide one of the best locations for such developments. One of the initiatives we have studied, Deltasync (2014), was founded based on their 2006 vision for a large-scale floating community near Amsterdam (De Graaf *et al*, 2006). Such a community would be self-sustaining from an energy perspective, would contribute positively to regional ecological and landscape values through wetland development, provide additional living space, and be an iconic demonstration project for the floating building industry. Similar ambitions are put forward by the Seasteading Institute. This is based in San Francisco as a non-profit organisation (in 2017 beginning cooperation with Rutgers de Graaf) founded to promote the development of self-sustaining, self-funded floating communities (Seasteading Institute, 2015). Other projects, for example 'Rijnhaven' in Rotterdam (Mees et al, 2013) and 'Floating Life' in Almere, both in the Netherlands, have been following similar paths.

Mobility

The mobility aspects of floating units – limited though this may be – should appeal to policy makers from a range of perspectives. It provides vulnerability reduction with the option of relocation in case of anticipatable disasters or recurring levels of unacceptable risk. In an urban renewal perspective, urban areas can be redeveloped when construction units and infrastructure resources are produced off-site and moved into place. Based on specific locations, floating developments can also have the ability to reconnect areas in social decline with the heart of the city, for example through re-purposing old water-based industrial or shipping related areas in long term decline (Kokhuis, 2013). The mobile aspect may also facilitate key spatial planning decisions for building floating houses, because local decision-makers may feel more comfortable permitting a relatively new technology if they consider the temporary nature of floating buildings at any one locale: a decision to allow development there that is not necessarily final.

Recreational and urban renewal amenity aspirations

As indicated above, municipalities recognise the possibility of using floating architecture as a method for building up real estate value, without sacrificing increasingly scarce land area in densely built-up flood-free urban areas. But the desire to add amenity values can also be an important societal driver here. Firstly, the novelty and innovation aspect of building on water can add visual appeal to cities, whilst also creating a more climate adaptive city (Mynett, 2015). Secondly, some of the recently designed communities are purposefully incorporating both residential and outdoor public spaces into the floating concept; a good example is the Stadswerven project developed by Baca Architects in Dordrecht, the Netherlands. Whatever the design, new landscapes can be created to add value to urban edges - and provide some inspiration to the occupiers - where often degraded landscapes have hitherto been accepted as inevitable.

Locational opportunities and constraints

The principal locations where floating domestic architecture could be deployed are, first, inner-city areas of industrial decline, secondly, urban and rural fluvial floodplains with the appropriate characteristics, and, thirdly, coastal zone areas not exposed to the full force of the sea. With the last of these, while there is a variety of adaptive measures to counter or mitigate the effects of climate change and floating houses could accommodate sea level rise if the locational characteristics are appropriate, they are not suited to withstand tidal surges of unpredictable magnitude or wave action induced by coastal storms. The locations where the majority of "floating experiments" are occurring reflect this need for calmer waters, not situations exposed to the open seas.

The decline of large centres of industry and major shipping activities in the inner harbours of major cities in recent decades, such as Hamburg, London and Rotterdam, appears to have a 'silver lining', at least for the real estate developers and proponents of floating architecture (e.g. Douglas, 2013; GLA, 2014). This transformation, which started in the early 1990s in the old abandoned city harbours, was based on the premise that people enjoy living near the water, and therefore the opportunity arose for developments of houses floating in abandoned docklands close to the relevant urban centres (Stopp and Strangfeld, 2010; Mynett, 2015). In the process, urban dwellers started reconnecting with the waterfront, coinciding with planners' aspirations of reconnecting degraded neighbourhoods with the revitalised and by now relatively unpolluted river environments; both trends combined to propel the floating movement (Kokhuis, 2013).

Other locations for floating and amphibious houses need to be approached with some caution (see Miszewska-Urbańska, 2016). Fluvial floodplains for this type of domestic architecture would be in large river valleys where floods rise slowly, predictably and to only moderate depth. Rapidly rising flood waters would destabilise, potentially, the amphibious architecture, and excessive water depth would lead to the disconnection of the vital services upon which these houses depend. Locations behind dikes could be favourable, so long as the probability of overtopping or breaching is very low and dyke design can be 'fail safe'. In general, locations adjacent to existing urban areas would be favourable, for the facilities they that they can provide for the population thereby housed.

These criteria may appear unduly restrictive, but in reality they leave many floodplain areas that are potentially suitable for such developments (Independent, 2013; Miszewska-Urbańska, 2016) yet which are currently almost universally embargoed in many countries for residential properties. Figure 2 identifies four such locations in the UK where the geographical conditions are likely to be suitable for floating or amphibious homes, but where current spatial planning strictures and practices designed to avoid floodplain areas would make them unlikely choices for any other type of residential development. Our examples are where the flood depths meet the criteria identified above, the locations are adjacent to existing urban concentrations, and each is faced with only slow rising inundation without the danger of flash flooding. Obviously detailed site investigations would be necessary to determine whether these locations are indeed suitable for floating homes developments and provide the desired landscape enhancements.

Other areas suitable for floating or amphibious development are large inland lakes, river edges (e.g. Hamburg; Rotterdam; the lower Columbia River, USA), polders (in the Netherlands mostly) and even abandoned but flooded open cast mines (Stopp and Strangfeld, 2010) or quarries. These areas share the necessary relative calmness of the water conditions, but also come with their own individual challenges and qualities. Large polders struggle with sufficient depth to allow for sufficient vertical movement of the house (De Graaf, 2009); estuaries may have excessive tidal range leading to unwelcome continuous movement. The project in an abandoned lignite mine in eastern Germany (Maasberg, 2012) presented water quality and pollution concerns (Stopp and Strangfeld, 2010), as well as local infrastructure connection challenges.

Construction types, technologies and materials

Any new architectural approach comes with new material requirements and opportunities (see Stopp and Strangfeld, 2017). Until now the use of concrete for floating houses has been widespread, driven by local availability, reliability and cost-effectiveness. However, research has investigated suitable substitutes that are "cheap, sustainable, carbon neutral and locally available worldwide" (Redahan, 2012).

A variety of challenges undoubtedly exist (Table 2). Currently, the majority of floating houses in the Netherlands are using watertight concrete walls filled with polystyrene foam to provide buoyancy via a floating basement, making the structure unsinkable (De Graaf, 2012; Mishutn et al., 2017). A variant here is a floating foam platform, topped by a concrete layer, and connecting such modules can create complete floating neighbourhoods (Redahan, 2012) as patented by Dutch Docklands and Waterstudio NL.

Alternative construction methods are available. The British company EcoFloating Homes suggests the use of a steel hull, protected with epoxy treatments (Redahan, 2012). For the house itself, red cedar is used to reduce the risk of decay. Floating Homes GmBH in Germany prefers a steel skeleton, with wood-clad permeable planking. Other methods involve steel and glass fibre reinforced concrete boxes as the foundation, depending on water composition (saline or fresh), as well as alternatives such as "composite materials, plastics, treated bamboo and aerated concrete" (Redahan, 2012).

The choice of building structures is predominantly driven by safety, durability and cost, but designs for the house itself are driven by architectural aspirations. Aesthetics and innovation, as well as the use of alternative, unique materials combine to play important roles in the industry's effort to appeal to a new audience.

While design variety is common in both floating and amphibious housing, the fundamental techniques used for flotation are similar. As Figure 3 illustrates, the Formosa House by Baca Architects appears to be a regular, static home in non-flood conditions. But instead of permanently elevating the whole house one floor (approximately two meters) to counter flood risks, sinking the house into the ground reduces the elevation in non-flood conditions, thereby meeting local regulations for maximum height, and floating flood-free as waters rise (Baca Architects, 2015).

The Rijnhaven project in one of Rotterdam's old inner harbours (Figure 2) is part of a larger aspiration of the municipality to create 13,000 new homes, including 5,000 floating homes near the urban centre (Mynett, 2015). A hollow concrete structure is used (Figure 2), formed via a 1-piece mould to prevent cracks. Freeboard of 300 mm is required for a guaranteed safety of the floating structure under the most extreme storm and wave height conditions. The anchoring poles provide horizontal stability, while vertical stability is achieved by lowering the centre of gravity (a heavy base; a light upper structure), by connecting multiple homes together, and by increasing the structure's overall weight (Mynett, 2015).

In the context of these challenges, an interesting concept is the AquaDock in Rotterdam, which is a collaboration between the local university RDM Campus, the municipality of Rotterdam and the Port Authority of Rotterdam (RCI – Rotterdam Climate Initiative, 2009). The collaboration focused on testing floating concepts for future commercial applications (www.rdmcampus.nl). In addition, the Campus hosts the International Centre for Sustainable Construction (www.icdubo.nl): a showroom of alternative building materials.

Potential residents

As the new sector develops, developers, designers, architects and municipal planning officials will need to address the needs of potential residents. Just as we can typify home styles and building techniques, we can also classify likely future residents of both floating and amphibious housing.

A University of Delft survey in 2008 (112 respondents) produced a profile of well-educated, higher income potentially interested floating home buyers aged 25-50 years (SEV, 2008; De Graaf, 2009). With those categories in mind, and based on reviewing the examples in Table 1 and insight from householders' response to the Maasbommel development (see Climate-ADAPT (2015); Figure 4), four types of potential residents emerge (based on Mynett (2015) and Baca Architects, 2019).

Type 1: A focus on 'nature' and landscape

The emphasis here is on available space, striking views, a certain level of privacy and a preference for detached housing options to maximise the feeling of freedom and 'living in nature'. Often these natural spaces are located in floodplains and fluctuations in water levels need to be addressed. There is no specific preference for amphibious, floating or pile constructions, but design preferences tend to lean to modern living with attention to durable and aesthetically pleasing materials.

Type 2: A focus on community

Like Type 1 residents these "communal floaters" also seek a free and peaceful living environment. However, the remote nature element is replaced by a small town feeling, providing comfort, safety and social contacts, as well as communal public spaces. The design and materials used are secondary to feelings of belonging and security.

Type3: A focus on modern urbanism

These urban dwellers are younger – between 18 and 34 years – and high earners. They are looking for the best of both worlds: the advantages of living in the heart of the city, yet are looking for a house that matches their exclusive and supposedly unique lifestyles (see Floating Homes Exclusive Living Concepts, 2013).

Type 4: A focus on active outdoors

More than any of the other three types, the active residents are looking for a way to interact with the water and benefit from its recreational and landscape values. Their lifestyle is tied to the water. Exclusive living, well-regulated access and continuous interaction with 'the outdoors' are the drivers for this group.

But amphibious (Figure 5) or floating living (Figure 6) is a relatively novel concept, and it appears that the market is still trying to decide who is the main target audience. This is reflected in the wide range of prices for floating or amphibious homes, determined by many factors, including location, size, and level of luxury and design, factors not so different from those influencing land-based housing developments.

Challenges and barriers

Despite encouraging market signals, many concerns and obstacles still remain (Climate-ADAPT, 2015). These challenges will need to be addressed definitively to remove potential barriers to market entry (Table 3).

Knowledge and skills

The development of the industry requires dissemination of skills specific to the design and construction of floating and amphibious homes (Baca Architects, 2019). In the early stages of today's market, it is predominantly entrepreneurs who have been attracted to the as yet untested potential of floating architecture. These entrepreneurs are characterised by an innovative capacity and willingness to experiment. But with relatively few fully successful pilot studies, it appears that the established construction companies, funding partners and municipal urban planners have tended to adopt a 'wait-and-see' approach.

Lack of knowledge regarding floating and amphibious homes in many aspects of the development – planning, permitting, feasibility and construction – hinders progress. Most municipal officials are unfamiliar and uncomfortable with floating homes and, as a result, are hesitant to issue building permits (De Graaf, 2009; Climate-ADAPT, 2015). Similarly, environmental assessors will struggle with the evaluation of water quality impacts and ecological risks without the scientific research to support their assessments.

Contractors and developers have limited experience with building on water, resulting in a relatively small group of companies willing to bid for floating development projects. This drives up prices and the limited initial volume of assignments reduces any economies of scale. As the Dutch Climate-ADAPT (2015) project recommended, capacity-building needs to happen at all levels, for example by standardising building codes and regulations for the industry, so that understanding and skill development can proceed more easily and rapidly.

Legislation and regulation

Without comprehensive legislation and standards governing the sector, floating and amphibious developments may suffer from an unfavourable public perception (De Graaf, 2009; Baca Architects, 2019) making potential buyers nervous. Lack of standards and technical guidance will make contractors wary about potential future liability claims.

But some standards have been developing. In Canada British Columbia has standards for floating home construction (State of British Columbia Ministry of Municipal Affairs, 2015), following concern by local municipalities about proper safety measures and accessibility for emergency services. These municipalities also stressed the need for building and design codes, as well as clarification about jurisdiction regarding various mooring sites.

While not a definitive construction code, nor legally binding, the International Association of Certified Home Inspectors in Boulder, Colorado, USA, offers information regarding construction, design and utility connections for floating homes, together with a checklist for floating home owners on safeguarding long-term property durability (InterNACHI, 2015). Other municipalities, such as Portland, Oregon, USA, have developed their own floating home standards (Portland Oregon Office of the City Auditor, 2015). Whilst again not a definitive code, in 2009 the Netherlands Ministry of Housing and Spatial Planning and the Environment issued a technical manual (in Dutch) for guiding construction companies, developers and architects in this field (VROM, 2009). But De Graaf argues for greater specification and standardisation, particularly on "buoyancy, stability, wave movement, freeboard, tilting, safety for collision with ships, fire safety and emergency exits" (De Graaf, 2009, 88). However the regulatory environment appears to remain relatively weak: these examples indicate that floating-specific construction and design codes tend to be delegated to the lowest levels of government authority and in some cases are not legally binding, rather than offering official guidance for the various stakeholders.

Another source of uncertainty is the legal status of floating homes (compared to land-based counterparts, or to boats), mainly caused by the homes' mobility aspect. In land-based units, taxation and mortgages can be unambiguously assigned to a clearly defined and fixed location; this is not so easy with a floating home. So we need careful definitions. Such homes could be said to have the same legal status as a land-based home if "there is an intention to stay on a certain location and the construction is connected to the underground with a mooring construction" (Vermande, 2009, translation Rutger De Graaf). Such a universally applied legal status for the industry and its houses would facilitate the planning and permitting processes and provide a level of transparency and comfort for homeowners and municipalities about taxation and insurance status, and hence facilitate mortgage financing. In the Netherlands, commercial banks and mortgage lenders are already offering floating home-specific insurance and mortgage products. This should build confidence and trust among potential buyers (De Graaf, 2009).

Infrastructure and planning issues

A continuing challenge is connecting floating developments with the existing infrastructure networks and incorporating them in spatial plans for urban centres.

While construction costs for floating homes are comparable to land-based units of comparable size, additional costs are incurred when connecting floating developments to utility grids and sewer systems (De Graaf, 2009). Because of current dependence on access to land-based infrastructure, floating projects are tending to be located near river embankments or in traffic-free inland waters. Extending electricity supply, freshwater supply and waste disposal services to these predominantly non-developed or neglected neighbourhoods requires significant infrastructure investment which adds to overall costs (Foka, 2014).

Furthermore, with floating homes the problem of car parking becomes aggravated: it will always be some distance away. This raises concerns about safety. Related to this are concerns about access for emergency services (De Graaf, 2009; State of British Columbia Ministry of Municipal Affairs, 2015). Indeed there are examples where the lack of nearby parking or large distances to urban transport connections have caused floating development projects to fail (Schuwer, 2007). The Rijnhaven project attempts to overcome this by offering parking on the connecting roads to floating homes (Mynett, 2015).

Finally, from an urban development perspective, it is essential for long-term city-wide spatial plans to include opportunities for floating developments, probably involving amendments to zoning or permitting arrangements (Foka, 2014). An example is the so-called EMAB-location planned by the Dutch Ministry of Spatial Planning in 2005. Conditions for building in the floodplain included the use of innovative construction methods that increase the spatial quality of the area and allowed for additional water storage (De Graaf, 2009; VROM, 2005).

But developers and municipalities need to overcome conflicting interests – or, at best, communication issues - within urban centres about water management planning and spatial planning for housing. Typically, these disciplines are operated through different municipal departments of government and finding common ground is not always an easy process. Conflicting mandates and targets can slow down the development process.

Technology and scale

Despite rapid advancement of research into alternatives, there is no consensus yet within the industry on preferred materials, nor the preferred construction method for floating homes.

Part of the challenge stems from the differences in aquatic environments. Riverbanks on smaller inland rivers will present different challenges to, for example, refurbished inner harbours or flooded polders. Part of the challenge in artificial lakes and flooded polders is the required water depth: approximately 1.5 metres is the minimum to enable the floating home to move safely up and down with the tide (if applicable) or to rise up and down with high water conditions during flood events (De Graaf, 2009). But polder waters, for example, are liable to be shallow – 1.00-1.50 metres – requiring there an amphibious or alternative lighter material approach. Other technical challenges remain, particularly on how to integrate the best practices of current floating housing technologies into an optimal model that provides the desired level of safety, sustainability and cost-effectiveness.

Further technical concerns relate to the scaling up of floating developments. For example, we do now know how many housing units can be safely interconnected to create a large-scale floating neighbourhood (Foka, 2014) and the scale economies this brings (Baca Architects, 2019). With regards to quality of life issues, the lack of public, recreational space is cited as a limiting factor to such scaling up (De Graaf, 2009). More research is required into floating utility units and the connectivity of homes and public infrastructure on the water, and the concept of floating utility units in particular advances the feasibility of a self-sustaining, large-scale floating community (Seasteading Institute, 2015).

Environment and ecology

The environmental impacts on the aquatic environment as a result of floating homes also require more research, particularly the potential impacts when floating structures significantly reduce incoming sunlight (Foka, 2014). Concerns over shading can be particularly constraining in the permitting process.

Environmental assessments may become a standard requirement for developers of floating communities. The USA has particularly stringent guidelines and has traditionally adopted a "better to be safe sorry" approach to obstructions of incoming sunlight as a result of permanent structures on the water. While almost exclusively for non-residential structures, for example piers or jetties, the U.S. National Oceanic and Atmospheric Administration has issued a Best Practices Manual for the management of small docks and piers (NOAA, 2005).This addresses a variety of concerns, such as damage to vegetation, orientation towards the incoming sunlight, materials used, construction methods, but also potential wave impacts and disturbance of benthic ecosystems (NOAA, 2005).

There are, however, already some useful results. The floating housing development in the Harnaschpolder in Delft, the Netherlands, was used for a study of water quality impacts, focusing specifically on the correlation between floating houses and dissolved oxygen levels, which can negatively impact biodiversity and overall water quality (Foka, 2014). The results indicated that floating housing has limited impact on the water quality compared to non-shaded water plots. Dissolved oxygen levels were reduced by 10% as a result of shading, but only in the upper layers of the water and not at deeper layers underneath the structures. Moreover the wind tunnelling effect - with floating houses connected closely together – increases turbulence and hence water mixing, reducing the adverse impact on dissolved oxygen levels compared to open water (Foka, 2014).

Public perception, pricing and investment

For the market for floating and amphibious homes to develop, potential consumers and the general public will need to embrace the merits of floating locations and overcome any reservations about permanently living on water.

But when faced with a life decision, such as purchasing a home, the majority of people will tend to be risk-averse. Concerns about safety will deter some – families with small children or non-swimmers – as will concerns about accessibility for the elderly or physically handicapped and for emergency services (De Graaf, 2009).

Too much uncertainty about the potential benefits of a floating home will deter many, until full transparency and a more universal consensus about floating architecture can penetrate the market. Financial factors also come into play (Mynett, 2015), including the availability of mortgage funding, the resale values of the house, and any maintenance costs that are atypical compared to land-based living. Social considerations include the safety of new floating neighbourhoods in former industrial areas and, again, access to public space (De Graaf, 2009).

In terms of pricing, the luxury designs of Dutch Docklands in Florida U.S.A. may imply that living in a floating home is reserved for the affluent and the owner of several properties. However, as with land-based real estate, the purchaser pays for both luxury and for location: both drive prices up to the multiple million US dollar range on private Maule Lake, Miami (Bojanski, 2014).

In contrast, in other locations the low value of floodplain land may make floating developments less expensive than elsewhere (Coutts, 2019). The prices in the Vancouver area have varied from the relatively affordable US$100,000 for a small c. 60m^2 detached house to the more comfortable multiple bedroom examples in the $425,000 - $ 625,000 range. But there can be extra costs, because some municipalities or privately-owned marinas may charge significant “mooring fees” (Van Evra, 2012).

In the Netherlands, where residents are perhaps historically more comfortable with direct proximity to the water, floating homes have been received enthusiastically by potential buyers and some at least appear reasonably priced. In 2006, over 380 applications were received for the first 37 water plots in Yburg’s floating community in Amsterdam at €116,000 to €142,000 each (SEV, 2008; De Graaf, 2009; Municipality of Amsterdam, 2012). Again, prices for 26 amphibious houses in the Maasbommel community (also in the Netherlands) started at €310,000 (Lee, 2007; Climate-ADAPT, 2015).

However, limited research is available on price differentials between comparable land-based and existing floating homes. A 2004 survey in the Netherlands revealed that floating homes tend to be 8-16% more expensive than their land-based counterparts (Bervaes and Vreke, 2004), probably reflecting the costs of connecting to on-land utilities (de Graaf, 2009). In the Maasbommel project (Climate-ADAPT, 2015) the sale prices for its houses was 44% above the then Netherlands all-homes average.

Finally, the Seasteding Institute and Delta Sync conducted a Contingent Valuation study measuring willingness to pay for self-sustainable floating cities. The results indicated that of those affording a floating city residence approximately half preferred a range of $500-$600/ft^2 (c. $5,000 - $6,000/m^2) representing the lower end of the offered willingness to pay scale (Seasteding Institute, 2015).

A final constraint may be that all developers and investors almost always have alternatives for their residential developments. Without confidence in the relevant developmental and planning processes (Hurlimann and March, 2012), investors may be hesitant about an untested market (Climate-ADAPT, 2015). Driven by profitability, developers seek a pre-determined rate of return on their investments and if the risks are lower and the potential payoffs higher in the “normal” residential market, they may prefer that option, rather than take chances on floating projects.

Conclusions

This review shows the floating architecture market has significant potential, and that the combination of population pressures and climate change creating larger areas at risk from flooding may well promote the adoption of all available urban adaptation measures, including floating and amphibious homes.

Globally, urban centres in developed economies are looking for redevelopment opportunities that provide additional housing, add recreational and aesthetic value to the city, and preserve or increase the city’s water storage capacity and urban resilience. Old city harbours and related industrial areas that have fallen into economic decline are typically very suitable for floating developments and are where the potential for landscape enhancement is often greatest. Those are areas where, surely, innovation is required. The development of floating homes is one such innovation that needs to be considered.

However, today floating domestic housing is still a niche market, driven by architectural novelty, and far from becoming a mainstream response to flood risk. There is no prototype customer, nor is there agreement on building types and standards. Decisions about permits are predominantly made at the local planning level with a degree of variation that is unhelpful for the public's understanding of what is practicable. Material usage and preferred construction methods also present a wide variety of options and challenges. The antidote to this level of uncertainty is the possibility to introduce the innovating permittings of new materials, designs and methods to those who are willing to experiment. The aims are ambitious, but the key players are still relatively few.

In terms of adaptation to likely increased future flooding, however, this measure could add another option for those seeking sustainable flood risk management and the potential for significant landscape and environmental enhancement. No doubt there are serious challenges, and initial public attitudes may be antagonistic. But in crowded countries in a crowded world this is one way whereby we could avoid the unwise 'sterilisation' of floodplains and similar areas if we were to forbid all development there (Coutts, 2019). Floating homes are not intended to replace existing flood risk management policy measures, but complement those efforts and in the interests of exploring a portfolio of sensible and landscape enhancing responses to what is inevitably a complex and uncertain picture of possible future climate change.

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Table 1.

The developments reviewed for this paper. They were chosen for their character and interest, within developed countries, rather than as some representative sample.

Project or Company Name	***Project or Company City***	***Project Country***	***Comment***
1. Baca Architects	London	United Kingdom	Amphibious & floating designs; Redevelopment in inner city harbours
2. Crown in the Royal Docks	London	United Kingdom	Redevelopment in inner city harbours
3. Deltasync	Rotterdam	The Netherlands	Leading specialist for floating urbanisation
4. EcoFloating Homes	Ware, Hertfordshire	United Kingdom	Private sector projects; Steel–wood structures
5. Floatec	Various	Spain / The Netherlands	AquaDock – Floating greenhouse; Floating infrastructure
6. Floating Life	Almere	The Netherlands	10-Year pilot sustainable floating development
7. Floating Pavillion	Rotterdam	The Netherlands	Exhibition space; Climate adaptation; Urban harbour
8. Hafencity	Hamburg	Germany	Redevelopment of inner city harbours
9. Harnaschpolder	Delft	The Netherlands	Residential development; Dutch polder location
10. IBA Dock	Hamburg	Germany	Floating office complex
11. Kalasatama	Helsinki	Finland	Redevelopment inner city harbours
12. Rijnhaven	Rotterdam	The Netherlands	Redevelopment inner city harbours
13. Suburbiton Filter Beds	Kingston-Upon-Thames	United Kingdom	Floating pontoon base; Environmental challenges
14. The Floating City Project	San Francisco, CA	USA	Seasteding Institute; Floating cities in open waters
15. Waterbuurt Yburg	Amsterdam	The Netherlands	New development within city limits; Artificial Islands

16. Waterstudio	Rijswijk	The Netherlands	Leading specialist of floating urbanisation; Large-scale projects (resort, apartment complex)
17. Maasbommel amphibious and floating houses	Nijmegen	The Netherlands	A well-known example of 32 amphibious and 14 floating houses developed in 2005

Table 2.

A non-exclusive list includes the following conditions, unique to floating development (adapted from Stopp and Strangfeld, 2010; Ambica and Venkatraman, 2015))

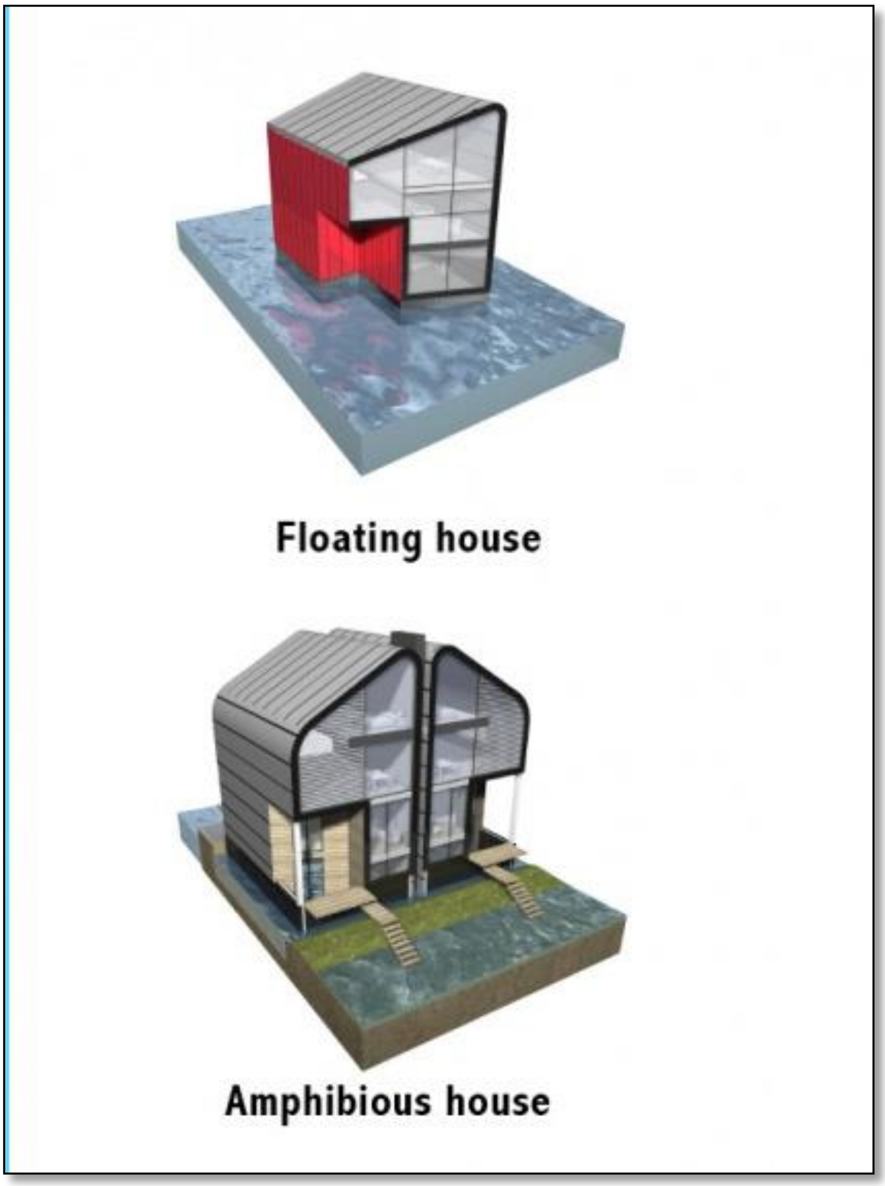
- Wave resistance
- Currents
- Water climate (temperature, composition, currents)
- Salinity
- Acidity (measured in pH-values)
- Solar Radiation
- Wind sheer
- Floating stability
- Seasonal fluctuations (water vs ice)
- Humidity
- Other non-structural challenges
    - Waste disposal
    - Water / Energy supply (centralised or decentralised)
    - Compliance with environmental regulations
    - Compliance with building guidelines

Table 3.
Some obstacles to floating urban developments

Knowledge and Skills
Regulation and Legislation
Exploitation and Economy
Planning and Design
Technology
Environment and Ecology
Public Perception

Source: adapted from De Graaf, 2009

Figure 1. Floating and amphibious Design Models (Source: Baca Architects, 2015)



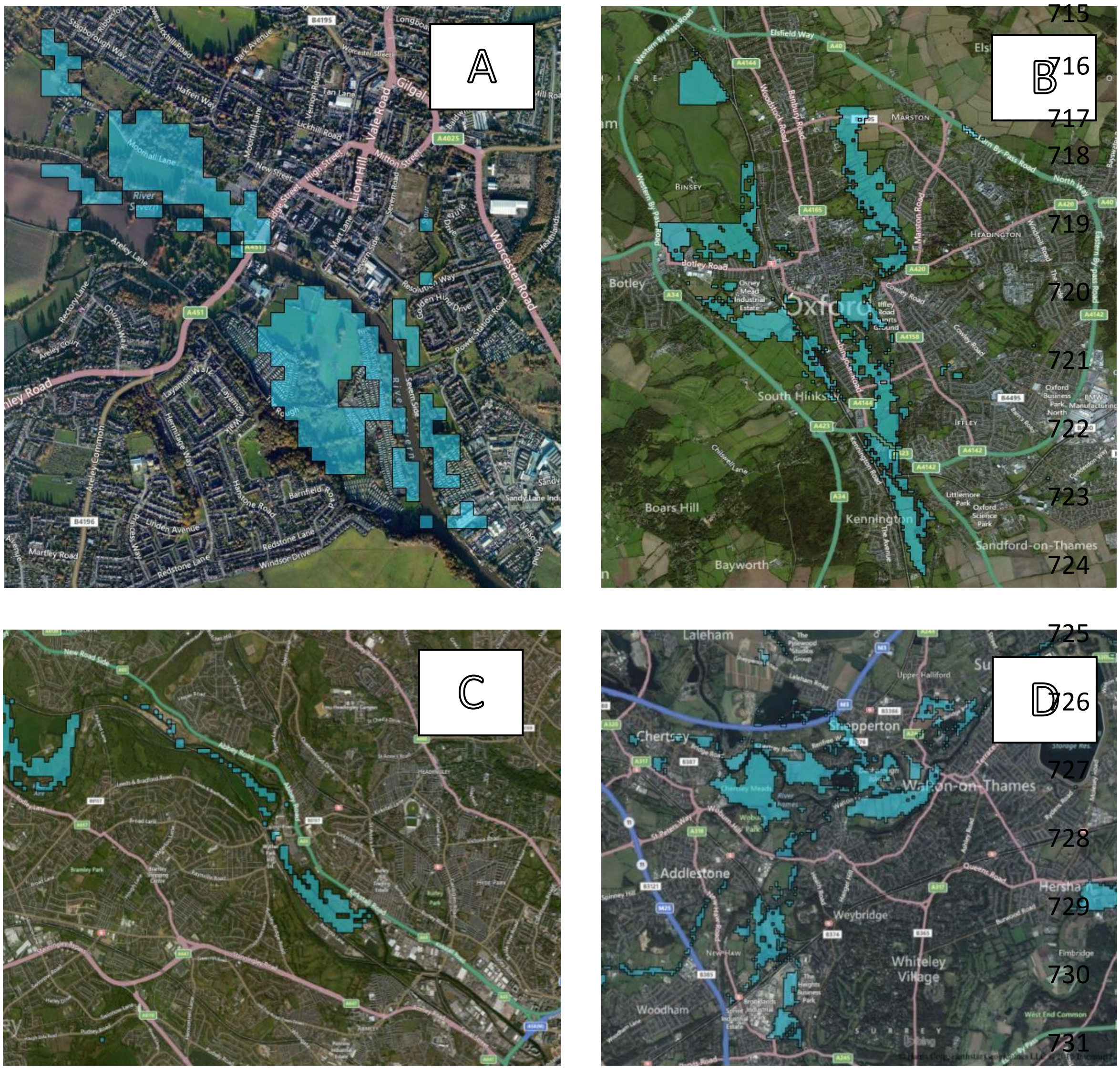
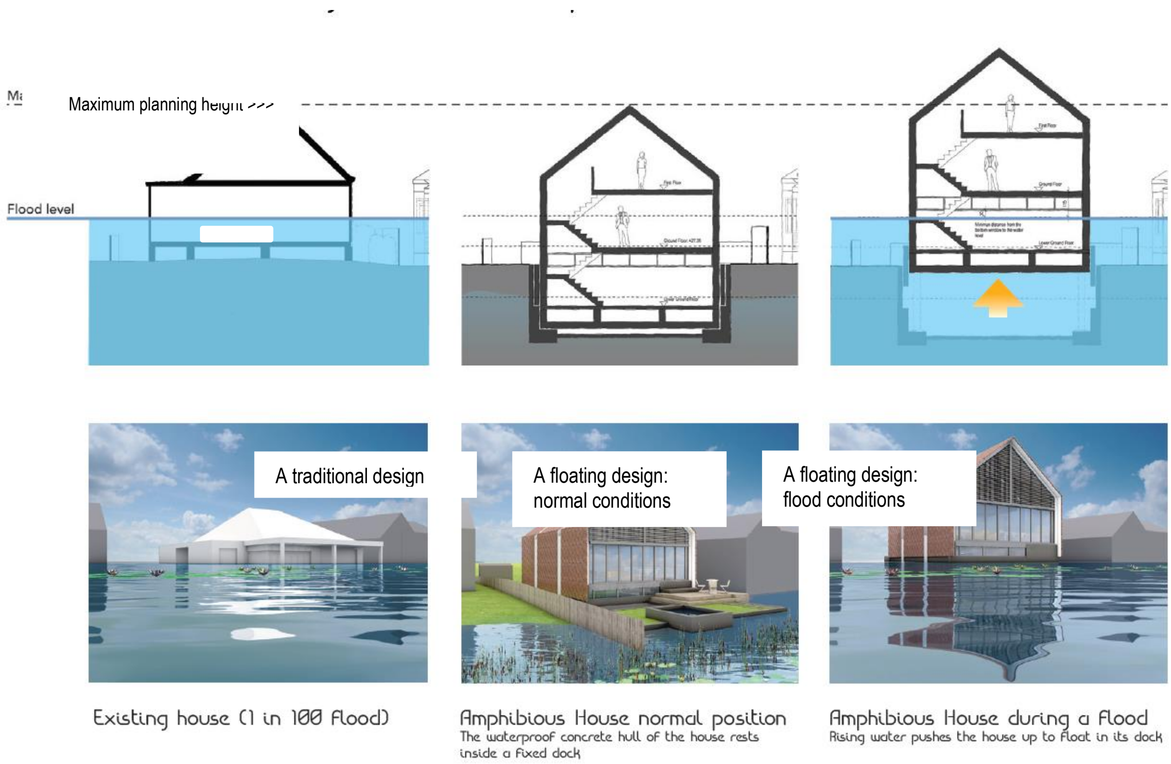


Figure 2. Possible UK locations for floating or amphibious home developments in Stourport (A), Oxford (B), west Leeds (C) and west London (D).



Source: Baca Architects, baca.uk.com

Figure 3: One possible technology for amphibious floating houses in floodplains

Figure 4. Floating houses at Maasbommel, The Netherlands

Figure 5. Amphibious house (left) in Marlow, UK, adjacent to a traditional fixed bungalow (right)

Figure 6. The ‘Chichester’ house developed by Baca Architects (Photo: Mark Junak)