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Toward autonomous floating architecture

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Abstract:
This study examines trends in floating architecture based on literature and 18 exemplary projects. 72% of the analysed structures are planned or built for open-sea conditions, highlighting the ambition of floating architecture to address climate change and the expansion of urbanisation at sea. The analysis covers three categories: individual floating objects (A), divided into housing/collective housing and other uses; floating complexes (B); and floating cities (C). Three aspects are evaluated – function, form, and sustainable solutions – to determine the level of autonomy in floating structures. This autonomy is defined at the building scale, distinguishing autonomous installations and sustainable structures, and at the urban scale, including independence from land, mixed-use programs, food production, and sustainable transport. Floating architecture is composed mainly of low-rise, compact forms that adopt modular systems to improve energy efficiency and enable extension and reuse. Platform geometries range from rectangular to circular, polygonal, or organic, with arrangements mainly radial, but also concentric, branching, or linear. This demonstrates the design flexibility of floating structures while simultaneously supporting a wide range of sustainable solutions. However, fully autonomous installations are present in only 33% of cases, confirming that achieving full autonomy – linking both the building and urban scales – remains challenging.

Keywords:
floating architecture, floating city, autonomous architecture, sustainability, floating building life cycle

1. Introduction

In the context of climate change and rising sea levels, floating architecture is becoming an increasingly relevant subject of research in relation to new models of habitation. They arise in response to challenges affecting coastal areas, such as the flood threat [1-3] and the shortage of land for urban expansion [4]. A new approach to coastal urban development, connected with the blue economy, is also driven by energy insecurity, water and food deficits [5]. Furthermore, floating architecture is related to the renewal of urban landscapes [6] and can serve as attractions, offering unique experiences for the surrounding community [7]. It positions floating architecture as a new form of leisure opportunities.

Floating architecture, defined as floating, amphibious, or floatable structures on water [8], can serve as a single building, a complex of buildings, or even an entire city. The article aims to analyse the characteristics of floating architecture through a literature review and the examination of 18 representative structures, focusing on function, form, and sustainable solutions, to assess the level of autonomy in floating structures.

The article seeks to present current trends and identify the potential for future design strategies, with particular emphasis on the development of autonomous solutions at both the building and urban scales. At the building scale, this includes strategies across the entire life cycle of floating structures, while at the metropolitan scale, it involves the challenges faced by emerging floating cities.

1.1. Potential and scope of floating architecture

In the literature, the potential of floating architecture is explored across various regions, emphasising that it is not only a futuristic concept but also a traditional way of living that has been practised for centuries, as seen in Vietnam. Nguyen's research aims to draw on conventional practices and innovative approaches to the development of floating architecture in other countries, serving as a motivation for developing design guidelines for sustainable floating houses and settlements in Vietnam. It focuses on safety, stability, and permanent living on water while addressing social, economic, and environmental issues [9] (Fig. 1, I). Vernacular building designs, such as the Bahay Kubo in the Philippines, can also serve as a reference point for new solutions. This approach was explored in the overpopulated and flood-prone Pampanga Delta, where a prototype house intended for expansion onto vacant former rice fields was evaluated as part of a participatory design process [10] (Fig. 1, II).

In relation to newly designed floating developments, the choice of a suitable location is crucial, serving as a key element of an adaptation strategy for areas threatened by flooding and rising sea levels. In this context, a methodological approach has been proposed for the multicriteria evaluation of potential locations in the Tiber Delta, Italy. The study considered climate-resilient housing solutions for populations living in unauthorised, substandard housing in high-flood-risk zones [4] (Fig. 1, III). An important location for the development of floating architecture, as an innovative urban response to the climate challenges and housing needs of contemporary cities, includes inner-city harbours and former industrial areas, contributing to urban landscape renewal. Such adaptations, highlighting the opportunities for urban landscape regeneration and the recreational and aesthetic value they bring to the city, have been examined primarily in reference to floating architecture in the Netherlands and the United Kingdom [6] (Fig. 1, IV, V).

The literature also addresses the evaluation of floating architecture, as innovative ways of living on water are often analysed in the context of land scarcity in metropolitan coastal cities. Studies show that floating houses demonstrate competitiveness and opportunities in terms of customer appeal, environmental sustainability, and support for local tourism. This was analysed using the "function analysis system technique" (FAST) diagram, which enabled a comparison between traditional and floating houses based on survey data from Hong Kong [11]. Another approach to evaluating floating structures concerns the impact of projects on communities, particularly in the context of the effectiveness of amphibious housing as a sustainable, flood-resilient solution. This assessment varies depending on local social, economic, and ecological conditions, which can be evaluated using indicators from the Baseline Resilience Indicators for Communities (BRIC), as demonstrated in comparative analyses of floating architecture in the Netherlands, Thailand, and Jamaica [12] (Fig. 1, IV, VI, VII).

This literature review articles present specific solutions for selected locations (Fig. 1, I–VIII). In contrast, this article focuses on cases presented on architectural portals, concentrating on the general characteristics of floating architecture and the range of sustainable and autonomous solutions. The locations of the case studies analysed are also shown in Fig. 1 (symbols correspond to Table 1) to emphasise the global scope of floating architecture development.

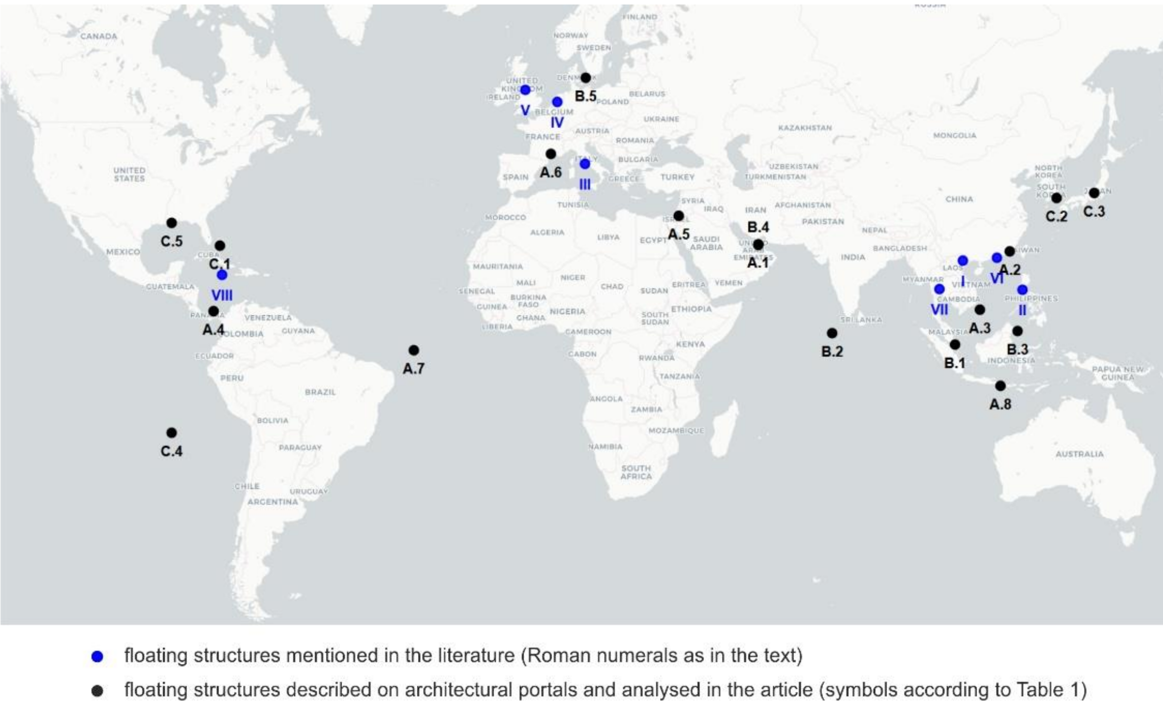

Fig. 1. Approximate locations of floating structures mentioned in the literature and those described on architectural portals and analysed in the article (in cases where no specific location data is available, the location refers to the economic zone of the respective country). Source: own study

1.2. Building life cycle and autonomy in floating architecture at the building scale

The building life cycle can be described by several stages: locality, architectural design, structural systems, material selection, building construction, usage and maintenance, reuse/regain/recycle, and waste disposal [13]. Considering that buildings account for 40% of the world's annual energy consumption, assessing their energy performance is a crucial issue that can be addressed through Whole-Building Life Cycle Assessment (WBLCA) [13,14]. Floating architecture can be considered in analogous phases: pre-design, design, production, construction, use, extension (which can be crucial for the development of modular units), demolition, and reuse or recycling. The phases of pre-design, design, material production, and construction methods directly impact the future usability and potential for reuse of a floating building (Fig. 2). In the long-term use stage, the concept of autonomy becomes particularly relevant. An autonomous building is defined as a structure capable of operating independently from external infrastructure, including energy, water, sewage, and communication networks, and, in extreme cases, even without access to public roads [15]. Similarly, this definition can be applied to a floating building.

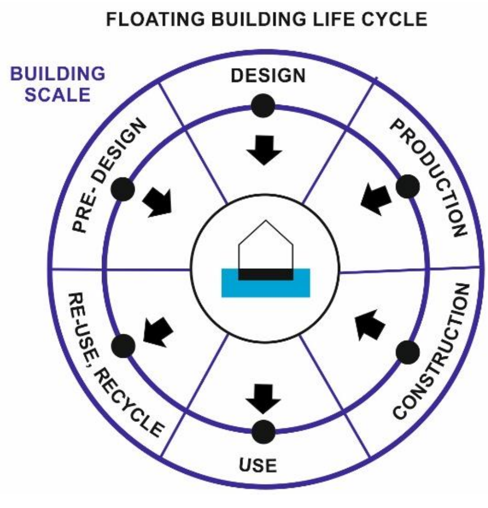

Fig. 2. Floating building life cycle – building scale. Source: own study

In the context of developing floating architecture at the pre-design stage, site selection, the structure's scale, and related mobility are key factors, while also highlighting opportunities for future floating structures and the degree of continuity between the existing coastal typology and its envisioned floating counterpart [16]. The pre-design analysis influences the design and type of installations, which, in turn, determine the level of building autonomy during the use phase. In the context of renewable energy for floating architecture, wave energy and sea power are key, as they are pollution-free and renewable. Technologies based on Ocean Thermal Energy Conversion (OTEC) are currently used in commercial projects. Alternative energy sources may also include offshore wind and photovoltaic (PV) cells [17]. Sustainable water management, including drinking water supply, grey water reuse, rainwater harvesting, as well as zero-waste systems, sewage treatment, and biomass energy, should also be considered [18].

Moreover, during the design phase, in reference to construction, sustainable, easy-to-recycle, and suitable construction materials are crucial. Additionally, the stability and seakeeping capabilities of floating platforms are critical to ensure the safety and comfort of residents. In this context, two types of floating structures can be distinguished: semi-floating structures, which are anchored to the seabed, and full-floating structures, which are not fixed to the ground [17]. For the first type – immense floating structures (VLFS) – it is necessary to account for various structural loads to ensure stability and safety, as well as adequate seakeeping. Key factors include dead load, hydrostatic pressure including buoyancy, live load, unusual loads such as ship collisions, soil weight affecting mooring systems like dolphins, wind pressure, wave impacts including swell, seismic effects including dynamic water pressure, temperature fluctuations, water currents, tidal changes, seabed movements, directional shifts, snow load, tsunamis, storm surges, transport waves, seaquakes, braking forces, erection loads, drifting ice and ice pressure, impacts from floating objects, and the effects of marine growth such as corrosion and surface friction. All these factors must be carefully considered to ensure the durability, stability, and safety of floating structures in dynamic marine environments [19].

Research has shown that hexagonal platforms, compared to triangular, square, octagonal, and dodecagonal options, offer superior stability and performance in various water conditions. Moreover, modularity is regarded as a key principle, alongside seakeeping, zoning, circulation, and feasibility, that facilitates construction and enables potential reuse [2]. The advantages of modular arrangements have also been demonstrated in the case of floating surface leisure platforms [20]. Moreover, the compact form is highlighted in the literature as a key feature for energy efficiency [21], and by analogy, it also applies to floating buildings. In reference to the construction phase, prototyping is worth mentioning, as it provides an effective way to test solutions before full-scale implementation, thereby optimising costs and impact [10]. Economic considerations are crucial for achieving feasibility, which is essential for any innovation – whether in floating architecture or other fields, such as movement and dynamic architecture [22], media architecture [23], or other concepts that could also be applied to floating structures. It is worth noting that as technology advances, the range of characteristics associated with floating architecture may also expand.

In this article, as a result of this study review, the case studies are examined with respect to the scope of sustainable solutions at the building scale, taking into account two main fields: autonomous installations and sustainable structures (Fig. 3).

1.3. *Challenges of autonomous floating architecture at the urban scale*

Growing pro-ecological awareness has led to the development of autonomous architecture, not only on land but also in the realm of floating architecture of various scales, ranging from single structures to entire floating cities, moving to the urban scale (Fig. 4 left).

The direction of water urbanism development toward sustainability and resilience is discussed by considering strategies and methods related to Biomimetics, including the Problem-Based Approach, which inspires solutions from nature, and the Solution-Based Approach, which draws on biological knowledge to inform architectural design. It is crucial to integrate multiple factors from the fields of ecology and climate change at the pre-design stage [24]. A key aspect here is the integration of floating cities with marine ecosystems, which is crucial for minimising their impact, protecting and enhancing biodiversity, and reducing water pollution [6,16]. This approach can also reinforce the blue economy by enabling the sustainable use of ocean resources for energy, food, and clean water production [5]. Similarly, food production can be supported through urban farming [25], which aligns with the development of a green economy [26].

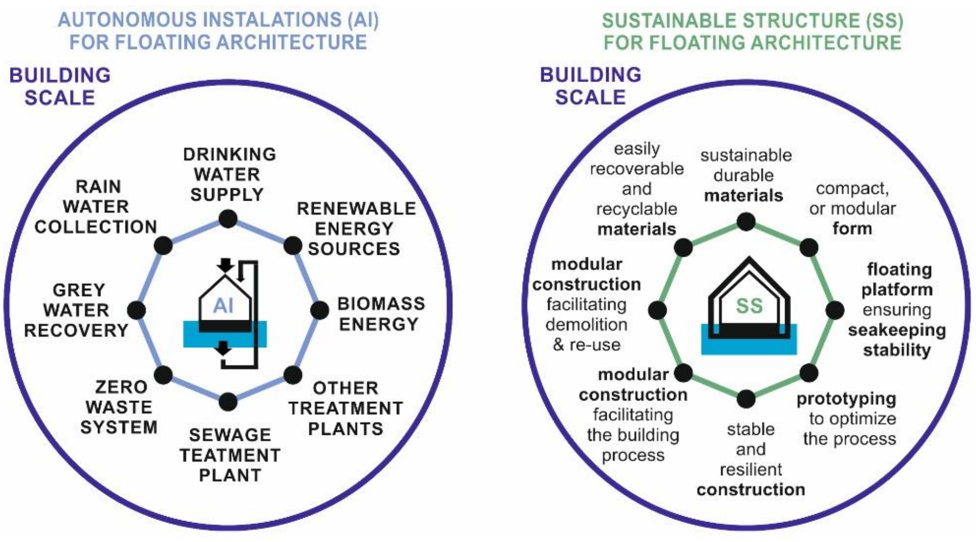

Fig. 3. Autonomous Installations (AI) and Sustainable Structure (SS) – main characteristics describing floating building autonomy at the building scale. Source: own study

Moreover, the anatomy of floating cities demands mixed-use spaces, necessary to provide not only habitable spaces for residents but also a comprehensive range of services, social infrastructure, and areas dedicated to work and recreation [2]. This requires a well-planned strategy that addresses the unique challenges of floating urban environments [27]. Moreover, analogously to traditional cities, a compact plan can serve as a guideline for a floating city, due to the concept of a compact city, as it enhances resilience and sustainable mobility [28]. In addition, platform modularity allows diverse configurations and facilitates future development through its expandable design and potential for reconfiguration, providing flexibility and adaptability to changing conditions [2].

Adaptive and resilient design is often emphasised in the context of floating cities, enabling them to respond to changing environmental conditions through systems for flood protection, climate regulation, and energy harvesting. It is moving them towards becoming smart cities [29]. Floating cities combine innovative, eco-friendly, self-powered solutions, offering sustainable living spaces that respond to climate change, particularly rising water levels [30]. Moreover, future autonomous floating cities, like land-based cities [31], should address all complex user needs, which have already been analysed by Maslow [32]. It is worth noting that floating architecture also offers excellent views and creates ideal conditions for water sports, which positively impact social welfare [33]. Indeed, creating a floating habitable environment can not only offer a range of essential benefits but also influence people's lifestyles and social well-being [17].

Summing up the literature review, the autonomy of floating architecture can be considered not only at the building scale but also at the broader human scale, including the urban scale. The concept of developing such urban environments is evolving in response to emerging technologies and innovations aimed at creating synergy with nature and users (Fig. 4, left), presenting a wide range of challenges for these potentially autonomous settlements (Fig. 4, right).

They should fulfil many human needs, starting with basic ones such as water, food, and physiological requirements. Some of these can be met through autonomous installations mentioned in the previous chapter, which, when combined with a sustainable structure, provide shelter, comfort, and safety at the building scale. Food, in turn, could be produced through urban farming. Other needs – such as stability, belonging, esteem, diversity, accessibility, sustainability, and others – are addressed at the metropolitan scale.

In summary, the human scale connects both levels of autonomy in floating architecture – at the building and urban scales – both of which shape human experience and highlight the complex challenges of designing floating cities, as discussed in this chapter (Fig. 4, right). These aspects will be examined in the analysed cases.

2. Methods

This article aims to present trends and key features of floating structures and to analyse the relationships between their characteristics and the proposed solution categories. Three categories were considered: individual floating objects (A), floating complexes (B), and floating cities (C) (Fig. 5).

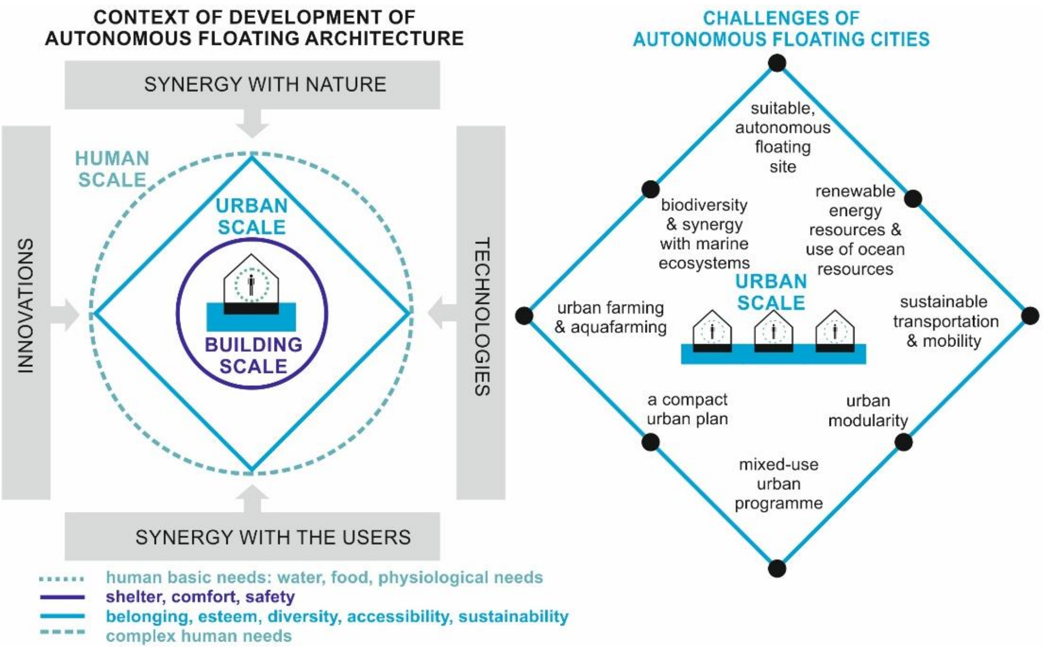

Fig. 4. Context of development of autonomous floating architecture concerning human needs at the urban and building scale (left) and challenges of autonomous floating cities at the urban scale (right). Source: own study

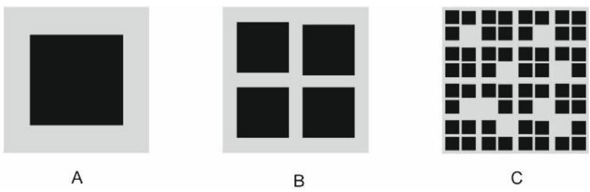

Fig. 5. Three categories of floating structures: A: individual floating objects, B: floating complexes, and C: floating cities; schematic diagram illustrating different scales. Source: own study

For the analysis, 18 examples of floating structures were selected, characterised by innovative design and published on international architectural portals, with 4–5 examples in each category or subcategory where it was distinguished. It was also crucial that the selected buildings were designed for diverse locations (Fig. 1). Each category was assigned a sequential number. In category A, the functions of the objects were distinguished, taking into account floating objects serving as housing and collective housing (A.1–A.4), and floating objects reserved for other functions (A.5–A.8). Category B consists of five examples of complexes combining living units with additional functions (B.1–B.5). Category C includes five examples of floating cities (C.1–C.5).

The research was conducted using data published on architectural portals such as:

- ArchDaily (https://www.archdaily.com/),
- DesignBoom (https://www.designboom.com/),
- Archello (https://archello.com/),
- and Inhabitat (https://inhabitat.com/),

taking into account descriptions, photographs, and visualisations of 18 selected floating architecture projects. The study covers three groups of characteristics: function, form, and sustainable solutions, which were analysed and presented in comparative tabular form. Function was analysed by structure scale, including area or dimensions, expected number of users, and brief program description (Table 2). Form was characterised synthetically, examining building height (low-rise (L), high-rise (H)) and platform and building shape (Table 3). Platform shape characteristics included rectangle (R), triangle (T), polygonal (P), circular / elliptical / rounded forms (C), and organic shapes (O) (Fig. 6, Table 4).

In terms of building form, compact (Cm) and biophilic/organic (B) characteristics were distinguished, as well as forms suitable for multiplication (Ml) (Table 4). The spatial composition was analysed, taking into account the modular (M), concentric (Cn), radial (Rd), branching (Br), honeycomb (H), island layout (Is), and linear (Li) arrangements (Fig. 7, Table 4).

Sustainable solutions were analysed at the building scale (BS) and the urban scale (US). Additional solutions outside these categories were also included. At the BS level, two groups were distinguished: Sustainable Structures (SS, Fig. 4, right) and Autonomous Installations (AI, Fig. 4, left). SS was characterised by form (Fr) – fulfilled through compact or modular configurations – and by the use of sustainable materials (Mt). AI was analysed according to the scope of solutions, considering low (Lo), high (Hi), and full (F) levels of installation autonomy. At the urban scale (US), additional autonomy-enhancing solutions (AA) were also examined, and their presence was noted when at least one such solution was identified (Fig. 5, right).

Finally, the literature review and case study analysis were used to summarise the life cycle of floating architecture, with a focus on developing autonomous structures based on sustainable solutions (Table 6). Moreover, the synthesis of the concepts of 'autonomy' and 'floating architecture' is presented in a graphic model that considers the building scale, illustrating the main relationships between the 'building life cycle' and other factors at the urban scale that impact autonomous floating architecture (Fig. 8).

3. Materials

The research is based on literature studies and the analysis of 18 floating structures. The list of selected floating structures, including their name, author, location, and year of design or completion, is presented in Table 1, organised by structure category and scale, as described in the Methods chapter. Additionally, their locations are shown on the map (Fig. 1) using the symbols for the floating structures from Table 1.

56% of the projects (10/18) represent conceptual designs (D-design), which confirms that floating architecture largely remains at the conceptual stage. 22% (4/18) can be classified as prototypes (P-prototype), and another 22% (4/18) are already realisations (R-realisation), indicating the tangible potential of turning visions into reality (Table 1). In terms of location, 28% (4/18) of the projects are situated close to the coastline (C – close to the coastline), while the dominant group, as much as 72% (14/18), are planned or implemented in the open sea (O – open sea/ocean) (Table 1). The selected examples are characterised by innovative solutions in form and function and thus provide an interesting basis for consideration of the potential development of floating architecture.

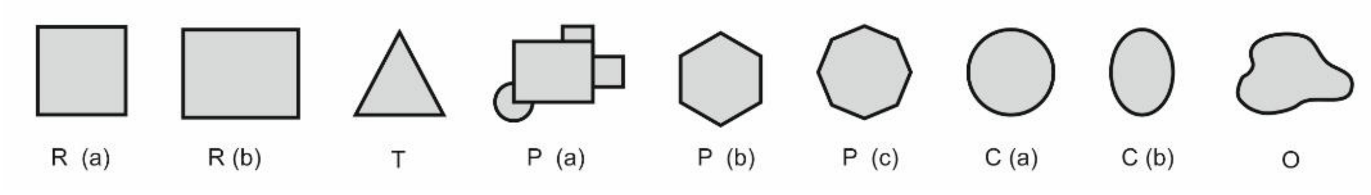

Fig. 6. Typical platform shapes of floating architecture: R – rectangle (a, b), T – triangle (T), P – polygonal (a, b, c, and others), C – circular (a), elliptical (b), and other rounded forms, and O – organic shapes. Source: own study

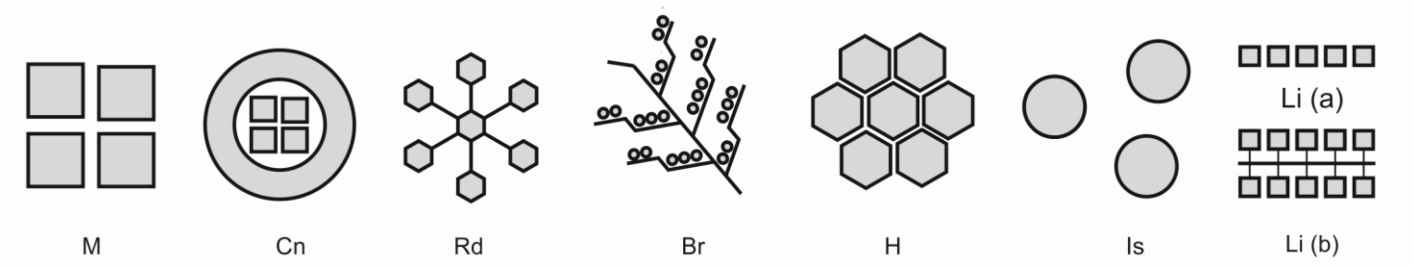

Fig. 7. Typical spatial composition of floating structures: M – modular form, considering: Cn – concentric, Rd – radial, Br – branching, H – honeycomb, Is – island layout, Li – linear arrangements: single-line (a), double-line (b). Source: own study

Table 1. Overview of analyzed floating structures (excerpt). Source: own study

Ct/S	Name	Author	Location / Distance from the cost	Date	D	P	R	C	O
A	Floating object (housing / collective housing)								
A.1	The Floating Seahorse	Kleindienst	“Sweden” island, Dubai / 4 km	2016		x			x
A.2	hi sea floating hotel	balance design (Dong Xinmeng)	Dongshan Island, Zhangzhou City, Southern Fujian Province, China / 500 m	2020			x		x
A.3	Habitat WaterNest	EcoFloLife	Flexible: along river courses, lakes, bays, atolls and sea areas with calm waters	ongoing			x		x
A.4	Seapods	Ocean Builders	Panama's Linton Bay Marina, Panama / about 1.7 km	2019 / 2023 (100 pods)		x			x
	A.1- A.4 together				0	2	2	0	4
A	Floating object (other function than housing / collective housing)								
A.5	Yarauvi	Miró Rivera Architects	at the center of the Dead Sea, between Israel and Jordan / 30 km	2020	x				x
A.6	Sea stem	Mathieu Collos	Occitanie region, Montpellier, France / 12 km	2020	x				x
A.7	City of Meriens	Jacques Rougerie	see / oceans	2015 (concept for 2050)	x				x
A.8	Marine Research Centre	Solus4	shore of Kuta Beach, Bali, Indonesia / 100-150 m	2010 concept	x			x	
	A.5 – A.8 together				4	0	0	0	4
B	Floating complex								
B.1	Ocean community	Wojciech Morsztyn	Singapore /800m		x				x
B.2	Infinite Maldives	Shigeru Ban	Maldives, Male Atoll 1 Island	2023	x			x	
B.3	Currents for Currents	Deo Alam and 228 Design Studio	Mindanao, Sitangkai island, province of Tawi-Tawi, Philippines	2018 (concept for 2050)	x				x
B.4	Kempinski Floating Palace	El Bahrawy Group	Dubai, in the ocean off the coast of Jumeirah Bay Island	ongoing, expected 2026			x		x
B.5	Land on Water	Mast + Fragile, Hubert Rhomberg	Denmark, Copenhagen	2023		x		x	
	B - together				3	1	1	2	3
C	Floating city								
C.1	Blue Estate Island	Blue Estate Group	Caribbean Sea, between Miami, Florida, and the Bahamian Island / 40 km	2020 concept / 2025 expected completion			x		x
C.2	Oceanix city	Bjarke Ingels Group	Busan, South Corea (prototype)	2019 / 2022		x			x
C.3	Dogen City	N-ARK	for the city in Japan	2008 / 2017	x				x
C.4	Lilypad	Vincent Callebaut	oceans	2008 (concept for 2100)	x				x
C.5	NOAH New Orleans Arcology Habitat	e. kevin schopfer	New Orleans, close to the costline	2009	x			x	
	C- together				3	1	1	1	4

Legend: Ct – category symbol, S – structure symbol, D – design, P – prototype, R – realisation, C – close to the coastline, O – open sea / ocean.

4. Results

Table 2 presents the main characteristics in terms of function of the analysed examples of floating architecture. Regarding individual floating units (category A), these are most often floating houses or research centres, which can also provide educational, cultural, and sports functions. Residential units vary in size from (27m² (B.1), 73 m² (A.4, B.3), 219 m² (B.3), 370m² (A.1), (Table 2) and often can be multiplied, and in such cases, these arrangements acquire the characteristics of complexes, consisting of several dozen, hundreds, or even thousands of units (Table 2). These complexes can gain additional recreational functions, such as spas and wellness centres or pools. They can also serve as hotels. As for floating cities, they integrate a wide range of functions, including residential, cultural, educational, recreational, sports, office, healthcare, and others. They also provide green spaces and urban farms to ensure food self-sufficiency. Regarding scale, analysed examples predominantly ranged between 40,000 (C.3, C.5, Table 2) and 50,000 (C.4, Table 2) inhabitants; however, the expansion of these systems with additional modules could support infrastructure for over 2 million residents (C.2, Table 2).

Analysing the form of floating structures, it was observed that they are mainly low-rise buildings (72%), especially in the groups of floating objects for housing or collective housing and floating complexes (100% of cases in each group). However, 28% are high-rise developments, found in the category of floating cities (60%) and floating objects serving as research centres (50%) (Table 3).

Table 2. Floating architecture - main characteristics in terms of function. Source: own study

Ct/S	name	function / programme	area / dimensions	number of users
A				
A.1	The Floating Seahorse	floating house – villa; possibility of multiplication of units	370 m^2	a few
A.2	hi sea floating hotel	small hotel – 3 rooms	591 m^2	a few
A.3	HABITAT WaterNest	floating house or office / lounge bar / restaurant / shop or exhibition; possibility of multiplication of units	no data	a few in one unit
A.4	Seapods	floating house; possibility of multiplication of units	73 m^2 (1000 pods are planned)	a few in one unit (up to aprox. 4000)
A.5	Yarauvi	necropolis	no data	no data
A.6	SEA STEM	research center, permaculture garden, restaurant	no data	no data
A.7	City of Meriens	research center for 7000 people with living areas, cultural, relaxation and sports zones	900 m x 500 m	7000
A.8	Marine Research Centre	research center with living areas, aquatic garden, swimming pool terrace, bar, library, auditorium	2500 m² (0.25 ha)	no data
B				
B.1	Ocean community	4 living units and the docking platform. (8 users: 2 people per unit); 28,000 units are planned	27 m² per unit (together 756,000m² – 75.6 ha)	8 users: 2 people per unit / complex for 224,000
B.2	Infinite Maldives	44 floating villas with private infinity pools + fitness center, spa, and wellness facilities	50,000 m² (5 ha)	aprox. 44x4=176
B.3	Currents for Currents	around 1000 houses with vertical hydroponic gardens	73 m² per floor (aprox. 73x3=219m²) (together aprox. 219,000 m²)	aprox. 1000x4=4000
B.4	Kempinski Floating Palace	hotel with 163-200 rooms with restaurant, bars, a spa, pools with a helipad and 48 buoyant villas with roof terrace, private pool parking for 16 yachts	2300 m² – 2780 m² (0.23 – 0.278 ha)	aprox. 200x2+48x4=400+192=592
B.5	Land on Water	fexible floating complex - floating houses, campsites, saunas	Fexible	A few per unit / aprox. 50 per complex
C				
C.1	Blue Estate Island	floating city with hospitals, schools, restaurants, boutiques, small shops, seafood markets, and a daily fresh farm; community centers and parks, including 4 artificial lagoon pools and a 186 000 m² public garden	1000m x 1500m (less than 100ha)	15,000
C.2	OCEANIX CITY	floating city with mixed-use space for living, working, and recreation, commercial functions; public squares, a market, and centres for spirituality, learning, health, sport, and culture	1 unit – 2ha; 6 units – 75ha (1.3km in diameter); even 18,900 ha (37 km in diameter) and more	1 unit – for 300 residents; 6 units – for 10,000 residents; even for 2,520,000 residents and more
C.3	Dogen City	floating city – smart healthcare city with residential areas, hotels, public facilities, schools, offices, services, hospitals, stadiums, halls, telecommunication stations, security centres, cemeteries & prayer areas, food production facilities, parks	1,58 km in diameter and approx. 4 km in circumference	40,000 (10,000 residents + 30,000 visitors)
C.4	Lilypad	floating city with shopping and entertainment, suspended gardens and aquaculture farms located below the water line	500,000 m² (50 ha)	50,000
C.5	NOAH New Orleans Arcology Habitat	floating city with residential units for 20,000 persons, 3 hotels, 3 casinos, retail space, parking for 8,000 cars, cultural facilities, public works, school system, health care facilities	no data	40,000

Legend: Ct – category symbol, S – structure symbol.

Table 3. Floating architecture - main characteristics in terms of form. Source: own study

Ct/ S	name	number of storeys/height	low rise (L)	high rise (H)	shape of the platform/building
A.1	The Floating Seahorse	2a + 1u	x		rectangle plan
A.2	hi sea floating hotel	1a	x		base rectangle base with extra parts
A.3	Habitat WaterNest	1a	x		spindle-shaped casing
A.4	Seapods	1a (entrance) + 1a (living)	x		circle plan at 3 supports (like a propeller)
	Total no of floating objects (housing/ collective housing)		4	0	
	Total floating objects (housing/ collective housing) (%)		100	0	
A.5	Yarauvi		x		a bowl-shaped, parabolic structure, open to the sky
A.6	Sea stem	30 m above 50 m under sea level		x	dome
A.7	City of Meriens	60 m above 120 m under the sea		x	shape inspired by manta rays
A.8	Marine Research Centre	2a + 3u	x		organic form, eight shape
	Total no of floating objects (other function)		2	2	
	Total floating objects (other function) (%)		50	50	
B.1	Ocean community	2a	x		a circular platform with four wings, with houses placed on rectangular-like platforms
B.2	Infinite Maldives	1-2a	x		liner axis for rectangle houses both sides
B.3	Currents for Currents	3a	x		linear system (units connected with bridges), like the branches of a tree; sail-shaped houses
B.4	Kempinski Floating Palace	villa - 2a; hotel - 4a	x		rectangle shaped boat villas and hotel connected by pontoons; 6 decagons per 8 villas
B.5	Land on Water	1-2a	x		rectangles and polygons based on modules, archetypal form (slope roof)
	Total no of floating complexes		4	0	
	Total floating complexes (%)		100	0	
C.1	Blue Estate Island	more than 42 m above sea level		x	irregular polygon (14 sides)
C.2	Oceanix city	4a	x		multiplication of triangular platforms arranged in circles of 6 around central harbour - like honeycombs
C.3	Dogen City	1-3a+1u	x		circle around and inside different shapes of platform (round, rectangles etc.)
C.4	Lilypad	multi-story complex; under water part as a ballast		x	a circular form inspired by a water lily leaf, magnified 250 times, featuring three marinas and three artificial mountains around a central lagoon; with the possibility of repetition in an island layout
C.5	Noah	multi-story, high-rise complex		x	triangulated floating platform
	Total no of floating cities		2	3	
	Total floating cities (%)		40	60	
	Total no of objects		13	5	
	Total (%)		72	28	

Legend: Ct – category symbol, S – structure symbol, L – low rise, H – high rise, a – above sea level, u – under sea level.

As seen in Table 4, in the case of floating houses, platform shapes were most often rectangular or circular (50% each), while other floating objects, mainly research centres, tended to use circular (50%) or organic platforms, adopting biophilic forms in 50% of cases.

Floating complexes consist mainly of buildings on rectangular platforms (100%) and also on polygonal platforms (40%), following various arrangements – mostly radial (60%), as well as concentric, branching, and linear (40% each), which are particularly popular in the group of floating objects for housing (50%) (Table 4). Floating cities consist of elements primarily based on circular (60%), triangular (40%), and polygonal forms (40%) (Table 4).

The most significant potential for multiplication of elements and modular composition is observed in the category of floating complexes (100%), followed by floating objects for housing or collective housing (75%). This feature was also noted in 40% of floating cities, which were planned on an island-based manner (Table 4). Floating structures follow modular systems in 56% of cases, which facilitates construction and potential expansion. Moreover, 89% of floating buildings are characterised by compact forms (Table 4), which is significant for energy efficiency.

Table 4. Floating architecture – comparison in terms of form. Source: own study

	platform shape					building form			spatial composition						
Ct/ S	R	T	P	C	O	B	Cm	Ml	M	Cn	Rd	H	Br	Li	Is
A.1	x						x	x	x				x	x	
A.2	x						x								
A.3				x			x	x	x	x					
A.4				x			x	x	x					x	x
no	2	0	0	2	0	0	4	3	3	1	0	0	1	2	1
%	50	0	0	50	0	0	100	75	75	25	0	0	25	50	25
A.5				x			x								
A.6				x			x								
A.7					x	x	x								
A.8					x	x	x								
no	0	0	0	2	2	2	4	0	0	0	0	0	0	0	0
%	0	0	0	50	50	50	100	0	0	0	0	0	0	0	0
B.1	x						x	x	x		x				
B.2	x						x	x	x				x	x	
B.3	x		x				x	x	x	x			x	x	
B.4	x						x	x	x		x				
B.5	x		x				x	x	x	x	x	x			
no	5	0	2	0	0	0	5	5	5	2	2	1	2	2	0
%	100	0	40	0	0	0	100	100	100	40	60	20	40	40	0
C.1			x												
C.2		x	x	x			x	x	x	x		x			
C.3	x			x			x			x					
C.4				x		x	x	x	x	x					x
C.5		x													
no	1	2	2	3	0	1	3	2	2	3	0	1	0	0	1
%	20	40	40	60	0	20	60	40	40	60	0	20	0	0	20
To no	8	2	5	8	2	3	16	10	10	6	2	2	3	4	2
To %	44	11	28	44	11	17	89	56	56	33	11	11	17	22	11

Legend: Ct – category symbol, S – structure symbol; platform shape: R – rectangle, T – triangle, P – polygonal, C – circular / elliptical / rounded forms, O – organic; building form: Cm – compact, B – biophilic / organic, Ml – possibility of multiplication; spatial composition: M – modularity, Cn – concentric, R – radial, Br - branching H – honeycomb, Is – island layout, Li – linear; no – number, To – total.

Regarding sustainable solutions, these were present to varying degrees across all types of structures and at different scales (Table 5). At the building scale, in terms of sustainable design, desirable characteristics of form are very often fulfilled (89%), but sustainable materials are mentioned in only 28% of cases, mainly among floating complexes (40%). In terms of autonomous installations, full autonomy is achieved in only 33% of cases, primarily within the group of floating cities (60%) and in floating structures serving functions other than housing, mainly research centres (50%), emphasising the responsible approach to large-scale floating architecture. However, low, high, and complete autonomy of installations is observed in 52% of cases, emphasising their recognised importance. Autonomy in the urban context is present to some extent in 28% of cases, meaning that the majority still depend on land-based systems.

5. Discussion and conclusions

This article examined trends in floating architecture – from single objects to floating complexes and floating cities – in terms of functions, forms, and sustainable solutions, moving toward autonomous systems. The majority of examples (83%) have potential for open seas and oceans, highlighting that these new forms of life respond to climate change, even though most are still in the conceptual phase (56%). The potential for application is evident in 44% of the analysed cases.

Research shows that individual floating units are most often floating houses or research centres. Residential units vary in size and can usually be multiplied. Complexes may include additional recreational functions, such as spas, wellness centres, or pools, and can also serve as hotels. Floating cities integrate a wide range of functions, accommodating an average of 40,000–50,000 inhabitants, and in some cases, over 2 million residents. Floating objects frequently provide residential and research functions, while complexes offer residential, recreational, and service functions on a larger scale, up to fully functional complex floating cities. Program definition is a crucial part of the pre-design stage and should be adjusted to the site, taking into account the impacts of climate, hydro, and seabed analyses, as well as socio-economic assessments. These analyses should inform the formulation of the program and any necessary modifications based on site conditions (Table 6).

Table 5. Floating architecture - main characteristics in terms of sustainable solutions. Source: own study

Ct/ S	name	sustainable solutions	BS					US	O
			SS		AI			AA	
			Fr*	Mt	Lo	Hi	F		
A.1	The Floating Seahorse	underwater "garden" of coral reef	x						x
A.2	hi sea floating hotel	harmony with nature – views of the water	x						x
A.3	Habitat WaterNest	sustainable materials – recyclable unit in 98%; 60 m^2 of photovoltaic panels	x	x	x				
A.4	Seapods	38 m^2 of solar panels on the roof (19 panels)	x		x				
		Total no of floating objects (housing/ collective housing)	4	1	2	0	0	0	2
		Total floating objects (housing/ collective housing) (%)	100	25	50	0	0	0	50
A.5	Yarauvi	no data	x						
A.6	Sea stem	a completely autonomous habitat in terms of installation; food waste for biomass energy; collection of rainwater for permaculture garden	x				x		x
A.7	City of Meriens	fully autonomous, renewable energy, zero waste program, aquaculture breeding farms; hydroponic greenhouses	x				x	x	
A.8	Marine Research Centre	low-E materials; wholly energy efficient; PV cells; tidal wave energy generation, natural ventilation, rain water collection, seawater for domestic and for radiant cooling	x	x		x			
		Total no of floating objects (other function)	4	1	0	1	2	1	1
		Total floating objects (other function) (%)	100	25	0	25	50	25	25
B.1	Ocean community	docking platform for fresh water, electricity and recycling the waste; the living unit uses sustainable energy such as water, sun, wind. photovoltaic array on the rooftop; energy from the wind is working as a cooling system; rainwater can be collected into the water filtration storage	x				x		
B.2	Infinite Maldives	prefabrication methods and local, lightweight, and recycled materials;	x	x					
B.3	Currents for Currents	autonomous production of energy with turbines; *resilient structures*	x			x			
B.4	Kempinski Floating Palace	solar panels are mounted at each end of the floating villas	x		x				
B.5	Land on Water	modules from recycled reinforced polymer; habitat for fish and crustaceans and an anchor point for molluscs and seaweeds;	x	x					x
		Total no of floating complexes;	5	2	1	1	1	0	1
		Total floating complexes (%)	100	40	20	20	20	0	20
C.1	Blue Estate Island	renewable sources for power to maintain a negative CO_2 output			x				
C.2	Oceanix city	local materials (bamboo with a negative carbon footprint); wind and water turbines and solar panels; farmland (food production and agriculture) on a zero-waste basis	x	x		x		x	
C.3	Dogen City	self-sustaining maritime city; extensive natural disaster program and evacuation in the event of earthquakes, floods, and tsunamis; food production, services	x				x	x	
C.4	Lilypad	self-sufficient, renewable energy sources (solar, wind, tidal, biomass, etc.); zero carbon emissions; recycling CO, waste, and purifying water, biotic corridors, aquaculture, and phytopurification for food and ecological balance	x				x	x	
C.5	Noah	solar energy, passive glazing system, wind turbines, fresh water recovery and storage systems, grey water treatment, sky garden heating/cooling vents, elimination of cars - pedestrian-friendly community, carbon neutral entity, internal electric transport links, designed due to LEED certification					x	x	
		Total no of floating cities	3	1	1	1	3	4	0
		Total floating cities (%)	60	20	20	20	60	75	0
		Total no of objects	16	5	4	3	6	5	4
		Total (%)	89	28	22	17	33	28	22

Legend: Ct – category symbol, S – structure symbol, BS – Building Scale, US – Urban Scale, SS – Sustainable Structures, AI – Autonomous Installations, AA – Additional Autonomy, Fr – Form, Mt – Sustainable Materials, Lo – Low autonomy, Hi – High autonomy, F – Full autonomy; * – data based on Table 3 and Table 4.

Research on form shows that floating structures are mainly low-rise buildings (72%), although 28% are high-rise developments. It should be considered whether the low intensity of development results from structural limitations, costs, or concerns for the marine landscape, which would require broader studies. In the analysed building, this is related to programmatic and aesthetic assumptions. It is worth noting that a tall building in the middle of the ocean would certainly create significant visual and environmental impacts, which is why the development of floating architecture requires a highly responsible approach. However, closer to the coastline, such structures can serve as a continuation of the waterfront.

Floating houses typically have rectangular or circular platforms (50% each), while other floating objects, mainly research centres, tend to use circular (50%) or organic platforms, adopting biophilic forms in 50% of cases. Circular and rounded forms may result from the advantages of a compact plan, aesthetic considerations, biophilic design inspiration, and the ease with which vessels can navigate around such forms as obstacles. However, literature suggests that hexagonal platforms provide superior stability and performance in various water conditions. For each case, thorough research and analysis are required to confirm the stability of different platform shapes. However, the variety of forms found in floating architectural structures shows that this field is not limited in terms of creativity and allows for diverse aesthetic expressions. Moreover, floating complexes follow various arrangements – mainly radial (60%), as well as concentric, branching, and linear (40% each) – and show the most significant potential for multiplication through modular systems, observed in 56% of cases. It opens the discussion on the most effective form of a floating city while emphasising the potential of modular forms for seakeeping, expandability, and reusability.

Returning to the building life cycle, it can be observed that the different stages directly influence one another. Additionally, the autonomy of floating architecture can be considered at various scales. The mutual relationships between these components are presented in the theoretical Autonomous Floating Architecture model (Fig. 8). Moreover, all phases of the floating architecture life cycle and the corresponding sustainable solutions are summarised in Table 6.

At the building scale, within the framework of a sustainable structure, the design approach, the materials used (related to the production stage), and the construction method all influence the recyclability of the structure or the possibility of its reuse (Fig. 8). The selection of platform shape, building forms, and spatial composition constitutes a key design phase from the architect's perspective, shaping the resulting structure in terms of sustainability. It provides a visible response to programme requirements and to the project concept expressed through architectural form. However, at this stage, not only aesthetic and functional aspects must be considered, but also construction requirements necessary to ensure stability, safety, resilience, and user comfort. These factors are closely linked to the required infrastructure, which in turn affects the architectural form. Economic considerations are equally important for achieving feasibility, and in this respect, prototypes are valuable for verifying assumptions at a smaller scale, reducing costs, and identifying optimal solutions. During construction, sustainable and durable materials should be used to ensure stable and resilient buildings. Modularity is also desirable, as it facilitates construction and supports the extension or relocation of the floating structure. During demolition and recycling, modular construction simplifies disassembly, while the use of easily recoverable and recyclable materials remains equally essential (Table 6).

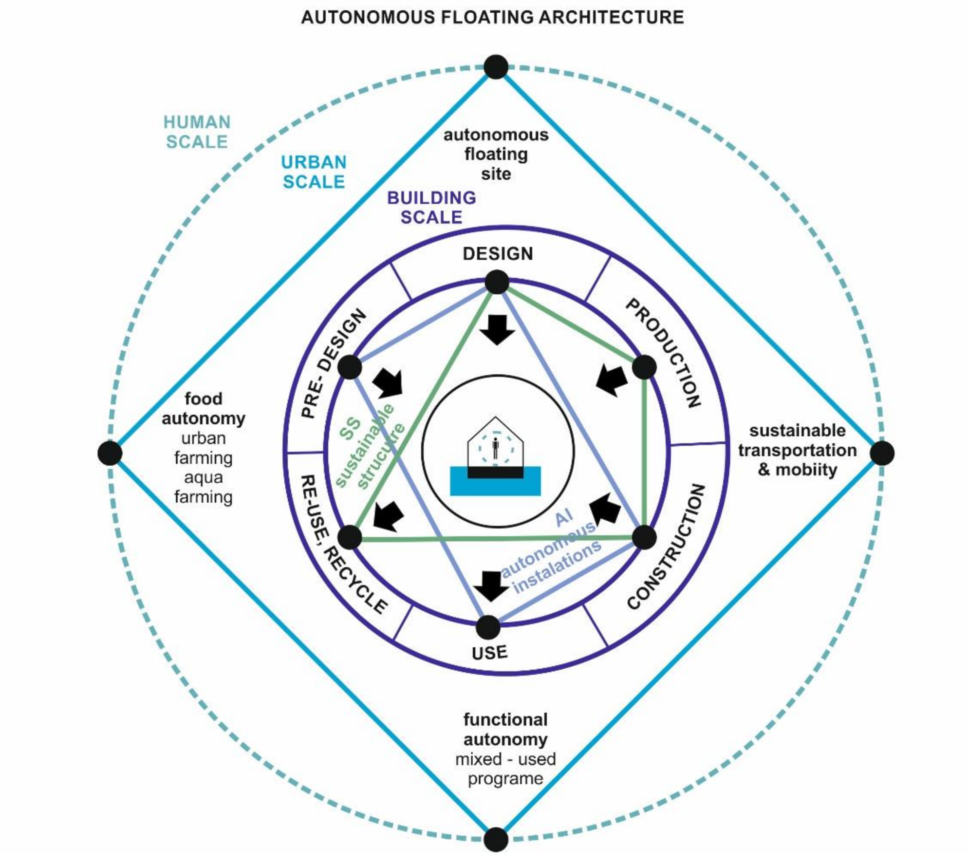

Fig. 8. Theoretical model of autonomous floating architecture considering the building scale and the urban scale, both incorporating the complex human scale. Source: own study

Table 6. Floating architecture – desirable sustainable solutions
at different phases of the floating architecture life cycle are required to achieve autonomy. Source: own study

different phases of floating architecture life cycle and sustainable solutions at different phases					
pre-design	design	production and construction	use –operational phase	use –extension, relocation, evacuation	demolition, reuse, recycling
consideration of climate, hydrological, and seabed condition analyses, as well as ecological-socio-economic assessments related to site selection; marine resource assessment; formulation of the program and its modifications due to site selection	sustainable structure: providing aesthetic values and seakeeping stability, as well as safety, feasibility, resilience; selection of platform type and type of form (compact/biophilic /modular); autonomous installation; mixed-use structures with sustainable mobility and transportation	sustainable structure: sustainable and durable materials for stable and resilient construction; modularity facilitating the building process; the use of prototypes to optimise the process; provision of infrastructure for autonomous installations	autonomous installation for energy, water, and food, as well as zero-waste systems – moving towards autonomous systems and smart city concepts; sustainable mobility and sea and air transportation for accessibility; access to all services, greenery, urban farming; habitat for aquatic life	modularity as a factor enabling easy extension and relocation; sustainable transport and mobility; provision of evacuation infrastructure - sea and air transport	sustainable structure: modular construction facilitating demolition and re-use; easily recoverable and recyclable materials

In the case of autonomous installations, assessing the site's potential during the pre-design stage and considering these factors during design and construction directly influences the building's performance during the operational phase of use (Fig. 8). Key solutions include the collection, storage, and recovery of energy and water, as well as zero-waste systems, moving towards autonomous systems (Table 6).

Additionally, greater autonomy for floating structures can be considered at the urban scale. Key elements include independence from land (autonomy of the floating site), food autonomy (related to urban farming), sustainable transport and mobility, and functional independence associated with mixed-use programs (Fig. 8, Table 6). Moreover, regarding the accessibility of floating structures via sea and air transport, evacuation strategies should be considered and require further research.

For floating structures at a larger scale, analogous to the building life cycle, the life cycle of a city should be considered, taking into account all stages – from initial analyses to potential relocation or reuse in case of the demolition of a floating city. This remains an area that requires further investigation for the development of autonomous floating architecture.

In summary, this article systematises the areas related to achieving autonomy in floating architecture. Each of the identified features, at both the building and urban scales, could be subjected to a more detailed analysis. However, the main aim of this study was to review current development trends in this field and identify potential areas for further investigation.

As the analysis shows, only 33% of autonomous installations achieve full autonomy. Moreover, there are no examples that meet all the requirements of autonomous floating architecture at both the building and urban scales. Achieving such a level of autonomy is very difficult due to the complexity of human needs. From necessities such as water, food, and physiological needs, as well as shelter, comfort, and safety, which must be addressed at the building scale, to stability, accessibility, belonging, engagement, and many other needs that require broader, urban-scale solutions (Fig. 4). However, the goal of implementing autonomous floating architecture should not be to isolate the floating city from the land, but rather to make it self-sufficient while ensuring user comfort, bearing in mind that the inhabitants of any town also need to travel and obtain goods. The occurrence of autonomous installations at 33% highlights current limitations. It suggests significant opportunities for innovation, indicating that this topic will be further explored and developed in future architectural practice and research.

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