buildings

MDPI

Article

Architecture towards Technology—A Prototype Design of a Smart Home

Pedro Racha-Pacheco [1], Jorge T. Ribeiro [1,2,3,*] and José Afonso [3]

1 Lisbon School of Architecture, University of Lisbon, 1349-063 Lisboa, Portugal; prachapacheco@gmail.com
2 CERENA, Centre of Natural Resources and Environment, 1049-001 Lisboa, Portugal
3 CIAUD, Research Centre for Architecture, Urbanism and Design, 1349-063 Lisboa, Portugal; jafonso@fa.ulisboa.pt
* Correspondence: jribeiro@fa.ulisboa.pt

Abstract: Humanity's way of life has been irreversibly transformed by new technological advancements during the past decades. Although such technological innovations have been gradually transposed into architecture, their full integration is not yet achieved. This article addresses the issue of incorporating cutting-edge technologies (such as smart thermostats, lighting sensors, security cameras, remote commands, graphic user interfaces, smartphones, mobile apps, gestures, voice commands, etc.) into urban small-scale residential architecture, in the future evolution context. For this purpose, a methodology was conceived that the main concepts regarding automation and information networks were researched, as well as their practice in some reference architecture cases. The guidelines for the prototype architectonic design were defined based on the previous knowledge acquired. Then, a prototype design of an intelligent home was iteratively developed as a machine for living in constant change. It was expected to contribute to increasing and disseminating knowledge in these fields, explaining their benefits and limitations. The prototype design presented in this article contributes to sensitizing architecture professionals to the importance of integrated and systematized thinking in all procedures of a smart home design.

Keywords: building automation; network components and devices; housing prototype; architectural design; smart home

Citation: Racha-Pacheco, P.; Ribeiro, J.T.; Afonso, J. Architecture towards Technology—A Prototype Design of a Smart Home. *Buildings* **2023**, *13*, 1859. https://doi.org/10.3390/buildings13071859

Academic Editor: Wolfgang Kastner

Received: 16 June 2023
Revised: 5 July 2023
Accepted: 20 July 2023
Published: 22 July 2023

1. Introduction

The technological development provided by the first two Industrial Revolutions known, especially since the second half of the 20th century, were an extraordinary and fast acceleration [1], which was translated into the Electronic Revolution (i.e., 3rd Industrial Revolution) and the Communication Revolution (i.e., 4th Industrial Revolution).

The Electronic Revolution occurred at the end of 1960s and drastically changed the technology for the controls of both electrical and thermal systems by introducing Programmable Logic Controllers (PLC), which were inexpensive and easy to program. Later, in the 1990s, Direct Digital Control (DDC)—a microprocessor that updates in real-time an internal information database by monitoring information of an environment and continuously produces corrective output commands as an answer to changing control conditions [2]—was used for the first time in heating, ventilation and air-conditioning systems (HVAC) [3] of commercial buildings to enable functions to run automatically. The core of the modern building automation and control systems (BACS) is based on PLCs and solid-state devices—an electrical component/system that is based largely or entirely on a semiconductor [4]. Although the BACS are often associated with commercial and service buildings, they can also be defined as home and building electronic systems (HBES). The BACS are one of the most critical enabling technologies for creating microgrids for smart buildings and energy communities [5].

The arising (the early 1960s [6]) of the internet and its exponential development (commercial phase 1984–1989 [6]) are the geneses of the 2000s Communication Revolution. By 2020, more than half of the world's population was estimated to have access to the Internet [7]. Further, that number is growing, largely due to the prevalence of smart technology and the Internet of Things (IoT), where computer-like devices connect with the Internet or interact via wireless networks [7]. These "things", particularly associated with homes, include smartphones, apps, thermostats, lighting systems, irrigation systems, security cameras, vehicles, and even cities [7]. Simultaneously, the Communication Revolution has further changed the BACS/HBES.

Although the first imagined visions of a Smart Home came from the early 20th century [8], and the first consistent references came from the 1960s [9], the first Smart House was designed by Pierre Sarda in 1974 (https://youtu.be/cqPsI1YBSgc (accessed on 21 March 2023). A Smart House is actually a dwelling where an organized automation system connects all the electrical devices by sensors and telecommunication systems (buttons, touchscreens, keyboards, and voice and gesture recognition) for remote control or assistance. It manages lighting, heating, air conditioning, ventilation, security alarm system, audio and video system, calls devices, energy control equipment, presence, automation (doors, windows, blinds, gates), technical alarms (e.g., in case of unwanted water spillage), household appliances, etc. [10].

Currently, the term Domotics—which comes originally from the Latin 'domus' which means house, and 'tics' which includes robotics, telematics, and computational science [11]—is also linked to building automation. It is a technology for private home automation, providing several services for the resident's comfort and security. Although many automation systems were also used in BACS—or Smart Homes—and Smart Houses, the Domotics also refers to additional functions such as multimedia home entertainment systems, automatic plant watering and pet feeding, and automatic scenes for dinners and parties.

Nowadays, smart systems are seen as context-aware systems for increasing building skills. They should be aware when something is not happening according to the user specifications or through environmental information—i.e., aimed to know what is happening and what are the users' intentions and needs in order to anticipate an action or an undesirable condition [12]. The future expectation regarding home automation is linked to contextual information that can be adapted to each user, which is essential to conceive user behavioral models. Architecture should promote a space design that collects the greatest amount of information, without compromising the inhabitants' comfort, and simultaneously promotes it through more efficient use.

Despite those technological advances, the mainly marketed building automation systems concern energy consumption management and thermal comfort control [13]. Thus, there is still a long path to the generalized application of BACS new features, and this article is a small step in that direction.

In fact, the above-mentioned advances established the main purposes of this paper: (a) systematizing and disseminate building automation knowledge, especially for traditional architecture professionals, highlighting the growing importance of automation for the contemporary world and for the new ways of living; (b) show the design of a smart home—housing prototype—defining the main technological concepts useful for architectural design, and the integrated and systematic thinking in all process is another contribution; and (c) sensitize architecture professionals to the new challenges of the near future in the architecture field.

This paper has five sections. After the Introduction, Section 2 describes the methodology conceived to develop the architectural design of the housing prototype. The main components of a building automation system were presented in Section 3. Section 4 describes, in detail, the housing prototype developed and discusses it in the contemporary context. Section 5 presents the main conclusions.

2. Methodology

The methodology conceived for the housing prototype design integrating the smart systems was adapted from Gomes et al. [14].

It starts with literature research on the concepts and smart systems applied to architecture. While intense literature research was carried out, several reference cases were also studied to consolidate the acquired knowledge. An empirical program that integrated smart systems was defined, balancing the two previous tasks. Then, iteratively, a housing prototype was developed until matching all requirements. All iterative models are performed in the Blender 2.7 software [15], including the final result presented in Section 4 as a housing prototype for a single inhabitant. Figure 1 outlines the methodological process to achieving the main objective—housing architectural design with home automation integration.

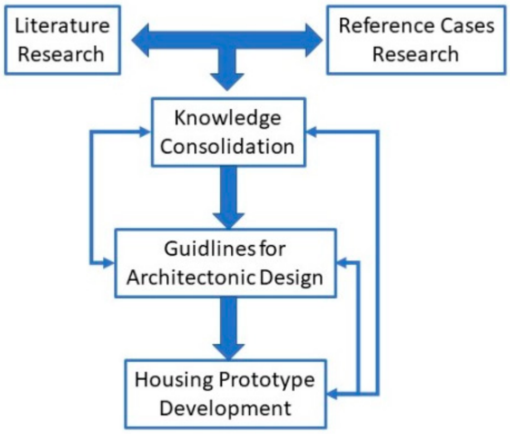


Figure 1. Methodology adapted from Gomes et al. [14].

3. Building Automation System

A building automation system mainly needs devices that communicate between them, with the user, and communication protocols. It is typically organized into three levels (Figure 2): field, automation, and management [3,16]. The field level interacts with the physical world, usually with sensors and actuators. At the automation level are developed control logic operations, by controllers, to execute appropriate actions. The management level is used by operators to monitor, configure, and control the whole system.

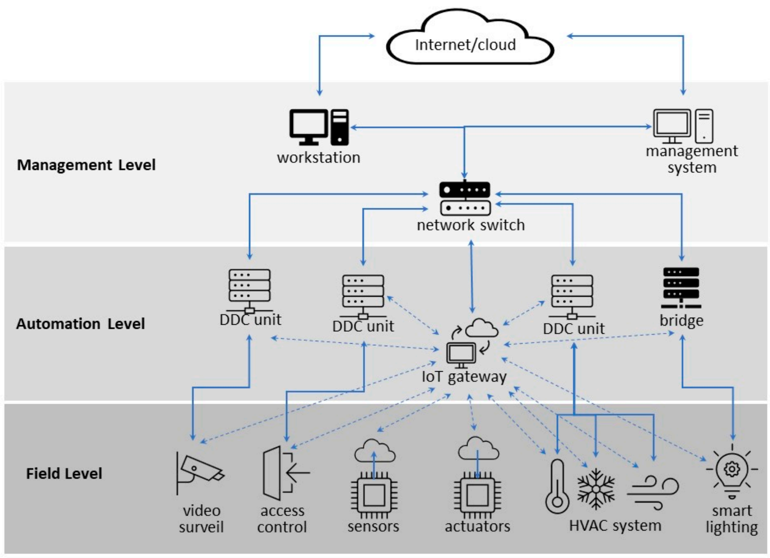


Figure 2. Three levels of the functional hierarchy of a building automation system. Source: second author.

3.1. Sensors and Actuators

Sensors and actuators are often contained in the same equipment. Sensors are devices that convert a physical reality into a signal that can be measured [17]. The most common are motion, pressure, or contact sensors, widely used in space monitoring and security. Actuators are also devices, such as window blinds or ceiling lamps [17], that react to signals by closing circuits or varying the intensity of electric loads. Actuators complement sensors by mechanically regulating a given system—e.g., the motorized shading system, removable walls, height-adjustable workstations, etc. In a simple way, the sensor captures and the actuator reacts by changing the environment by automatic or manual instruction.

3.2. Controllers

Controllers operate joined with actuators to regulate the operation of valves or other devices—e.g., an intelligent lamp that knows to turn on when the level of natural light justifies it through a brightness sensor. This control is done through a network that connects all electrical or mechanical instruments by DDC [3].

To establish the connections, each vendor develops specific drivers for different protocol systems and applications, such as Konnexbus (KNX), LonWorks, BACnet, etc. [17].

3.3. Interfaces

Interfaces can be understood as devices that allow communication between two different systems. User interfaces establish communication between the user and the system, which can occur with remote commands, mobile applications, gestures, and voice commands, depending on the complexity. These devices often use GUI (Graphic User Interface) to translate instructions into graphical and user-friendly support.

System interfaces, in addition to interacting directly with the system, allow diagnosis and maintenance [3,12].

3.4. Communication Protocols

Communication between devices is carried out through an Application Programming Interface (API), which translates the "language spoken" by each of them. In fact, one of the biggest challenges is the need to articulate many communication protocols and standards without compromising compatibility [12,18]. Despite the experts' awareness, the scarcity of authoritative literature and international rules regarding the subject remains a surprising aspect of building automation. This situation disturbs communication between developers and contributes to worsening the heterogeneity problem, making it difficult for the articulation and integration of different manufacturers' systems [17].

Until the creation of international standards, building automation systems were mainly guided by the technical documentation of the suppliers of each automation system. KNX, LonWorks, and BACnet systems are examples of open standardized protocols [17,19].

In the European context, the Konnexbus (KNX) protocol stands out—standardized through the EN 50090 standard—and is currently recognized internationally as ISO/IEC 14543-3 [17]. It is more field- and automation-levels oriented and can be used for the automation of every building type and size—from family houses to office complexes and airports [19]. Each device's own "intelligence" allows it to know what to receive/send from/to the bus and how to process the received data [19]. That skill makes that complex home and building automation system fully decentralized.

LonWorks, or Local Operating Network (LON), is also available as the European standard EN 14908 and as the international standard ISO/EIC-14908 [17]. More popular in North America than in Europe, LonWorks is mainly focused on automation and field levels. Currently, it is not only used for building automation, given its great flexibility and complexity [19].

Building automation and control networking protocol (BACnet) was published as ANSI/ASHRAE 135 standard and later became a CEN and ISO standard within the ISO 16484 series [17]. It is focused on the management and automation levels and is used mainly in non-residence buildings as a Building Management System (BMS). The information exchanged between devices on BACnet uses objects and services, basically. According to Nývlt [19], besides traditional tasks (HVAC and light control), BACnet is able to supervise BMS and complex building tasks (e.g., security and fire safety systems, access control systems, vertical transport systems, elevator control, maintenance or waste management).

3.5. Network Topologies

The communication between devices, via wired (e.g., coaxial cables, electrical network, Ethernet cables, etc.) or wireless (e.g., Bluetooth, etc.), establishes a network, whose main topologies [20] are summarized in Table 1.

Table 1. Network topologies.

Network Topology	Description	Advantages	Disadvantages
Bus	a single cable is used to connect all the devices on the network	easy installation and minimal cabling required;	performance limitations on the number of network nodes;
		failure of one node does not affect other nodes;	network connectivity shut down when the cable fails.
		messages from one node can be seen simultaneously by all other nodes.	
Ring	each node is connected to two other nodes, and the last is connected to the first		relatively long transmission time between nodes;
		messages sent in one direction or both directions (using two cables between each connected node);	cabling failure between two nodes has a broader effect on the entire network;
		commonly used in networks with low inter-node traffic	relative communication delays between nodes;
			network expansion or reconfiguration requires new cabling
Star	requires the use of a top-level central node to which all other nodes are connected	reduced messaging delay between nodes;	need for more wires;
		a connection failure between a higher-level node and any of its subordinate nodes, or failure of one subordinate node, will not affect the entire network;	a failure of the top-level node will disrupt all communication on the network
		cabling failures location;	a limited number of higher-level node connections
		often used in LANs with larger geometrical area	
Tree	built by creating a set of star topologies below a central node or by connecting a set of star topologies directly through a bus	easy network scaled;	
		cabling fault location;	a higher-level node failure or the cable connection failure, then the partial network will be lost to communication.
		expansion can be as simple as attaching an additional star network topology to the bus	
Mesh	full—each node is directly connected to all other nodes; section—has a number of network nodes that are indirectly connected to other nodes	path redundancy;	
		for high traffic between nodes;	high cost of setting up the network;
		reduced probability of single-point network failure;	each node needs a routing algorithm to compute the path
		source nodes define the best route from sender to destination	
		wireless suitable	

Many networks are described as hybrid topologies, which combine the features of two or more of the above networks [20].

3.6. Network Components and Devices

Networks use several components and devices, which are described below, based on Bird & Hartwood [21].

Repeaters, mostly linked to coaxial network configurations, were used in the past to increase the usable cable length. As coaxial networks are less used currently and repeaters' functionality was included in other devices, such as hubs and switches, repeaters are now rarely used.

A hub is a multiport repeater. It means that the hub has the basic function of collecting data from one of the connected devices and forwarding them to all the other ports. It is a layer-one device that regenerates signals. Currently, hubs are slowly being replaced with switches, mainly due to the continuously increasing demand for more bandwidth and also due to their inefficiencies.

Bridges are data link layer devices that are used to connect subnets and manage the traffic flow between them. In fact, sometimes networks must be divided into subnets to reduce the amount of traffic or for security reasons. Driving data frames from one segment to the other are decided based on the MAC (Media Access Control) address, a unique number that is stamped into each data frame. Today, network switches have largely replaced bridges.

A switch is a multiport bridge and is a two devices layer. It receives incoming frames and, in contrast to a hub, uses the devices-connected MAC addresses to determine specific addresses and forwards the frames to the correct port. Like a bridge, a switch is used to increase the capability of an Ethernet LAN (Local Area Network) by dividing the network into several collision domains. This reduces the data traffic in each subnet and increases the usable bandwidth. When larger networks are needed, they can be created through the multiple switches' interconnection.

Routers are network devices, as the name suggests, that route data around the network. The router can define the data destination address, examining it upon arrival. It uses defined route tables (software-configured) to make decisions—that is, to determine the best way for the data to follow its tour. This approach, contrary to bridges and switches which use the MAC address (hardware-configured) to determine the data destination, makes routers more functional. It also makes them more complex because they have to work harder to determine the information destination.

Gateway is any device, system, or software application that can perform the function of translating data from one format to another. The key feature of a gateway is that it converts the data format, not the data itself.

A Channel Service Unit/Data Service Unit (CSU/DSU) changes the signals' digital format—computer signals to communication signals. It is used as a translator between the different technologies of LAN and WAN (Wide Area Network) links. The increasing use of WAN links means that some router manufacturers are now including the CSU/DSU functionality in routers or are providing the expansion capability to do so.

Network Interface Card (NIC) is the mechanism by which computers connect to a network.

ISDN (Integrated Services Digital Network) terminal adapter is an external device that allows this type of digital communication, using a conventional phone line. It is available as add-in expansion cards fitted into computers, which connect to the serial interfaces of PCs—or modules—in a router.

Wireless Access Point (WAP) is a transceiver (see brief description below) network device used for wireless LAN (WLAN) radio signals. A WAP is typically a separate device with a built-in antenna, transmitter, and adapter. It can operate as a bridge connecting a standard wired network to wireless devices or as a router for data transmissions. In wireless networks, there may be multiple access points to cover a large area or only a single access point for a small area, such as a single home or small building.

A modem is a contraction of the terms modulator and demodulator. Modems translate digital signals from a computer into analog signals that can travel across conventional phone lines. However, due to the relatively slow communication, other remote access types (e.g., ISDN) are commonly preferred.

A transceiver (a contraction of the terms transmitter and receiver) has the function of transmitting and receiving analog or digital signals. It can be found embedded in devices such as network cards, as well as external devices.

A firewall is a networking device that controls (either hardware or software-based) its access, protecting data and resources from outside threats, and typically protects internal networks from public networks. For that reason, it is typically located at the entry/exit points of a network. In small offices and homes, a firewall is commonly installed on the local system and configured to control traffic.

4. Results and Discussion

4.1. Housing Prototype

The housing prototype that is described below, scaled for a single user, includes automation systems, but is not an executable architecture design. It intended to merge the architectural shape into its canonical elements, combined with the technological components, creating an automated capsule with four functional areas: bedroom, personal hygiene, cooking, and work [22]. The architecture design fit into prefabricated modular construction and was influenced by metabolism, a movement driven by Kisho Kurokawa, advocating the architectural idea as a living organism in constant change and adaptation. The strong reference to Kurokawa's capsules was due to their status as the house of the future (designed around 50 years ago), and because they were a synthesis considered useful for simplifying the house concept.

The capsule typology justified the mention of the minimum habitable space concept addressed by authors such as Walter Gropius and Le Corbusier, favoring the functionality of the space [23]. This line of thought defended that Man should adapt to Architecture—the housing prototype intended to show a hypothetical solution to the needs and expectations of interaction with the digital environment, based on the conceptual axioms of a limited architectural space.

To cope with the mass housing needs, authors such as Buckminster Fuller, Jean Prouvé or Pierre Koenig defended modular construction strategies, inspired by the industrial processes of prefabrication and mass production, providing themselves with an ethical conscience in the establishment of more sustainable, affordable, and adaptable.

In general, the influential modernist authors defend, in the light of reason and logic, the reduction of architecture to the essential, proposing an architecture that promoted minimum conditions and defining a behavioral criterion in the inhabiting act. However, the scarcity of space and resources can also be an engine of creativity, establishing constraints, but guiding the architectural design of which Ernst May's experience of social architecture in Frankfurt—which is at the origin of the concept of *Existenzminimum*—which is an example [24]. Le Corbusier proposed *a contrario*, the *maison maximum* concept as an analogously inverse answer to the same problem, proposing the maximum space that should be inhabited [22].

Considering the current and growing importance of technology in society and its digital development, the housing prototype attributed greater relevance to the technology, than to the construction process or to the comfort, which depended on the context—cultural, temporal, spatial, etc. In this sense, the capsule proposed with contemporary devices, expands on the type of relationships between the inhabitant and his space, making it progressively more reactive and interactive in a continuous adaptation.

The shape of the capsule was designed according to the devices that were part of the daily experience of human beings in the 21st century. Regarding the intelligence of a technological environment as its contextual information, it could be stated that the inhabiting machine creation was analogous to the living being creation, according to the metabolist principles. The architectural environment design, fed by the information that was introduced and captured, is able to react and adapt to human variables. The individual is an extension of his home and vice versa. Taking into account the smartphone and personal computer interoperability potentials, a way of life characterized by the synchrony between all the technological devices of an individual, including his house and the respective components, is hypothesized in the housing prototype.

The capsule, inspired by the Kurokawa's Nakagin Tower [25], is a prefabricated steel structure, clad in galvanized steel panels with an exterior waterproofing treatment. Conceived by injection molds, in order to reduce the joints, the manufacturing process involves the structural envelope design for a molded parts aggregation (Figure 3).

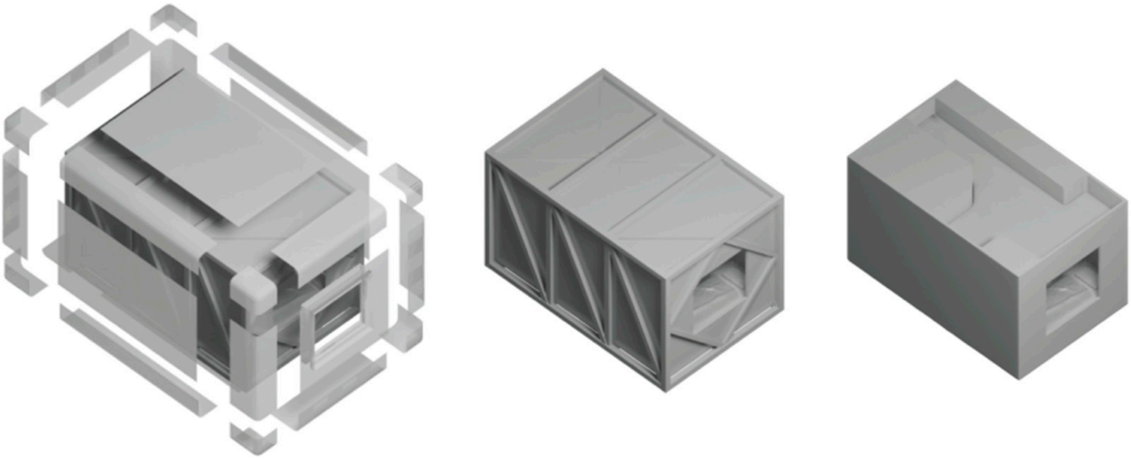


Figure 3. Structure scheme. Source: first author.

The technical systems—i.e., water, air quality, interfaces, sensors/actuators, lighting, security/privacy, and sound (Figure 4)—which will be further developed by experts, were accessed from the inside and/or outside and located in specific places designated by the technical team. Technical assistance would be carried out from the inside. Photovoltaic panels on the capsule roof would be fitted. The capsule joints in a tower were also foreseen, which required adaptations in some capsules, such as their individual removal for technical assistance and photovoltaic panels setting only in the top capsules.

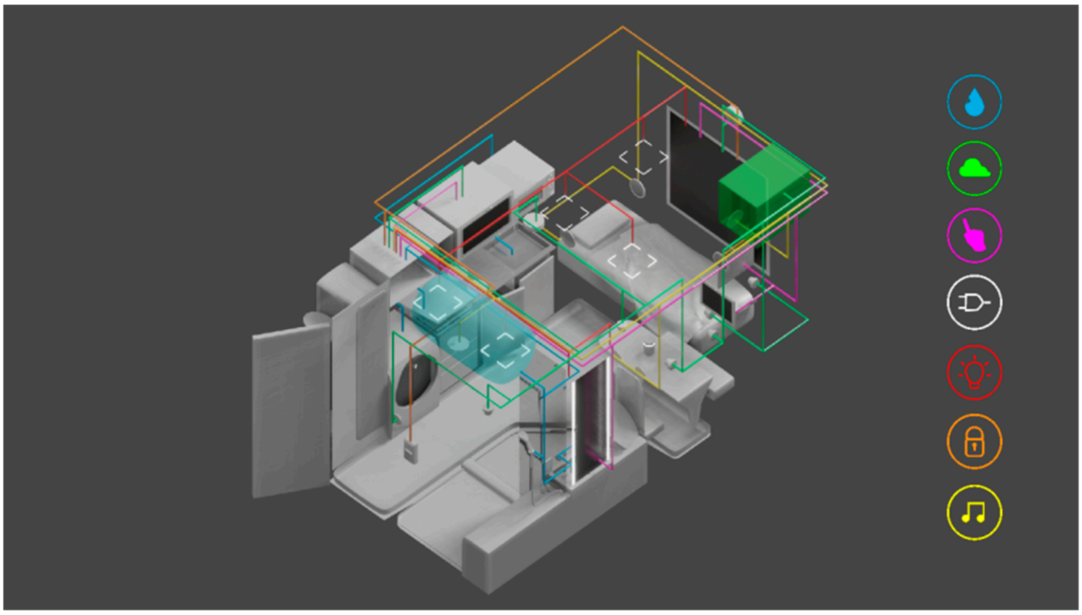


Figure 4. Technical systems. Source: first author.

As in the Welfare Techno House (WTH) [12,26], the Intelligent Room Project [27], and MavHome [28], the capsule will have a set of sensors (e.g., on the floor [29] or on the smart mattress), microphones and cameras to information capture at several levels, e.g., ECG (electrocardiogram) and body mass recording. This information is used, through Artificial Intelligence and Machine Learning systems, to build the inhabitant's behavioral model [27] and for accident prevention, allowing also for the monitoring and connecting to emergency systems. Although, the images and sounds captured are sensitive matters in terms of privacy preservation and security of inhabitants. So, those issues should be solved at the individual level by the owner and technical team.

The weather information is monitored by a sensor located on the outside of the capsule.

At the entrance there will be access control through a smart lock with the biometric reader and an intelligent thermostat will be implemented for the direct control of the HVAC system. The atmospheric sensor on the ceiling records and monitors air quality and detects fires.

A signal diffusion strategy adopted is wired combined with wireless, organized in a mesh to avoid signal collisions (interference). A network of KNX devices and its gateway will also be foreseen to enable control by external devices—e.g., smartphone, smart assistant, etc. The network includes a set of touch sensors to provide direct control of the lighting system. Devices without native intelligence will be used in the system via smart plugs.

As in Nakagin [25], water is drained from the collectors at floor level. If the capsule can be connected to an external sewage network, the system would be similar to the traditional one. If this does not happen, a dry system was foreseen. Additionally, a cistern would be implemented to collect rainwater, similar to the EcoCapsule [30].

The plan design was based on Kurokawa's Nakagin Tower capsule, as it is an architectural reference previously tested in terms of efficiency and is focused on house intelligence (Figures 5 and 6).

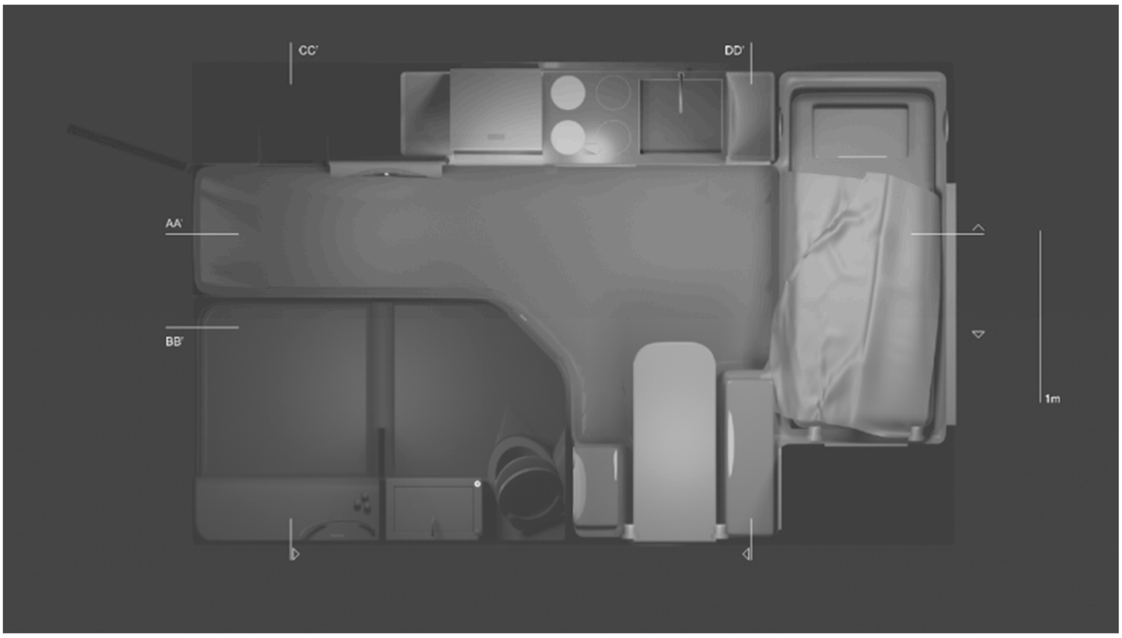


Figure 5. Capsule plan. Source: first author.

The negative space, related to the structure and technical infrastructure, was understood as the entire interstitial space between the interior and exterior cladding, which assumed a prominent role in the design of this capsule. Flexibility between storage and technical infrastructures spaces was considered, depending on needs, allowing different sizes for each space and, consequently, the type and diversity of technological systems. The access point to the automation system infrastructure was located in a technical cabinet located at the upper limit of the capsule (Figure 6a). This location was chosen for its relevance to the geometric volume design, corresponding to the negative space of the capsule. This extends inside the capsule, tangent to its perimeter so that the useful space for circulation and permanence was free.

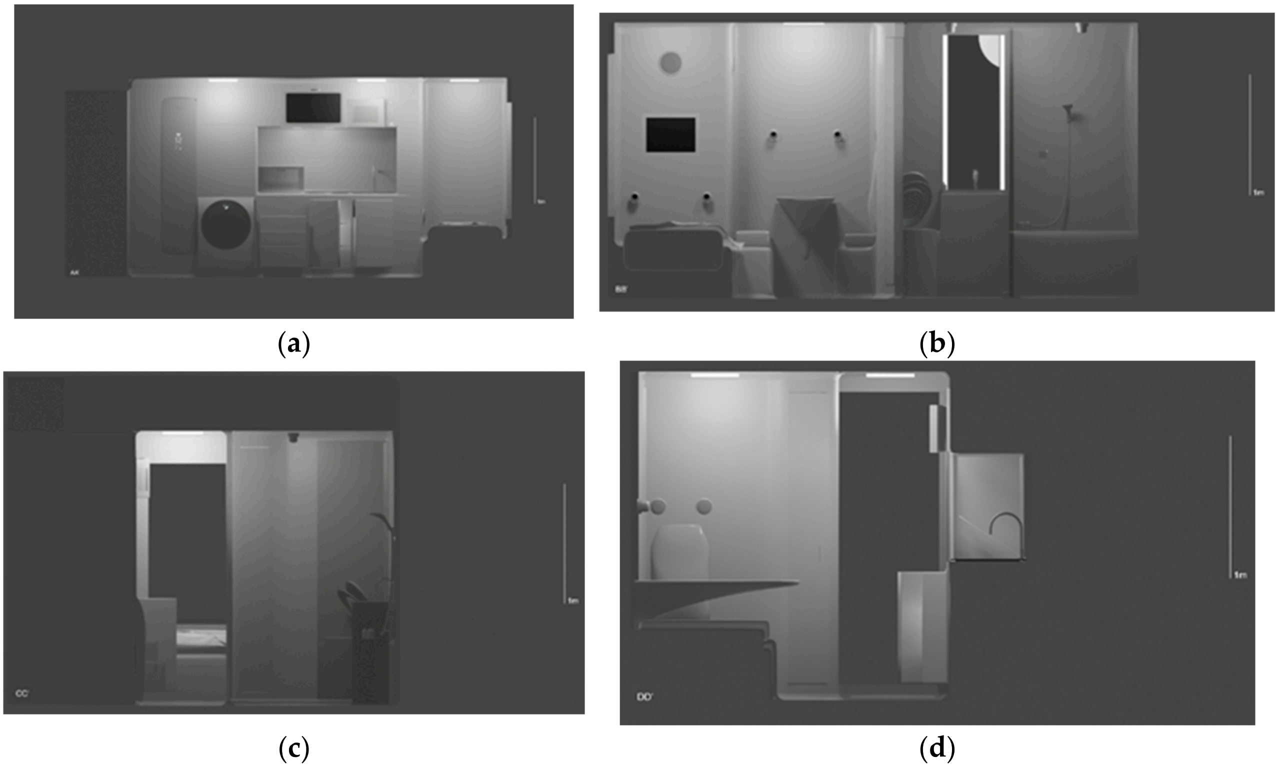


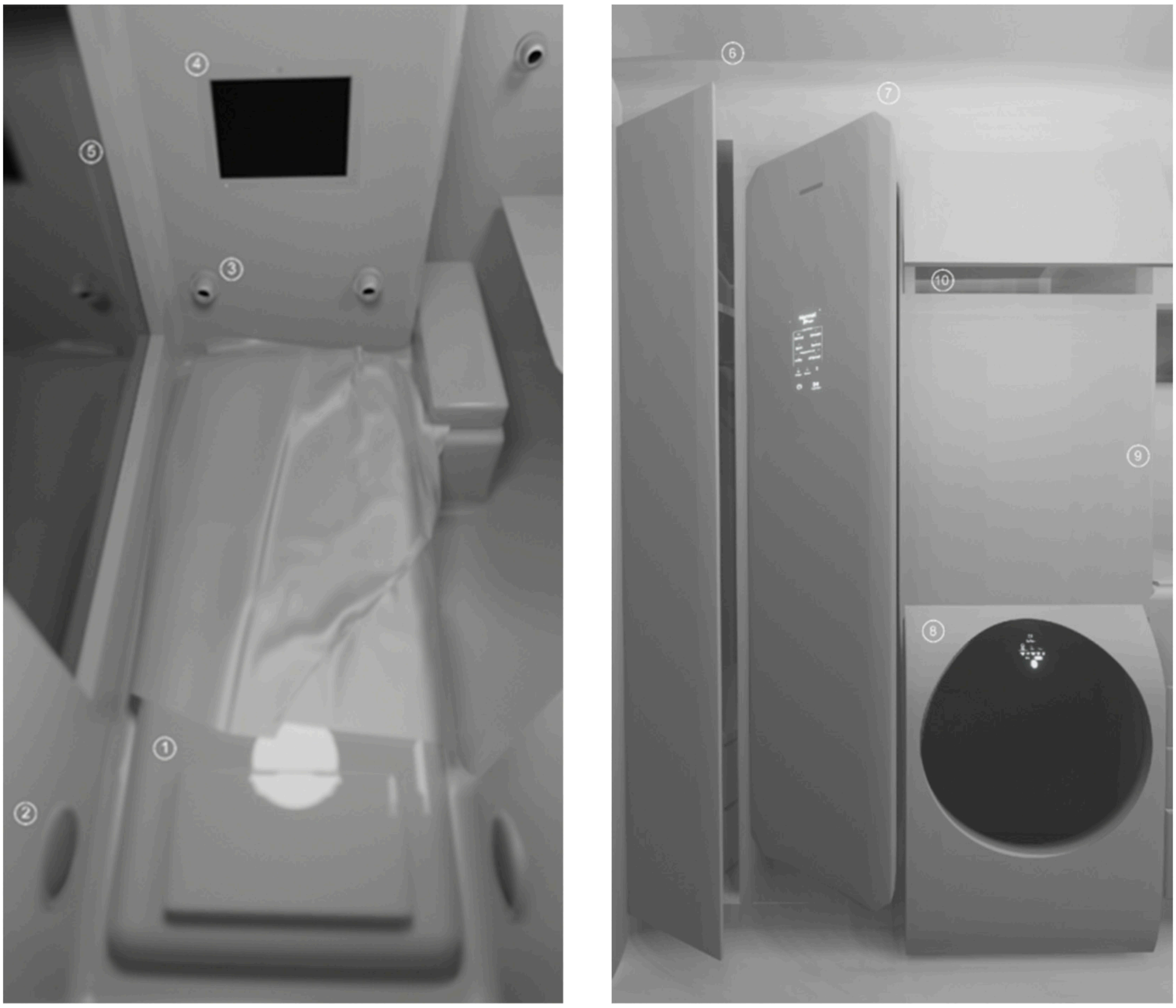
Figure 6. Cross sections located in Figure 5: (**a**) cross section AA′; (**b**) cross section BB′; (**c**) cross section CC′ and (**d**) cross section DD′. Source: first author.

4.1.1. Bedroom

The bedroom was designed for rest and entertainment purposes (Figure 7a). The mattress (#1 in Figure 7a), with built-in heating, has ergonomic articulation, allowing it to be adapted to the user's physiognomy and stiffness configuration according to preference. Two speakers located laterally close to the cushion (#2 in Figure 7a) and a screen (#4 in Figure 7a) was the entertainment system. Behind the screen, the technical column (negative space) included the necessary connections and the ventilation system (#3 in Figure 7a). There was also a built-in induction charger, close to the rest area, for charging mobile devices. Additionally, an intelligent compartment (#5 in Figure 7a) was proposed to regulate the transparency through the electrochromic glass and display information regarding the capsule. This was a transparent LCD (Liquid Crystal Display) touchscreen that served the entire capsule, excluding the sanitary room, and can be considered as an interface of the automation system.

4.1.2. Textile and Laundry Area

At the entrance was located the textile and laundry area (Figure 7b). It was characterized by four compartments: clothes storage (#6 in Figure 7b), a laundry system built into a closet, using steam and gravity to wash and iron clothes (#7 in Figure 7b), a washing and drying machine (#8 in Figure 7b), and the access point to the central domestic control system (#9 in Figure 7b) from which the technical installation (#10 in Figure 7b) is developed. The size of each of these compartments could be adjusted according to the specific needs of each user, e.g., #7 and #8 could have been neglected to increase the storage area (#6).



(a) (b)

Figure 7. (**a**) Bedroom [20]; (**b**) Textile and laundry area. Source: first author.

4.1.3. Personal Hygiene Area

The personal hygiene area (Figure 8a) was protected by the only visual barrier of the capsule, which could be replaced by electrochromic glass. The area had a smart toilet (#11 in Figure 8a) and a shower area. The washbasin (#12 in Figure 8a) was equipped with a gesture-controlled mechanism. The basin base moved vertically between two positions: aligned with the height of the washbasin, or making the cavity that confined the basin. The smart mirror (#13 in Figure 8a) was equipped with technology identical to the capsule window, as described above, enabling tactile interaction with the control system and also providing information about it. The shower area (#14 in Figure 8a) had a water-resistant panel built into the shower wall, which interacted with the control system, replacing the faucet mechanism. This device could be centrally controlled from a smartphone or smart assistant, programming different types of showers and interacting with the water heater and smart valves in the water network.

(**a**) (**b**)

Figure 8. (**a**) Personal hygiene area; (**b**) Cooking area. Source: first author.

4.1.4. Cooking Area

The cooking area (Figure 8b) was for cooking meals and the cook robots were excluded. A solution was favored that attributes centrality to a kitchen hub (#16 in Figure 8b), which served as the main interface to the capsule. Meals could be cooked in a combined oven/microwave (#17 in Figure 8b) or on an induction cooker (#20 in Figure 8b). The stove had two surfaces with circular cutouts used as induction bases for cooking, another cutout used as a weighing scale, and a fourth as an induction charger. The adjacent area (#21 in Figure 8b) was occupied by a basin with an identical mechanism to the basin in the personal hygiene area. The dishwasher (#19 in Figure 8b) is built-in and accessible from the top of the workbench. The lower space of the bench contained storage for kitchen utensils (#22 in Figure 8b), and a smart fridge (#23 in Figure 8b) with the functionality of inventorying the items contained and communication with ordering services. There was also a space for waste disposal (#24 in Figure 8b). The side spaces of the workbench (#18 in Figure 8b) were equipped with smart electrical sockets for not foreseen equipment. These, as previously mentioned, allowed for the basic control of additional equipment that was not natively smart.

4.1.5. Work Area

The work area (Figure 9) was multipurpose, as it fulfilled work, socializing, and meal functions. It was equipped with a screen (#25 in Figure 9) that served as a second monitor for the laptop used on the desktop. There were three sound columns (#26 in Figure 9) in the work area. One was located at the upper limit of the capsule, working together with the bedroom. The remaining two speakers were positioned on either side of the workstation user. There were also two HVAC system diffusers (#27 in Figure 9) on the side wall of the work area in order to contribute to general or zonal thermal control of the capsule.

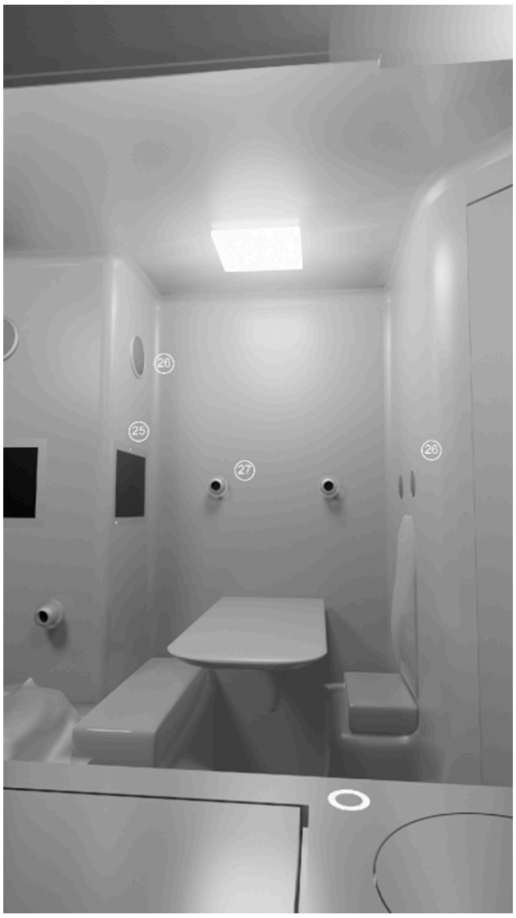


Figure 9. Work area. Source: first author.

4.2. Discussion

According to [3], it was expected that an intelligent building would be able to satisfy the needs of its users in four domains: security, multimedia, temperature, and lighting control, which could be manually or automatically controlled.

Nevertheless, the automation systems do not yet significantly add value and present solutions for problems that do not need to be solved (most people do not need a new thermostat, a Wi-Fi fridge, or a smart lock to replace their manual and/or mechanical devices, which in most cases were not yet obsolete). Changing these devices for more expensive and potentially more complicated devices was not something that most people were willing to do, and instead were happy with their current situation. Beyond the high equipment costs, concerns regarding privacy and security, lack of standardized equipment and compatibility issues were also limitations to smart systems market expansion [8,12]. Nowadays, interoperability is being put forward as the main challenge not only for building automation, but also for IoT technologies [17]. Thus, perhaps installing smart systems in pre-existing buildings was still not recommended.

However, the BACS allows for optimizing the operational energy costs of a building, maintaining the comfort and accessibility of its users [17], and will be the future for new buildings.

The smart home can also play an active and decisive role in preventing domestic accidents and supporting weak (mental or physical) individuals. Contextual information, combined with the monitoring and forecasting of impaired individuals' activity, can be the key to formalizing a safe and accessible space.

5. Conclusions

Krueger [31] believed, in 2006, that architecture had neglected the possibilities offered by new technologies. To cope with the previous statement, increasing and disseminating knowledge in these fields was needed. This article brought those areas of knowledge closer together, encouraging their relationship to provide mutual benefits and developments in the near future.

The potential provided by the new technologies was explored by architecture in this paper through summarizing technical knowledge, which was useful for the building automation architectural project. Far from exhausting the subject, it intended to be a starting point for the design of a living and constantly evolving intelligent system—the house as an information cell that integrates the urban fabric, extending to the city and the world scales.

The housing prototype developed, not being an executable project design, should be seen as an exploratory and hypothetical architectural solution of what the future could be. The project design will be further developed, in a collaborative way, with experts in several technical aspects.

The housing prototype intended to show the house automation architectural design as a technological product at the service of the user. Understanding that the house can be one more product that can integrate (or coordinate) a smart grid, can decisively change the field of architecture and challenge its limits. The capsule can be used as assisted living, however, presenting challenges to be overcome in terms of interior mobility.

It was foreseeable that the current competitiveness of the BACS market generated integrated operating systems that provided the connection between all the smart devices in the house. Architecture, by its nature and through its design, may have an increased responsibility in the adoption and dissemination of these systems. The house of the future is repeatedly reinvented, and architects must know how to position themselves in a volatile market.

A business model for architecture could be created, similar to that used by large technological companies—e.g., Google, Facebook, etc.—that promote a free service linked to monitored user data. These data and information have intrinsic value for entities and companies interested in the targeted promotion of their products or services. It is possible that this data trade could represent a revolution in today's housing market, transforming the value and ownership notions.

Author Contributions: Conceptualization, J.T.R. and J.A.; methodology, J.T.R.; formal analysis, J.T.R. and J.A.; investigation, P.R.-P. and J.T.R.; resources, P.R.-P. and J.T.R.; writing—original draft preparation, J.T.R.; writing—review and editing, J.A., P.R.-P. and J.T.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Roser, M. Technology over the Long Run: Zoom out to See How Dramatically the World Can Change within a Lifetime. Available online: https://ourworldindata.org/technology-long-run (accessed on 31 March 2023).
2. Coffin, M.J. Introduction to Direct Digital Control Systems. In *Direct Digital Control for Building HVAC Systems*; Springer: Boston, MA, USA, 1999. [CrossRef]
3. Merz, H.; Hansemann, T.; Hübner, C. *Building Automation—Communication Systems with EIB/KNX, LON and BACnet*, 2nd ed.; Springer Nature: Mannheim, Germany, 2018.
4. IEEE (Institute of Electrical and Electronics Engineers) Technology Navigator 2023. Solid State Devices. Available online: https://technav.ieee.org/topic/solid-state-devices (accessed on 31 March 2023).

5. Martirano, L.; Mitolo, M. Building Automation and Control Systems (BACS): A Review. In Proceedings of the 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Madrid, Spain, 9–12 June 2020. [CrossRef]
6. Cohen-Almagor, R. Internet History. *Int. J. Technoethics* **2011**, *2*, 45–64. [CrossRef]
7. Dennis, M.A.; Kahn, R. Internet Computer Network. 2023. Available online: https://www.britannica.com/technology/Internet (accessed on 3 April 2023).
8. Serrenho, T.; Bertoldi, P. *EUR 29750 EN*; Smart Home and Appliances: State of the Art—Energy, Communications, Protocols, Standards. Publications Office of the European Union: Luxembourg, 2019. [CrossRef]
9. Harper, R. Inside the smart home: Ideas, possibilities and methods. In *Inside the Smart Home*; Harper, R., Ed.; Springer: London, UK, 2003; pp. 1–13. [CrossRef]
10. Dvoršak, B.; Havelka, J.; Mainardi, E.; Pandžić, H.; Selič, T.; Tretinjak, M. Smart Home Systems. This Publication is Part of the SHVET Project, Funded with Support from the European Commission. Available online: https://ec.europa.eu/programmes/erasmus-plus/project-result-content/4df4e928-8958-4552-80da-146977e666b9/Smart_Home_systems_FINAL.pdf (accessed on 22 April 2023).
11. Simonet, C.; Noyce, A.J. Domotics, Smart Homes, and Parkinson's Disease. *J. Park. Dis.* **2021**, *11*, S55–S63. [CrossRef] [PubMed]
12. Bejarano, A.; Fernandez, B.; Jimeno, M.; Salazar, A.; Wightman, P. Towards the Evolution of Smart Home Environments: A Survey. *Int. J. Autom. Smart Technol.* **2016**, *6*, 105–136. [CrossRef]
13. De Groote, M.; Volt, J.; Bean, F. *Is Europe Ready for the Smart Buildings Revolution*; Buildings Performance Institute Europe (BPIE): Brussels, Belgium, 2017.
14. Gomes, I.B.; Ribeiro, J.T.; Macedo, C.L. Lisbon's Águias Villa's conversion into a hotel: Merging sustainability, architectural rehabilitation, and tourism concepts. *Int. J. Architecton. Spat. Environ. Des.* **2021**, *15*, 85–108. [CrossRef]
15. Blender Foundation. Software Blender 2.7. Available online: https://www.blender.org/ (accessed on 22 November 2020).
16. Kastner, W.; Neugschwandtner, G.; Soucek, S.; Newman, H.M. Communication systems for building automation and control. *Proc. IEEE* **2005**, *93*, 1178–1203. [CrossRef]
17. Domingues, P.; Carreira, P.; Vieira, R.; Kastner, W. Building automation systems: Concepts and technology review. *Comput. Stand. Interfaces* **2016**, *45*, 12. [CrossRef]
18. Miori, V.; Russo, D. Domotic evolution towards the IoT. In *International Conference on Advanced Information Networking and Applications Workshops*; IEEE: Victoria, BC, Canada, 2014; pp. 809–814.
19. Nývlt, O. *Buses, Protocols and Systems for Home and Building Automation*; Department of Control Engineering Faculty of Electrical Engineering Czech Technical University in Prague: Prague, Czech Republic, 2009–2011.
20. Thakur, M.; Verma, P. A Review of Computer Network Topology and Analysis Examples. *Int. J. Adv. Eng. Manag.* **2022**, *4*, 1523–1530. [CrossRef]
21. Bird, D.; Harwood, M. *Network+ Training Guide*; Que Publishing: Indianapolis, IN, Canada, 2003.
22. Corbusier, L. *Towards A New Architecture*; Dover Publications Inc.: New York, NY, USA, 1986.
23. Seelow, A.M. Function and Form: Shifts in Modernist Architects' Design Thinking. *Arts* **2017**, *6*, 1. [CrossRef]
24. Brysch, S. Reinterpreting *Existenzminimum* in Contemporary Affordable Housing Solutions. *Urban Plan.* **2019**, *4*, 1–20. [CrossRef]
25. Ishida, A. Metabolic impermanence: The Nakagin capsule tower. *Inflection J.* **2017**, *4*, 32–43.
26. Tamura, T.; Kawarada, A.; Nambu, M.; Tsukada, A.; Sasaki, K.; Yamakoshi, K.-I. E-Healthcare at an Experimental Welfare Techno House in Japan. *Open Med. Inform. J.* **2007**, *1*, 1–7. [CrossRef] [PubMed]
27. Brooks, R.A. The Intelligent Room Project. In Proceedings of the Second International Conference on Cognitive Technology Humanizing the Information Age, Aizu-Wakamatsu, Japan, 25–28 August 1997; IEEE: Piscataway, NJ, USA, 1999. [CrossRef]
28. Cook, D.J.; Youngblood, M.; Heierman, E.O.; Gopalratnam, K.; Rao, S.; Litvin, A.; Khawaja, F. MavHome: An agent-based smart home. In Proceedings of the First IEEE International Conference on Pervasive Computing and Communications, Fort Worth, TX, USA, 26 March 2003; IEEE: Piscataway, NJ, USA, 2003. [CrossRef]
29. Yamazaki, T. The Ubiquitous Home. *Int. J. Smart Home* **2007**, *1*, 17–22.
30. Pospisil, M. EcoCapsule, self-sustainable microhome. In Proceedings of the DARCH 2021 1st International Conference on Architecture & Design. International Organization Center of Academic Research, Online, 12–13 July 2021; pp. 85–91.
31. Krueger, T. Metadermis: Like a second skin. In *Architecture—Machine and Body: Notes on the New Technology in Architecture*; Afonso, R.B., Furtado, G., Eds.; Carneiro, A.; Peck, B.; Alves, I., Translators; FAUP: Porto, Portugal, 2006; pp. 87–98.