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Housing Design: Furniture or Fixtures? Accommodating Change through Technological and Typological Innovation

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Abstract: The recent global pandemic has sped up architectural research in residential design aimed at rethinking housing layouts, services, and construction methods to accommodate the changing needs of the rapidly evolving contemporary society. New typological and technological design approaches are required to address, on the one hand, the adaptability of the plan as a result of higher flexibility and temporariness in familiar and working patterns, together with a downsizing of the layouts to ensure affordability and quality of life. On the other hand, the issues of sustainability and circular economy require specific attention to interpret the resilience of the building and the reuse/recycle of the fit-out systems. The paper aims at interpreting the notion of integration between fixtures and furnishing in housing design, based on a comprehensive literature review enriched with a case study analysis that shows design concepts and approaches rooted in theories and experiences of 20th-century architecture. Principles, potentials, and barriers to the development of integrated systems are highlighted and the possible implementation of industrialised production components, the potential for modularity, flexibility, and assembly are discussed.

Keywords: micro-living; built-in furniture; prefabricated fit-out; dry assembly construction systems

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1. Introduction

The recent COVID-19 pandemic has added new momentum to research and experimentation in housing design already committed to responding to a dramatically increased and evolving residential demand and to new needs emerging from the cultural, societal, and economic changes of the new millennium.

The quantitative increase in the demand is the result of urban population growth, especially in metropolitan areas, and in the rise in the number of households due to societal and demographic shifts towards single-person families [1].

The recession and economic uncertainty caused by the spread of COVID-19 has accelerated the growth of the rental market leading to high fees and unaffordable living spaces, because the target has enlarged from low-mid income and young tenants to progressively include a larger percentage of the population affected by the economic crisis and forced to abandon the idea of purchasing a home [2]. The greater difficulty of access to the housing market is due to financial restrictions, increasing prices and changes in life habits, especially among the new generations. In fact, the so-called Millennials were born in the age of the sharing economy and thus conceive the house rather as a service than a social good as a consequence of the emerging duality between ownership and usage.

Following this transformation of the house tenet, higher performances are required at low management costs, within a single "package" that includes property, furniture/equipment, energy supply contracts, maintenance, and management [3]. These housing requests find a response in the private rental real estate market and also through the development of online platforms, which enhance the level of services provided and offer a "ready-to-use product", where temporariness and flexibility are integrated into the lease [4,5].

Such a transformation, together with the recent forced indoor living during the pandemic, is questioning the size, the programme [6], and the indoor/outdoor, private/public relationship of residential spaces.

In addition, fluctuating working patterns stemming from the recent developments in corporate culture paved the way, on the one hand, for a more flexible business environment leading to higher occupational mobility (on average, 3% of European workers change jobs every year [7]), and, on the other hand, for the need of homeworking facilities and spaces also sped up by the remote activities determined by the lockdown periods.

In this sense, the residential market—the Living sector reached USD 83.4 billion in investments in 2020 [8]—diversifies investment strategies to address segments of the housing demand focused on short-term rental agreements. These transformations involve the sharing of spaces and services within homes and new users such as digital nomads, city users, young professionals, off-site students, singles, and young people in general [9,10].

Accordingly, issues of housing and mainly rental affordability, as well as of appropriate size and a diverse programme, orient housing design trends towards downsizing and adaptability as the main spatial features to simultaneously respond to global cost control and quality of life [11]. In large metropolitan areas, the convergence of these factors requires a cost-effective housing response that integrates, in a small space, a high technological level based on functionality [12]. A demand is emerging linked to flexible spaces and more fluid market conditions, gauged on a temporary work or study horizon [13]. The concept of micro-living [14–20] in combination with real-time adaptation [21], transformability [22], and multifunctionality [23] may represent a possible solution requiring an investigation on both the layout organisation as well as the fit-out and the equipment of the space, to be thus developed from a typological and technological point of view.

The research on the design of space-saving housing units equipped with multipurpose built-in furniture can be traced back in the history of 20th-century architecture to provide for "internal variability of the dwelling [. . .] driven by the desire to make minimum sized apartments as tolerable and as cheap as possible" [24] or by the exploration of flexibility as the expression of the relationship between human experience and space [25]. It is a field of investigation which periodically emerges in times of urgent housing demands, especially after the World Wars [26], also according to a pragmatic [27], common-sense approach [28] and in combination with studies on prefabricated dwelling units [29].

Hence, this paper sets out to investigate this typological and technological design concept, to understand its current viability [30] and to update it in order to address contemporary issues of space and resources' consumption. In particular, the work drives from the research developed in the late 1970s in Italy [31,32] focused on the building sector industrialisation and on the efforts to merge standardisation and prefabrication of the construction system with the furniture equipment of the house to pursue quality and cost efficiency in order to respond to a high housing demand. This paper shares the belief that off-site manufacturing and industrialisation in the construction sector, boosted by recent innovations in digital technologies and new materials, represent a possible means of improved quality and cost reduction through labour and time cuts [33–37]. In addition, following the principles of circular economy to simultaneously achieve environmental and economic benefits, the research focuses on mechanical fastening and dry assembly solutions [38] to allow for the possible reuse and recycling of the building components through disassembly and reversibility [39]. The goal is to understand how such an integration between the construction system and furniture/fixtures can deliver the equipment of all-inclusive micro-housing units by a rationalised cost-effective supply chain based on principles of transformability and disassembly.

Therefore, the paper explores the following Research Questions: How can this integration be interpreted and conceived (RQ1)? Which technological elements of the construction system can provide an integration with the fit-out and furnishing of living spaces (RQ2)? What are the design problem variables, encompassing limits and opportunities to explore further developments for standardised mass-produced integrated systems for equipped ready-to-use micro-living solutions (RQ3)?

Accordingly, the proposed methodology encompasses a comprehensive literature review addressing the concept of built-in furniture, prefabricated furniture, and technological and typological strategies for housing downsizing with the aim of clarifying, deepening, and updating the notion of integration between fit-out and construction systems.

In order to answer RQ1, different design approaches emerging in different historical social and economic contexts are thus disclosed, showing how the integration tenet has been interpreted and applied throughout the recent architectural history. A new approach is then introduced arguing how it responds to current social, environmental, and industrial demands.

Secondly, addressing RQ2, a selection and analysis of case studies was carried out mainly focusing on contemporary architecture but rooted in significant examples from the past to investigate the many categories of integration based on the building classification system.

Finally, in order to answer RQ3, these categories are evaluated and discussed according to design feasibility criteria in order to highlight barriers and potentials of the possible implementation as standardised solutions for the construction industry. A problem setting methodology is applied to list the design variables involved, to provide initial guidelines for the future development of the solutions.

2. The Integration between Furniture and Architecture

In the following section, categories of interpretation of the notion of integration are listed to highlight how the cultural, societal, and economic backgrounds have influenced and determined its insurgence, especially since the early 20th century. Finally, the paper attempts to develop and propose an updated definition, resulting from the issues of the contemporary context.

2.1. A Tectonic Concept

A first interpretation of the integration can be considered as embedded in the construction principle and stemming from a strong functional and practical purpose which also includes the enhancement of indoor comfort performances. In ancient massive architecture, the thickness of loadbearing walls still allows for the inclusion of cavities to equip the interiors with storage space as well as with fireplaces and chimneys. In historic masonry buildings, the window opening allows for the inclusion of shelving and cabinets as well as alcoves to sit, giving the benefit of more direct daylighting. The medieval towers [40], which are also known to have inspired Louis Kahn for the marked organisation of his layout design, are a clear example and demonstrate how the boundaries between fitting and servant space can be blurred, especially when including building services and appliances in the equipment category.

The fireplace nooks of the Arts and Crafts houses and manors, the built-in benches, and shelves to fill in the niches around the mantelpieces expand the heating device enclosure to exploit the indoor thermal comfort and provide a family gathering place. These buildings, intended as a celebration of design and craftmanship, represent a display of integrated woodwork to include the building as well as the fitting and furniture [41].

Moreover, North American examples of the Arts and Crafts movement show how in some cases cabinets were a hinged section of the board and panelling [42], thus encompassed in the framed timber construction system. Since American millwork companies started to launch a standardised prefabricated production listing all the wooden components from doors, to colonnades, to sideboards and cabinets [42] (ibidem) together, such an integration as belonging to a general construction system clearly emerges.

Although, in the work of Frank Lloyd Wright, the functional decorative, design, and craft elements are still present to realise a "whole as an integral unit", taking inspiration from traditional residential Japanese architecture making use of integrated furniture [43], the architectural design pursues a dynamic spatial concept that introduces a different idea of integration [44].

2.2. A Spatial Concept

As the application of the innovative reinforced concrete or steel frame construction at the turn of the 20th century allowed for the realisation of the continuity of the interior layout and the open plan, the functional and residential prevailed in the structural requirements, allowing for free separation of the rooms. A second possible design concept at the basis of the integration of the equipment into architecture focuses on efficiency as well as on perception of the space in a seamless continuity between indoor and outdoor areas. In sharp contrast with the preceding excesses of fitting, stuff, and decoration, the Modernist ideal conceives "furniture as a necessity but also, perhaps, as something that gets in the way of the flow of space" [45]. The process of rationalisation of function did not eliminate furniture but simply triggered a complete redesign of the elements [46] to be placed freely and provide a humane connotation to the abstract interiors without "hindering neither the movement of the body nor the eye" [47]. "Le Corbusier, for example ... came to view furniture as 'equipment' [responding to utilitarian needs] which was both conceived in architectural terms and integrated with the architecture" [47] (ibidem, p. 7). The notion was the result of the collaboration with Charlotte Perriand, who continued experimenting with "incorporated equipment" and "utilitarian walls", drawing inspiration from her experience in Japan [48]. Although Eileen Gray designed extensive built-in furnishings in the E. 1027 house that was never realised, it is in the tiny Badovici apartment in Paris that the concept was applied to a micro-living scenario anticipating some approaches of contemporary design to use every bit of available surfaces [49]. Richard Neutra exported and reinterpreted the Modernist approach in the United States, also including this concept of built-in equipment [50].

In addition, the concept of flexibility was explored to respond to the changing needs of the residents, both for a long-term reconfiguration and for real-time adaptation [24] (ibidem). Transformable and movable elements, from the well-known sliding partitions of Gerrit Rietveld's Schröder House (Utrecht, 1924) to Le Corbusier's Cabanon with its rich set of mobile devices equipping his micro-living design, were proposed not only to address the *existenzminimum* issue for affordable homes but also to rethink the ample residences of higher classes following canons of modernity [51].

Finally, within the idea of the *raumplan* beyond the economy of space, the built-in storage and sofa elements of Adolf Loos villas contribute to enhance the perception of the separated alcoves they create as "theatre boxes" within the fluid interior, as spatial psychological devices to provide comfort through a perception of intimacy and control [52] (pp. 5–15). In his projects for fitted furniture, conceived for efficiency and durability, practical reasons prevail in the consistency with the rationale of the whole, in evident opposition with many of his contemporaries committed to fully designing interiors.

2.3. A Design Approach Concept

Inspired by Richard Wagner's mid-19th century theory of *Gesamkunstwerk*, the notion of total design refers to a design approach extended to every detail of the architectural shell and of the fitting, aimed at providing a singular intense interior experience, an overall seamless multiscale creation. From the Arts and Crafts movement to Secession and the Deutscher Werkbund, even, in a way, to Bauhaus, the "absence of a firm distinction between the frame and the artifacts being framed is, of course, the whole point of the total work of art" [53]. In fact, as Wigley points out [53] (ibidem), such a romantic attitude encompasses both an implosive and explosive concept: the former relying on the collaboration between architects and artists to resist to the homogenising consequences of standardisation and industrialisation, the latter to embrace progressive machine-age reproduction as a means to spread the salvific powers of design.

A related idea in the continuous concept of architecture and furniture can be rooted in the application of the grid as a common design ratio to establish relationships, define principles, and generate form [54]. "The grid is not only an organizational principle and a tectonic structural device, but also entails a frame that absorbs variation, where multiplicity, heterogeneity, and diversity are resources capable of yielding singularity." [54] (ibidem, p. 2). This integration in terms of a modular, geometrical matrix to synthetise architecture and furniture into an organic whole can perhaps be recognised in Mies van der Rohe's work, from the early residential projects to the Farnsworth House [55], and it is undoubtedly linked to prefabrication and serialised modular systems in construction and equipment production.

2.4. A (Mass) Production Concept

Although the relationship between industrialised construction and prefabricated interiors has yet to be thoroughly investigated, the possibility to exploit the properties of new, especially lightweight, materials and innovative industrial fabrication technologies to mass produce off-site components and systems to respond to the requirements of the increasing housing demand in quantitative and qualitative terms informs both interiors as well as architectural design history. In fact, according to Schneiderman, "prefabrication in the built environment owes much of its advancement to concepts first investigated for use in the interior" [56]. Anticipated by the early explorations of the Modern Movement, the post-Second World War research achieved significant results in both fields, especially focusing on two main objects: the equipped wall and the service core. The first line of investigation aims at integrating room dividers and equipment in a single industrialised system exploring the potentials of modularity, flexibility, assembly, and performances of the solutions and of their joints [57]. The second stems from the innovations entailed by the introduction of an increasing set of building services (plumbing, sewing, electrical systems) and appliances in the home, which fostered dramatic changes in domestic culture [58] and from the parallel efforts into the spatial and comfort improvements of bathroom and kitchen design following hygienic and spatial efficiency issues. A third line focusing on the house as a prefabricated infrastructure implemented as a lightweight, temporary, and disposable capsule can be traced back to the first proposals for the Dymaxion House (1927) by Buckminster Fuller [59]. It was then continued and encouraged in the 1950s by the moulding potentials of plastics as a disrupting new material to revolutionise the world of interiors and architecture. Similarly, in The House of the Future (1956) and the Appliances House (1957–1958), the Smithsons explore on the one hand the "influence of furniture and household appliances on the architecture of the house" [60] and, on the other hand, the plasticity of the new synthetic materials to create a continuous curvaceous surface. However, the investigations on a single building solution to construct equipped architecture as a whole "habitat" [61] are mainly theoretical and generate provocative hypotheses such as the visions by Archigram and Radical Design.

However, following these abundant research studies and experimentations, the social context, and the economic push from the industry—including, on the one hand, component manufacturers and construction companies and, on the other hand, furniture, equipment, and appliance companies interested in expanding their markets—in the late 1970s, the perspective of a possible convergence of the two sectors towards industrialisation seemed on the horizon.

The goal of offering an all-inclusive, built, equipped, and working home releasing the future inhabitants from the burden of providing for the fitting out appeared as an interesting opportunity, especially for low-cost housing. The question of industrialisation had already led to the breaking down of the construction system to deeply analyse the performances of the built environment to address the issue of dwellings as a whole. Therefore, equipment cannot be considered simply the addition of furniture in an enclosed space. A similar path had been previously undertaken by school and health facilities designed to reduce costs and the time of production of finished ready-to-use spaces. Moreover, experimental projects culminating in the Italian "New domestic landscapes" (MOMA, 1972) could pave the way to explore the application of these ideas from something for the cultural elite to mass production [62].

2.5. The Proposed Integration: A Circular Economy Concept

The concept of integration between equipment, furniture, and construction that this paper addresses is based on the diverse spatial and technological notions previously drafted to understand whether the different systems of the building can simultaneously provide for the organisation, equipment, and comfort of residential interiors. It is on the one hand grounded in the breakdown of the building system in different levels to adapt to change. The initial Infill and Support separation [63] developed and implemented afterwards as Open Building theory [64] experimented over the years with the involvement of inhabitants in the fit-out and reorganisation stages through technological and design innovation. The Shearing layers [65] have different levels of longevity of its systems to enable the increase in the circularity potential from the start and for an easy conversion and adaptable reuse over time, thus boosting the resilience of the building. In both cases, a special design approach to allow for the physical and technological separation of the layers/levels is necessary focusing on the interface (the joints between two different building systems) and detailing.

On the other hand, it draws on the assumption that industrialised lightweight dry assembly construction can respond to the same principles of circular economy in terms of construction waste reduction, recycle of building components and materials, disassembly, and life cycle control, in addition to the time, economic, and environmental costs decreasing and having the quality enhancement typical of prefabrication [66]. This technological integration in the different subsystems of construction in combination with the spatial and typological concepts of transformability, multifunctionality, and downsizing can additionally respond to the needs of the contemporary housing demand while simultaneously pursuing sustainability goals [67].

Moreover, as a possible implementation, the easy disassembly and reuse of such systems, in line with the aforementioned concept of house as a service, can allow for the delivery of the integrated fitting-out solutions within a product service system delivery, to be temporarily rented by the real estate investor/owner of the asset and afterwards returned to the manufacturer to be further let.

3. A Phenomenology of Integration

In this section, the paper, mainly focusing on the building solutions, aims at understanding which technical elements of the construction system can be revisited to allow for the integration with furniture/equipment and thus achieve the technological and spatial multifunctionality pursued by the research study. The study drafts a possible taxonomy of the integration between the equipment and the technical elements of the construction system through the selection of contemporary case studies and projects. The collection includes prototypes, exhibition installations, micro-living examples (smaller than 40 sqm), and larger flats searched through a literature review and websites. A total of 50 contemporary case studies were catalogued, built between 1980 and 2023 (Table 1), which adds to a selection of more than 40 historic examples. Although the case studies are mainly customised designed solutions, the understanding of their design has contributed to highlight principles and suggestions for a possible future implementation into components of industrialised production to pursue the reduction in environmental and economic costs.

The selection criteria considered the following aspects:

- Multifunctionality to allow for the downsizing of the home.
- Space enhancement, exploiting the three dimensions to identify space-saving solutions, and integrating furniture in the horizontal/vertical shell of the room.
- Transformability, thanks to mobile devices, which can instantly change the character and perception of the interior environment depending on the position.

3.1. The Integrated Structure

The structural system might host cavities and spaces to integrate storage/equipment and to increase the liveability of the domestic space in terms of use as well as to improve the thermal performances of the enclosure. In "The Box House", a 20 sqm cabin designed by Ralph Erskine in the 1940s (Figure 1), the north loadbearing façade is expanded to accommodate stacked firewood on the external surface and storage on the internal one [68]. This contributes to improve the thermal insulation of the wall.

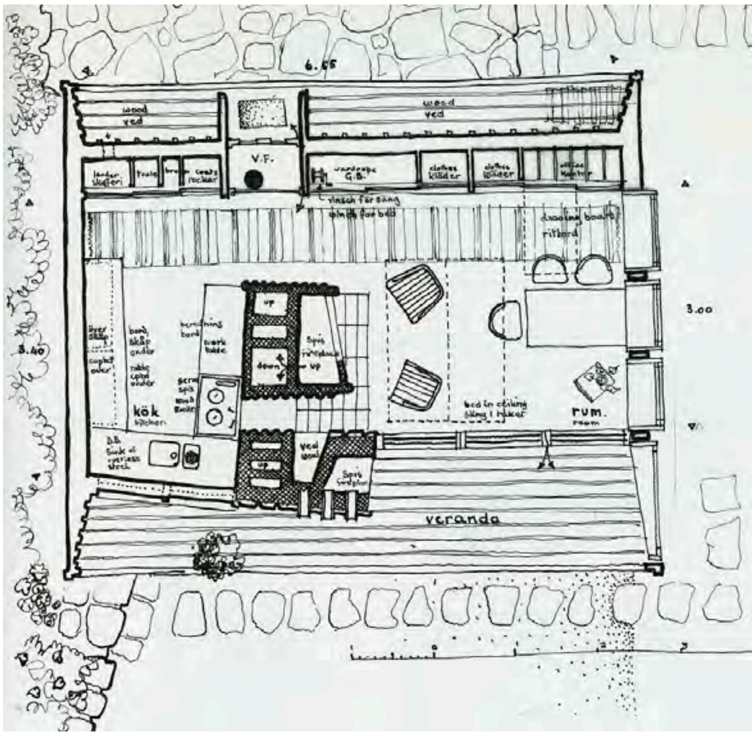


Figure 1. The integrated structure. The Box House, by Ralph Erskine, Lissima, Sweden 1941–1942 (https://fraserfolio.ca/the-box) (accessed on 10 July 2023).

In his holiday house built in 1945, Jean Prouvé [69,70] experiments with lightweight standardised components prefabricated in his workshop to build a framed wall structure where the aluminium battens are used to support cabinets and shelves. New materials and technological transfer from the nautical industry are at the base of the dry assembly easily dismountable building.

In the Shigeru Ban's Nine Grid Square House (1997), the open plan, divided by sliding partitions, is furnished by storage spaces enclosed between the steel studs of the loadbearing wall [71].

The concept can be related to a tectonic principle developing the spatial potentials of filigree construction which can be easily conceived with industrialised solutions taking direct inspiration from the Prouvé home; however, it is mainly employed for low-rise construction.

3.2. The Integrated Envelope/Window

The idea to replace the infill wall with a system of ancillary spaces/equipment finds an outstanding example in the "Domus Demain" project (1984) by Yves Lyon and François Leclerq [72], where a transparent and translucent strip replaces the façade and encompasses the kitchen, bathroom, and furniture components (Figure 2). Like the external loadbearing wall, the equipped envelope is expanded and can also be used to improve the insulation of the external wall.

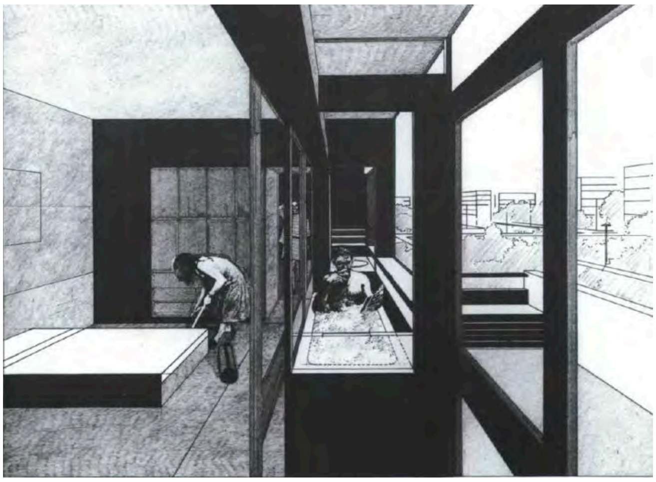


Figure 2. The integrated envelope/window. The Domus Demain, by Yves Lyon and François Leclerq, 1984 (http://hiddenarchitecture.net/domus-demain/) (accessed on 10 July 2023).

In the "Tempe à pailla" villa (1932), Eileen Gray [73] anticipated the "Finestra attrezzata" (equipped window) by Giò Ponti, where the opening becomes an opportunity to play with light and transparency to enrich shelving and store space with a visual backlit effect. In fact, in Gray's retreat, the equipment is simply juxtaposed to the window, whereas in the "Alloggio Uniambientale", developed for the X Triennale di Milano (Milan, 1954) by Gio Ponti [74], the shrinkage of the liveable surface is balanced by the amount of natural light and continuity with the outdoor environment thanks to the glazed façade integrated with furniture and paintings fixed on and in-between windows, creating the impression of a transparent wall.

An analogous concept can be recognised In the "Weekend House Straume" (Knut Hjeltnes, Alesund, 2016) [75], where the kitchen cabinets are integrated in the ribbon window enclosed between two layers of fixed transparent and internal translucent sliding glass.

A different approach towards the integration mainly focused on transformability relies on the presence/addition of volumes colonising the façade to host sliding furniture/storage space that disappears from the interiors, thus in turn changing its function.

This is the case of the "Penthouse T.O" of 18 sqm by Pool Architektur ZT GmbH [76] (p. 62), where the bed, desk, and wardrobe can vanish in the thickness of the wall, thanks to a system of niches added to the envelope [77]. Similarly, in the installation project "Azioni a scomparsa" Giovanni Lauda created for the exhibition "Italia e Giappone. Design come stile di vita" (Japan, 2001) [76] (ibidem, p. 152), a central neutral space is enclosed between two 2 m thick walls from which mobile furniture can be extracted and the kitchen and bathroom are located.

This augmented notion of the building envelope can offer interesting applications, especially for the renovation of the existing buildings with a stress on energy upgrades. The possibility to replace the windows with equipped solutions as well as the infill façade or dress it with a prefabricated system that can integrate furniture, insulation, and a new vertical distribution of the building services can open up possible new production sectors to work on the built environment.

3.3. The Integrated Raised Floor

Inspired by the higher proximity to the floor areas in domestic traditional culture, interpreting the floor not as a continuous plain surface but as a system of articulated varied levels to accommodate furniture can become an opportunity to rethink the standardised technologies of the raised floor for an advanced use. In fact, such a tradition emerges in the "Newton House", by Yukawa design lab (Tokyo, 2016) [78], or in the "Tatsumi apartment" house by Hiroyuki Ito architects (Tokyo 2016) [79], organised on different levels employed as sitting areas, desks, and storage space [80]. The multifunctional (home/office) space, "Womb" (an acronym for work, office, home, base), is designed by Johnson Chou [76] (ibidem, p. 20) to be four rooms in one, offering different automated disappearing/pivoting devices including the bed that can be sunk into a raised platform. In the "Apartment in Tessaloniki" (Figure 3) by 27 Architects (Greece, 2009) through the creation of recesses and extrusions in the floor different activities can take place (sitting, circulation, library) [81].

Figure 3. The integrated raised floor. Apartment in Thessaloniki, by 27 Architects, Thessaloniki, Greece, 2009 (https://www.archdaily.com/52530/apartment-in-thessaloniki-27-architects) (accessed on 10 July 2023).

In the "Suitcase house" (2001) by Gary Chang [77] (ibidem), the floor conceals inhabitable spaces that are accessible thanks to pneumatically assisted floor panels that completely liberate the interiors of furniture and activate the open plan room.

The project "Occultamento" by Ugo La Pietra (1974) [82] questions the codified fit-out middle-class culture to propose a new integrated system intended for social housing programmes and thus targeting the downsizing issue, including the raised usable floor in the rethinking strategy. In the "Optibo" proposal, a 25 sqm accommodation, White Design explore dining area equipment that vanish underneath the wooden floor, thanks to a mechanical system, to cater for a real-time change of function [76,83] (ibidem, p. 186).

The development of this concept for a standardised production raises questions of fruition within a design-for-all concept and of the related compliance with building regulations, including minimum ceiling height, especially in building renovations. However, the combined integration of the horizontal distribution of the building services' networks can offer interesting suggestions both for new construction as well as for refurbishment projects.

3.4. The Integrated False Ceiling

Since the 1909 patent of the disappearing bed by James Rountree, the integration of furniture and equipment in the ceiling is already offered in the market as a space-saving solution with different types of manual or automated mechanisms for retractable beds and tables/desks more or less concealed in the false ceiling and facing the issue of the presence of the suspension ties in the room space. The American manufacturer Bumblebee [84] has already targeted the market of temporary micro-living apartments delivering sophisticated high-end products, competing with other minor local companies.

However, some recent projects can suggest a further development of this idea of integration focusing on the coincidence between the false ceiling grid and a system of rails to suspend and slide equipment/furniture.

The "Circuit Box" by Studio X Design Group [76] (ibidem, p. 36) is composed of a series of rings equipped with accessories compacted in box in the wall and hanging to a rail system along which they slide passing one through the other. Similarly, in the

"AMRA7 apartment", by Piratininga Arquitetos Associados + Bruno Rossi Arquitetos (São Paulo, 2019) [84], a shelf system of modular steel panels, sometimes filled with wood cabinets, moves along rails to reconfigure and dynamise the spaces, creating different living environments.

In the perspective of the implementation of an industrialised system, an equipped modular grid possibly providing an electrical connection can offer a diverse set of applications from the sliding (equipped) or rolling partitions to the inclusion of suspended plug-in appliances, albeit to be thoroughly investigated and integrated with the structure of the flooring system above.

3.5. The Integrated Partition

Since the initial proposals by Modern architects, the integrated partition has represented a field for innumerable explorations, although it is still neglected in contemporary culture [85]. It includes examples of storage/equipped interior walls that, when separating different rooms, are faced with the issue of providing acoustic insulation. The case studies also show different sliding and pivoting solutions to allow for instantaneous transformability, to realise the multifunctionality of interiors, extracting or hiding support surfaces or containers, and modifying the spatial layout by opening or closing compartments between the rooms.

The market offers a set of diverse solutions mainly intended for office or health facilities in spite of the huge amount of research and experimentations not only for the application of affordable and public housing but also to definitely replace traditional partitions in housing design for a new modern style of living. The "Nelson's StorageWall" [86] is an example of this concept together with the sophisticated research by Angelo Mangiarotti, culminating in the Cub8 equipped wall [87]. The design challenge is represented by the development of modular systems providing for acoustical performances, diversity of equipment integrations, and ranges of transformability. The building services integration as for the office products should be included, perhaps encompassing in addition the mechanical and plumbing/sewage systems. However, issues of customisation concerning decoration and materials emerge as well as rooted domestic cultures.

3.6. The Service Cores

In contrast to the previous categories, service cores are not embedded in the shells that enclose the rooms but rather entail a different relationship with the spaces they are located in. These units are "elements that are created in their entirety as single all-inclusive pieces" [38] (ibidem, p.21). Mainly intended as prefabricated bathroom or kitchen units, these products are already available on the market and are delivered in different materials and finishes.

Recent projects show efforts in terms of transformability such as the "Wildbrook" intervention, which proposes a kitchen block with a variable (rotating) position, bound in a point of the floor to the building systems [76] (ibidem, p. 145).

However, an interesting approach towards the development of industrialised integrated systems also aimed at micro-living solutions can be that of expanding the concept of all-inclusive pieces to include a diverse set of fixtures and fittings to equip a neutral space. This unit can also be moved around the house to provide a specific quality and function to the areas of the room. The concept drives from the "Spazio abitabile" (Figure 4) proposal by Bruno Munari that [88], addressing the economy of space, gathers all the furniture of the house in one single container or, also, although more aimed at investigating the modern living culture for higher classes, the Ettore Sottsass or Joe Colombo projects portrayed for the Emilio Ambasz curated Moma exhibition "Italy. The new domestic landscape" (1972) [62] (ibidem).

Figure 4. The service core. Spazio abitabile, by Bruno Munari. (https://www.lombardiabeniculturali.it/fotografie/schede/IMM-3u040-0002975/) (accessed on 10 July 2023).

Still, anticipated by Bruno Munari's "Abitacolo" for kids and by other projects, the idea of also using the roof of such cores to increase the available space can offer some inspiration. An example, which exploits the position of the bathroom and the height of the rooms to create a mezzanine space, is the project "Abitazione per una giovane", a house of 17 sqm by Cini Boeri in 1978 [89]. Also, in the "Naked House" by Shigeru Ban [71] (ibidem), the surface otherwise occupied by three-dimensional mobile elements is restored on their roof.

Accordingly, the possibility to explore a modular prefabricated system that can either integrate the ancillary servant spaces or just the furniture with transformable devices appears as another path for addressing downsizing and multifunctionality in a micro-living accommodation.

Table 1. The list of case studies analysed classified according to category of integration.

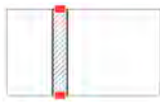
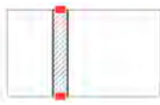
N	Project Denomination	Architect	Location, Year	Surface Sqm.	Reference	Category of Integration
1.	Domus Demain	Yves Lyon and François Leclerq	1984	70 sqm	[72] (ibidem)	
2.	Casa Insinga	Umberto Riva	Milan, Italy, 1989	70 sqm	[90]	
3.	Built-in furniture Rothman Apartment	John Pawson	London, UK, 1990	-	[91] (ibidem, p. 26)	
4.	Void Space/Hinged Space Housing	Steven Holl Architects, Hideaki Ariizumi, Pier Luigi Copat	Fukuoka, Japan, 1991	45 sqm	[92] (ibidem)	
5.	Vinyl Milford	Allan Wexler	Katonah, New York, USA, 1994	12 sqm	[76] (ibidem, p. 158)	

Table 1. *Cont.*

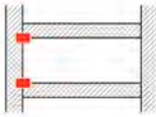
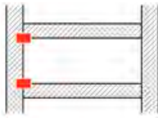
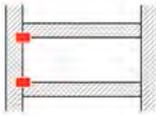
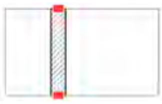
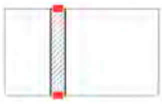
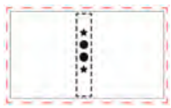
N	Project Denomination	Architect	Location, Year	Surface Sqm.	Reference	Category of Integration
6.	Apartment in London	Guard Tillman Pollock	London, UK, 1996	70 sqm	[93]	
7.	Furniture House	Shigeru Ban Associates	Lake Yamanaka, Japan, 1996	60 sqm	[71] (ibidem)	
8.	Nine Grid Square House	Shigeru Ban Associates	Hadano City, Japan, 1997	60 sqm	[71] (ibidem)	
9.	The Montecarlo Apartment	Lazzarini & Pickering	Montecarlo, France, 1997	38 sqm	[91] (ibidem, p. 292)	
10.	Petit maison du weekend	Patkau architects	Columbus, Ohio, USA,1998	8 sqm	[94] (ibidem)	
11.	Portable construction training centre	Office for mobile design	Los Angeles, California, USA, 1999	30 sqm	[95] (ibidem)	
12.	Penthouse T.O.	pool Architektur ZT GmbH	Wien, Austria, 1999	18 sqm	[76] (ibidem, p. 62)	
13.	Sarphatistrat Offices	Steven Holl Architects	Amsterdam, The Netherlands, 2000	-	[92] (ibidem)	
14.	Villa les Roses	Fabienne Couvert & Guillaume Terver	Aix-en-Provence, France,2000	60 sqm	[76] (ibidem)	
15.	Azioni a scomparsa	Dante Donegani, Jae Kyu Lee, Elena Mattei	Exhibition "Italia e Giappone. Design come stile di vita", Tokyo, Japan, 2001	20 sqm	[76] (ibidem, p. 152)	
16.	Suitcase house	Edge design institute	Beijing, China, 2002	-	[95]	
17.	Wildbrook	Urs Hartmann, Markus Wetzel	Zurich, Switzerland, 2002	4 sqm	[76] (ibidem, p. 145)	
18.	Drawer-House	Nendo	Mejiro, Tokyo, Japan, 2003	50 sqm	[76] (ibidem, p. 196)	

Table 1. *Cont.*

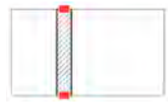
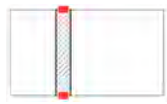
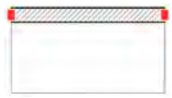
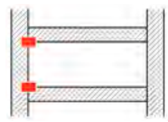
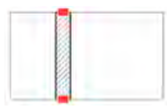
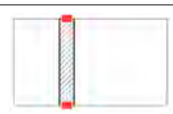
N	Project Denomination	Architect	Location, Year	Surface Sqm.	Reference	Category of Integration
19.	CircuitBox	STUDIO X DESIGN GROUP Lara Rettondini, Oscar Brito	"Tokyo Design Week 2004", Tokyo, Japan, 2004	16 sqm	[76] (ibidem, p. 136)	
20.	Social housing	Aranguren + Gallegos Arquitectos	Madrid, Spain, 2005	80 sqm	[96]	
21.	Optibo	White Design	Goteborg, Sweden, 2006	25 sqm	[76] (ibidem, p. 186)	
22.	Home/office for a graphic designer	Roger Hirsch Architect + Myriam Corti	New York, USA, 2006	56 sqm	[76] (ibidem, p. 70)	
23.	Womb: work, office, meditation, base	Johnson Chou	Toronto, Canada, 2006	30 sqm	[76] (ibidem, p. 20)	
24.	Black Treefrog	SPLTTERWERK	Bad Waltersdorf, Austria, 2006	200 sqm	[76] (ibidem, p. 105)	
25.	Salon Blauraum	Blauraum Architekten	Hamburg, Germany, 2006	-	[76] (ibidem, p. 137)	
26.	Casa Engadina	Elisabetta Terragni	Samedan, Switzerland, 2006	95 sqm	[97]	
27.	Life Style	L.M. Rojo, R. Montero, M. Dominguez, E. Ontiveros, C. Vélez, G. Morale	Barcelona, Spain, 2007	-	[98]	
28.	Apartment in Thessaloniki	27 Architects	Thessaloniki, Greece, 2009	100 sqm	[81] (ibidem)	
29.	BIQ	Schenk + Waiblinger Architects	Hamburg, Germany, 2011	50 sqm	[99]	
30.	Darlinghurst Apartment	Brad Swartz Architect	Darlinghurst, Australia, 2014	27 sqm	[100]	
31.	Susaloon	Elii architects	Madrid, Spain, 2014	24 sqm	[101]	

Table 1. *Cont.*

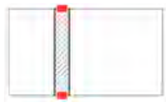
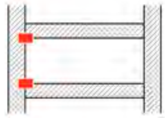
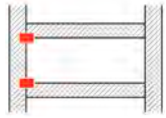
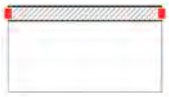
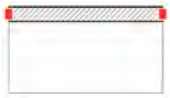
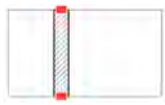
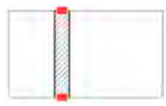
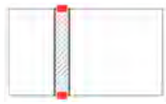
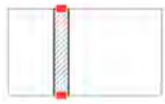
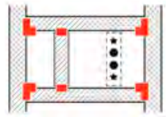
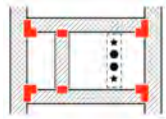
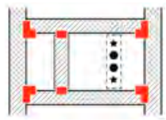
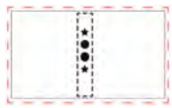
N	Project Denomination	Architect	Location, Year	Surface Sqm.	Reference	Category of Integration
32.	Estradenhaus 1 Berlin	Wolfram Popp	Berlin, Germany, 2015	80 sqm	[102]	
33.	Kramergasse 13	OLK Ruf	Wien, Austria, 2015	-	[94] (ibidem)	
34.	Cell bricks	Atelier Tekuto	Tokyo, Japan, 2015	-	[94] (ibidem)	
35.	Appartamento Viadutos	Vão	São Paulo, Brazil, 2016	35 sqm	[103]	
36.	Studio flat	CIAO	London, UK, 2016	35 sqm	[104]	
37.	Weekend House Straume	Knut Hjeltnes	Ålesund, Norway, 2016	140 sqm	[75] (ibidem)	
38.	Newton House	Yukawa design lab	Tokyo, Japan 2016	99 sqm	[78] (ibidem)	
39.	Tatsumi apartment	Hiroyuki Ito architects	Tokyo, Japan 2016	34 sqm	[79] (ibidem)	
40.	Micro dwellings	Kasita	Austin, Texas USA, 2017	33 sqm	[105]	
41.	Micro home	Ana White	Alaska, USA, 2017	16 sqm	[106]	
42.	ScopeHome	MINI LIVING Urban Cabin, Penda	"Exhibition House Vision", Beijing, China, 2018	30 sqm	[107]	
43.	Apartamento Consolação	Canoa Arquitetura	São Paulo, Brazil, 2018	33 sqm	[108]	
44.	Appartamento AMRA7	Piratininga Arquitetos Associados + Bruno Rossi Arquitetos	São Paulo, Brazil, 2019	300 sqm	[84] (ibidem)	

Table 1. *Cont.*

N	Project Denomination	Architect	Location, Year	Surface Sqm.	Reference	Category of Integration
45.	Studio Brasilia 27	Fabio Cherman	Brasilia, Brazil, 2019	27 sqm	[109]	
46.	Andradas Apartment	OCRE arquitetura	Porto Alegre, Brazil, 2020	29 sqm	[110]	
47.	Micro-apartment	Proctor and Shaw	London, UK, 2021	29 sqm	[111]	
48.	Smart Zendo apartment	Sim-Plex	Hong Kong, China, 2021	45 sqm	[112]	
49.	Urban Loft	NeuronaLab	Poblenou, Barcelona, Spain, 2022	55 sqm	[113]	
50.	Doméstico	Juan Alberto Andrade, María José Váscones	Quito, Ecuador, 2022	27.5 sqm	[114]	

4. Setting the Boundaries for the Development of Integrated Systems

The analysis of the historic and contemporary case studies collected illustrates a rich phenomenology (cf. Table 1) encompassing both furniture and equipment as well as kitchen and bathroom fixtures, which has been classified according to defined integration categories (cf. Table 2). The technological multifunctionality of these systems allows for spatial multifunctionality when implemented with a transformability feature. Hence, furniture and fit-out disappear behind shutters, cavities, or pivoting devices enabling the shrinkage of the living space.

The integration can characterise either the shell (vertical and horizontal surfaces) enclosing the interior space or ancillary space-making cores, which can additionally be inhabitable, that can articulate and organise the room layout determining its function; movable elements allow for real-time flexibility. Accordingly, the design focus shifts from construction to spatial layout and from architecture to interior design, exploring an intermediate range of competences, sometimes referred to as "furnitecture" [95] (ibidem).

This work mainly addresses the problem setting for the design of advanced products which can replace ordinary building subsystems and which complement the primary purpose and performances with the added value of place making, delivering an augmented fruition of the dwelling spaces. The focus will be on the shell to cater for the basic equipment of the interiors as it offers a more original field of investigation and wider ranges of integrability in comparison with the cores. In fact, prefabricated bathrooms and kitchen units are already available on the market and furniture cores seldom involve the integration with construction subsystems.

Following the case studies' classification, in this section, the paper sets out to deepen the understanding of the integrated systems between construction subsystems and furniture/fixtures to offer a basic problem setting and analysis for the development of spatial and technological design.

First, the integrated system is examined per se, considering its place making potential, the enhanced performances, and the time variable. In fact, as combined components, these structures entail, on the one hand, the packing of the sequence of building activities to reduce construction time; on the other hand, as adaptive and responsive elements, they allow real-time flexibility of the space.

Accordingly, the multifaceted categories of integrability, transformability, and multi-functionality are proposed and defined (cf. Table 3) as criteria for the breakdown structure of the design problem and to allow for its analysis.

Table 2. Categories of integration.

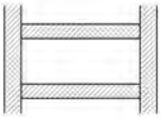
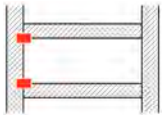
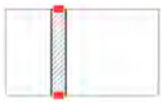
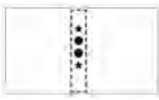
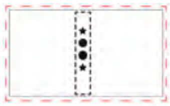
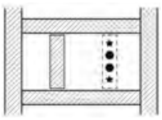
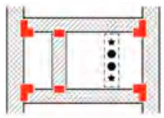
N	Category	Place of Integration	Interface between the Technical Elements
1.	Integrated structure		
2.	Integrated envelope/window		 Lower flooring system Upper flooring system
3.a	Integrated raised floor		 Vertical walls (enclosure) Interior partition walls
3.b	Integrated false ceiling		 Vertical walls (enclosure) Internal partition walls
4.	Integrated partition wall		 Lower flooring system Upper flooring system
5.	Service cores		 Whole building
6.	Total integration		 Whole building

Table 3. Integrated systems. Parameters and feasibility conditions. Definitions and performance specifications.

Parameters		Definitions and Performance Specifications	
Integrated systems		Industrialised dry assembly prefabricated systems integrating furniture/equipment and construction subsystems, in compliance with circular economy principles	
Typologies of integrable furniture/equipment	Multipurpose 3D elements	Functions: storage, support, stowage, . . .	
Integrable components	Cabinets, wardrobe, shelving, appliances, installations, bed, . . .		
Degree of integrability	Total	Relationship/integration with all the technical elements of the construction subsystem	
	Partial	Relationship/integration with some of the technical elements of the construction subsystem	e.g., partial (with a limited extension) replacement of the false ceiling of the room

Table 3. *Cont.*

Parameters		**Definitions and Performance Specifications**	
Degree of transformability of the integrated furniture/equipment	Partial	Appearance variation through movement of components (turning, tilting, sliding, retractable, . . .)	Disassembly and reassembly of components with the same purpose
	Total	Arrangement variation as components change place and position	Changing position and replacing components with different purpose
Multifunctionality of the solution	Real-time multipurpose characteristic	Technological purposes Functional purposes Spatial purposes	Multifunctionality varies according to position (cf. Table 2. Categories of integration)
Feasibility conditions of the solutions	Regulatory	According to regulation requirements	Planning/building
	Design	According to new construction/renovation According to products/materials employed for the construction of the adjacent subsystems	Factors related to building technologies
		According to the degree of integration with the adjacent subsystems	Structural system Partition walls Upper and lower flooring system Fixtures and installations
		According to the location, installation, usage, and accessibility of the integrated system	e.g.,: integration with the enclosure, fixed to floor or ceiling, with or without floor and ceiling finishes, recessed, . . .
	Construction	Building technologies employed for the installation of the integrated system layering/components	Dry assembly technologies Mechanical fastening Chemical bonding technologies
		Installation and usage of the integrated system according to the layering of the adjacent subsystems	Shape, dimensions, weight, components and joints
	Spatial	Real-time flexibility	Quick changeability of the spatial arrangement Reversibility Easy modification of the components Diversity of the usage conditions Customisation, ...
	Technological	Compliance with the mandatory or design performances	Acoustic Hygrothermal Insulation Sound absorption Fireproofing Impact strength Compressive strength Stability Anti-seismic Durability Morphological dimensional Compatibility Modularity Easy disassembly/reassembly, . . .

Table 3. *Cont.*

Parameters		**Definitions and Performance Specifications**
Added systemic value of the solution	Enhanced value through the integration	Degree of integrability Degree of transformability Degree of multifunctionality Feasibility conditions and compliance

Secondly, as the object of the research encompasses subsystems, albeit augmented, belonging to an architectural whole, the complexity of the problem is addressed considering both the elements and the interfaces with the adjacent technological subsystems of the building, as outlined in Table 2. In fact, the joints between the different subsystems represent a significant aspect of the problem to hinder the overall quality of the home if neglected. It is a design challenge to implement these detailed design issues anticipating faults during the assembly process and envisaging the aggregability/modularity control of components in relation to the other construction systems.

Finally, design environment variables are mapped to cater for the multiscale dimension of the problem including the regulatory, industrial, and economic context of architectural design. Hence, Table 4 also includes a breakdown of feasibility conditions as an attempt to map the complexity of the problem.

Table 4. Integrated false ceiling, main design requirements.

Place of Integration Localisation and Movement of Integrable Equipment/Built-in Furniture	**Integrated False Ceiling** Integrable Equipment/Built-in Furniture, with Vertical up/down Movement	
Feasibility conditions	Regulatory	Determined by the relationship with interior heights set by local planning/building regulations
	Design	Determined by the integration with the flooring system above and with the building systems; by the relationship (existing or non-existent) with the enclosure; by the relationship with other technical elements (internal partition, etc.)
	Construction	Determined by technical building solutions; design choices and decisions in relation to reduce/reuse/recycle principle; degree of eco-compatibility of materials; mechanised and/or digital movability
	Spatial	Determined by ensuring a flexible range of products; ensuring spatial flexibility; ensuring quick mechanised movement
	Technological	Determined by compliance with regulatory, production, installation, and circularity requirements both of the component and of the integrated system (product/technical elements + interfaces)

Table 4. *Cont.*

Place of Integration Localisation and Movement of Integrable Equipment/Built-in Furniture	**Integrated False Ceiling** Integrable Equipment/Built-in Furniture, with Vertical up/down Movement	
Multifunctionality combined performance	Technological performance	Acoustic Sound absorbing Anti-seismic Structural Cleanability/Maintainability, ...
	Functional performance	Accessibility Ease of use Usability Operational ease, ...
	Spatial performance	Usage space of the integrated system Functional overlap Dimensional checks Real-time transformation, . . .

In Table 4, the breakdown structure is applied to one of the categories of integration to exemplify and illustrate the complex interrelated issues that the design phase has to address, encompassing the many opportunities as well as highlighting possible issues and warnings concerning the integrated system and its interfaces.

5. Discussion

The breakdown analysis of the different categories of integration between the furniture/equipment of the house and the construction subsystems displays design issues and paths for future development. In particular, it sets a range of spatial and technological interdependent variables which represent an abstract setting of the problem. However, according to specific design goals and strategies, to the specific programme of the building (e.g., according to end users), or to the context, a hierarchy can be set to determine changeable factors and invariants and thus better orientate design. It is the case of the possible application of the integrated system to the renovation of the built heritage where geometric and technological features of the building as a whole are already predetermined. It is a growing market especially in Europe [115], where these multifunctional solutions can efficiently respond to the issues of requalification and refurbishment, providing enhanced performances to the existing building [116] and equipping the interiors with easily accessible vertical and horizontal distribution networks of the building services.

Following the application of the breakdown structure to each category of integration, some considerations emerge from the understanding of the feasibility conditions related to building regulations and the geometry of the integrated transformable system. In fact, on the one hand, these solutions allow for space-saving strategies through the superimposition of the functions and movement spaces; on the other hand, the minimum height and area of inhabitable rooms, as defined by hygienic regulations, may represent a limit to the downsizing of the space. In addition, the integrated system, embedding equipment, and fixtures constitute an increased version of the original simple construction system, resulting in a higher occupied volume. This leads to issues of possible redundancy of the solutions to allow for flexibility and adaptability, which requires to think "more specifically about the type(s) of change that might occur and about how they can be accommodated" [117]. Such a deeper simultaneous understanding of the spatial, technological, and building system variables as set by the problem analysis presented demonstrates how a new comprehensive design approach is required merging specialised competences. Such a new design culture should also encompass the skills required for the development as well as the application of the modular, industrialised systems [118].

6. Conclusions

The paper reports the partial results of our ongoing research on the topic moved, on the one hand, by the awareness of a paradigm change in the building sector where, finally, the goals of circular economy, rationalisation of the industry, and technological innovation converge to push forward a long-standing demand for off-site manufacturing.

On the other hand, signals can be detected in the market of a slow change towards ready-made dry assembly mechanical systems emerging from the building industry manufacturers and of a mild entrance of the fixtures and fit-out companies, for example, into the more traditional sector of room dividers and finally from the growing market of high-end albeit still high-cost automated transformable furniture manufacturers [119]. In fact, a possible impeding barrier to be further investigated is represented by the two supply chains traditionally involved in the fitting out and furniture delivery and assembly, characterised by different organisational structures.

The rising demand for transformability and adaptability significantly contributes to this change. Accordingly, a systematic investigation of the ongoing industry trends to evaluate the market feasibility for the introduction of the integrated systems investigated should also be carried out to thoroughly understand the economic feasibility of the concept.

Finally, domestic culture should be addressed, not only questioning consolidated habits or expectations but also modular design [120] and production [121] and the customisation vs. standardisation trade-off, investigating the decoration potentials of these solutions to enrich a catalogue of possible materials, finishes, and combinations. In this direction, significant potentials arise from processes of digital manufacturing and mass customisation [122,123] to understand whether the target of temporary housing and micro-living can be expanded and how to encompass a larger demand.

Accordingly, the cultural shift from extraordinary to ordinary solutions, from handicraft to reversible technology [124], entailed by the embedding of the basic equipment/fixtures in the construction of buildings, can found a possible parallel in the recent history of the introduction of installations and building services in the home, expanding the path of mechanisation [125].

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