Industrialhousing is a new word that links together 'industrialisation' and 'housing'. This work identifies a possible way by which industrialisation can improve housing buildings. It intends to demonstrate the central role of the design and its relevance in giving value to project. The design process of today must accept complexity as the only project charter able to overcome division and segmentation of construction. The book concentrates upon building industrialisation meaning and development path. Industrialised Building System (IBS) is an essential means to face today's living requirements, in particular sustainability and resilience, to which only full organic processes and off-site dry-joint buildings can give appropriate answers. It defines the domain, the potentiality and the limits of pre-fabrication and industrialisation of today, also introducing design-centred building process categories as tools for analysing and managing the project and for evaluating and comparing different design approaches and techniques. IBS for housing is also one the few possible strategy to achieve the mandatory and ambitious targets of PNRR (Italian National Plane of Recovery and Resilience) towards green and circular economy and Industry 4.0.
Starting from a terminological analysis, inside the proposed design-centred classification, it identifies the 'open system on-demand' category as a specific approach to design that can produce sustainable buildings (from an economic, environmental, institutional and social point of view), resilient and, at the end of life, easily re-convertible, re-usable and recycling, thanks to the re-use of transfer objects and dry-joint clamping, by an oriented network of stakeholders and their expertise and concerted solutions.
Open on-demand high-industrialised technique can give suitable answers not only to contemporary living needs, but it also can overcome some recurrent preclusions that have been making IBS difficult to increase and spread with satisfying results for housing buildings. In conclusion, among other, guidelines and criteria are proposed for approaching the design of a project in a resilient way and to lead it in a sustainable scenario.

Gianluca Pozzi, architect, PhD. He conducts research activities and contract teaching at Politecnico of Milan, Department ABC, in particular in the fields of flexibility, industrialization and building requalification for resilience and circularity. He is the author of publications on the themes of the technological culture of design and innovation in architecture. Professional activity in the aspects of requalification and environmental sustainability supports university experience.

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INDUSTRIALHOUSING

Gianluca Pozzi

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INDUSTRIALHOUSING

Or the way industrialisation can improve housing buildings

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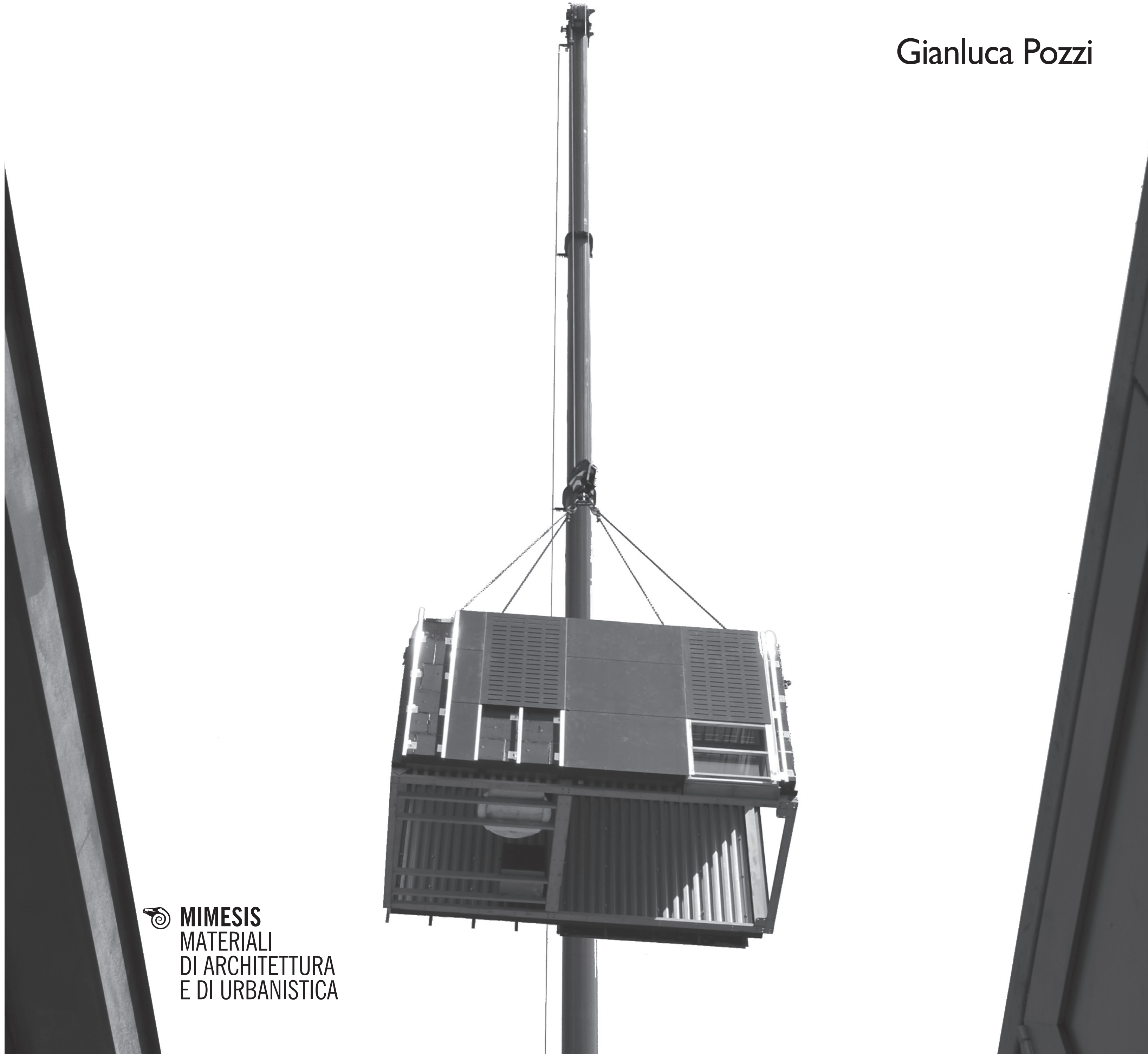

MIMESIS
MATERIALI
DI ARCHITETTURA
E DI URBANISTICA

Materiali di architettura e di urbanistica

Collana di progetti, piani, paesaggi

La collana, avviata nel 2014 da docenti del Politecnico di Milano, raccoglie lavori di architettura e di urbanistica anche distanti per argomento e impostazione ma sempre improntati al rigore del metodo, alla dimostrazione degli assunti, alla fondatezza e ripercorribilità dei cammini analitici e progettuali. È stato scelto di non assumere limiti di scala e di confine promuovendo così la pubblicazione di studi che spaziano dai temi della dimensione regionale al progetto della cellula residenziale e, di conseguenza, intersecando e confrontando competenze disciplinari diverse. I *materiali* della collana sono destinati a chi, anche privo di radicati fondamenti specialistici, intenda farne uso nella prospettiva d'una architettura e urbanistica di reale cambiamento, come impone l'evoluzione della società, della cultura e delle scienze.

Architecture and Urban Planning Materials

Collection of projects, plans, landscapes

The collection, launched by professors of the Politecnico di Milano in 2014, collects a variety of architectural and urban planning works. Though these works concern a wide array of arguments and settings, they are shaped to the rigor of the method, to the demonstration of assumptions, and to the legitimacy and retracement of analytical and project paths. The decision was made to not adopt limits of scale and boundary, thereby promoting the publication of studies that range from themes of the regional dimension to the plan of a single residential cell. In this way, different disciplinary competences are intersected and compared. The collection's materials are intended for those who, even if devoid of rooted specialized foundations, intend to use them in prospect of an architecture and urban planning of true change, as the evolution of society, culture, and science today imposes.

建筑与城市规划材料

项目、规划和景观集锦

本书在2014年由米兰理工大学建筑与城市研究学院的三位教授推出，收录了多个建筑和城市规划的项目。这些项目涉及了广泛的内容和议题。通过严谨的方法，对假设的论证、重演分析的基础和功能、以及展示项目的过程等来形成最终项目。本书观点并不拘泥于项目规模和范围的限制，而是促进扩展性的研究，范围可从区域性尺度到住宅单元，以应对交叉学科和不同学科的能力。如今随着社会、文化和科学的各方面急需转变，因此书中所提供的材料的目的是在于提供建筑和城市规划真正的前景，即使是对非本专业的认识也将有所启迪。

Certificazione scientifica delle opere
I volumi della collana sono soggetti a un processo di *Blind Peer Review* di cui è responsabile l'editore e, prima della loro pubblicazione, viene informato il Comitato scientifico.

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The volumes of the collections are subjected to a blind peer review process directed under the editor's responsibility, and supported by the scientific committee, informed of such process before the volumes publication.

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INDUSTRIALHOUSING
Or the way industrialisation can improve housing buildings

INDUSTRIALHOUSING
L'industrializzazione per la residenza

Gianluca Pozzi

MIMESIS
Materiali di architettura e di urbanistica

TABLE OF CONTENTS

LIST OF ABBREVIATIONS USED IN THE TEXT

BIM _ Building Information Modelling
DFMA _Design For Manufacture and Assembly
IBS _ Industrialised Building System
IPD _ Integrated Project Delivery
MMC _ Modern Method of Construction
OSC _ Off-Site Construction
OSF _ Off-Site Fabrication
OSM _Off-Site Manufacturing
OSP _ Off-Site Production
PPVC _ Prefab Volumetric Construction
RPS _ Robotic Prefabrication System
SCB _ Shipping Container Building

SOMMARIO

PREFACE

Elisabetta Ginelli
Politecnico di Milano DABC

I'm pleased to present 'Industrialhousing. Or the way industrialisation can improve housing buildings'. It is the result of years of studies by the Author, inside constant scientific research developed within Department of Architecture, Built environment and Construction engineering of Politecnico of Milan.

The book is among the contemporary debate on ecological transition, identified also by PNRR (Italian National Plane of Recovery and Resilience). It proposes, after a substantial cultural and scientific framework, possible guidelines of processual and technological solutions that are becoming more and more mandatory also for housing. I am referring to essential issues related to intrinsic qualities of the project, to flexibility, to end-of-life, in a comprehensive viewpoint embracing global themes of sustainability and resilience.

Housing industrialisation, today more than ever, is an unavoidable choice and is perfectly inserted in the new production system of Industry 4.0. For the first time, from the debates in the Sixties, the boundary conditions of the regulatory system and the political climate seem to facilitate this kind of approach.

European Green Deal asks for a change of paradigm, not only for building plants, but a radical rethink of housing approach, from design to construction system, management, transformation and adaptability. Technological Culture of Design area, in which this book is right located, can help to guide this time, in which you can easily find drifts toward informatics/engineering expertise or outward appearance of the gesture. It should be able to propose valuable solutions, feasible and easily transferable, without renouncing high quality buildings prerogatives.

The work starts from a useful glossary to frame the principal contemporary points of view on covered topics, then it analyses positive and negative aspects of industrialisation and prefabrication, also through market investigation and survey on stakeholders.

Thanks to a four dimensions SWOT, it relates in a systematic approach which factors can more affect pro and con choices for industrialisation. It also defines which negative factors can be overcome by an on-demand design method.

The original approach to innovation building chronicle allows to follow the evolution of the seven identified categories of the process, giving to each one its own place in the contemporary panorama.

The design guidelines are an executive synthesis that summarises factors that make the development of industrialisation difficult, together with possible proposals that can effectively overcome them and that belong to essential requirements of sustainability and resilience.

These guidelines are a helpful opportunity to reactivate the debate on which kind of innovation is possible and appropriate today and on which purpose we want to give to the housing project in the near future.

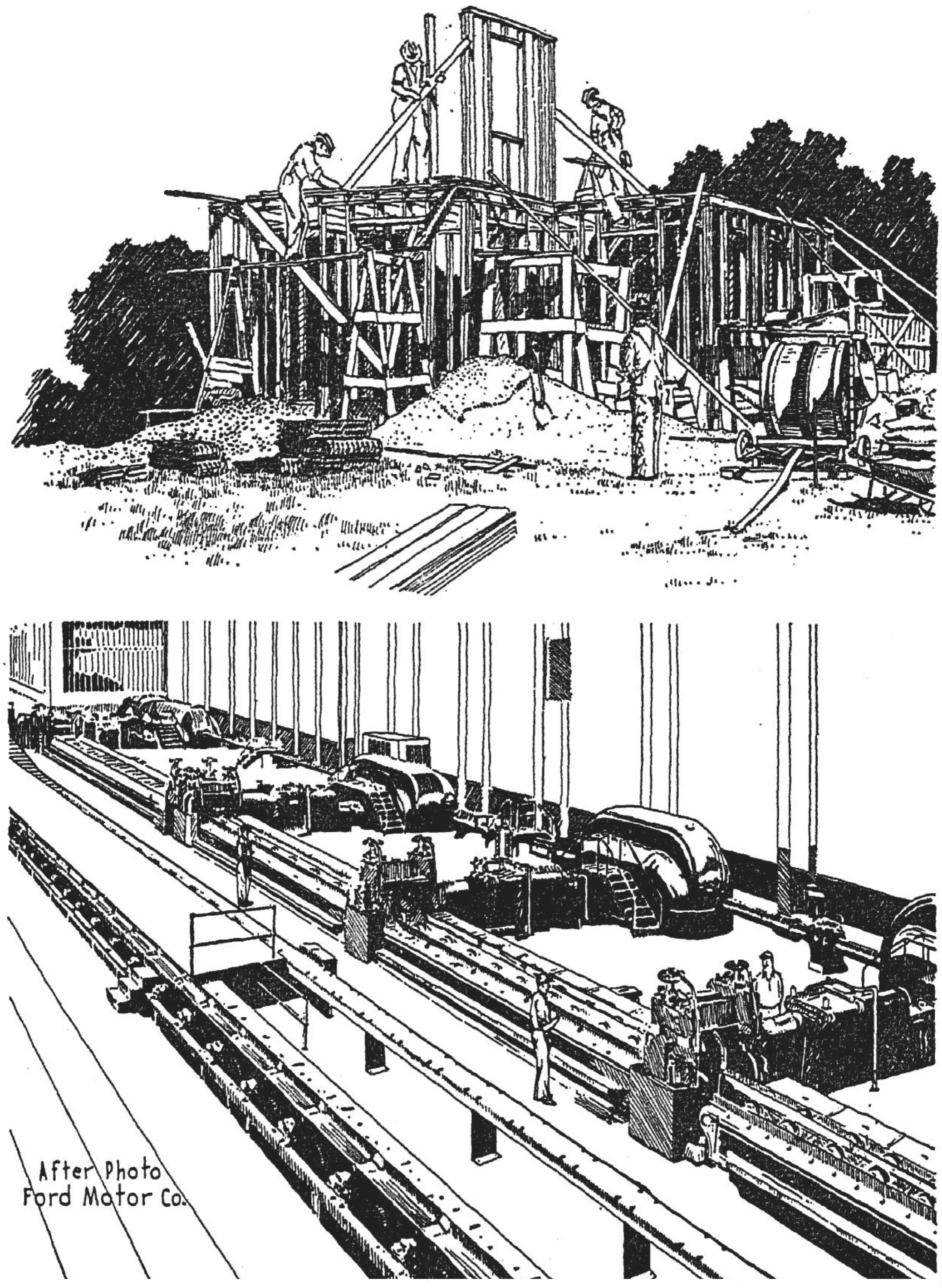


Fig. 5. CONTRAST BETWEEN HOUSE BUILDING AND MOTOR-CAR MAKING

The disorderliness of a typical house assembly and the order of the production line of a motor-car assembly plant

INDUSTRIALISING HOUSING
THE ROLE OF THE TECHNOLOGICAL CULTURE OF DESIGN

... la complessità è fatta di legami, di interazioni, di integrazione, di emergenza, di connessioni indisgiungibili; la complicazione è fatta di accumulazione, di differenziazioni, di composti scomponibili, semplificabili.
(Ceruti, Belluschi, 2020, p. 58)

The design of innovation and contemporary research lines

Technological Culture of Design has been reflecting on the concept of 'innovation' in building since its origins.

The word *Technological* is related to technology as *a means to fulfil a human purpose;* technology is *a set of practices and components*; technology is *the entire collection of devices and engineering practices available to a culture*. In the same way *Culture*: refers to the production of a spatially and temporally defined community and to the process by which theoretical and working knowledge is accumulated (Arthur, 2009; Campioli, 2017).

For the word *design* is meaningful the following definition:

«[Design] Un processo finalizzato o intenzionale, altamente innovativo e multidisciplinare, per la soddisfazione dei bisogni; processo implicante, in particolare, l'apporto dei fattori tecnologici originati dal clima culturale in atto»[1] (Ciribini, 1979, p. 78).

For the purpose of this book, design can be defined as *a process with an intention and a direction, innovative and multidisciplinary, starting from needs, creating relations that can involve heteronomy factors*.

It is possible to identify many guidelines that the technological design culture has been following in recent years: performance, quality, complexity, sustainability, resilience, performance based design, …, all supported by new research and development techniques, especially digital, but all with the potential risk of moving away from the project as a 'test case' (Torricelli, 2017).

Despite the risks and difficulties, they all try to overcome two major problems : a) the possibility of forecasting and interpreting the changing needs of society (for which concepts linked to sustainability and resilience have been introduced); b) creating system and integrating in a coherent way the exasperated specialisms (through BIM systems, big data, …) (Carrara, 2017).

Inside this complexity, we can summarise 3 current trend lines (Campioli, 2017) with which the technological culture is comparing: 1) design, sustainability and circularity of processes; 2) design, digitization and Industry 4.0; 3) design, uncertainty and resilience.

[1] A finalized or intentional, highly innovative and multidisciplinary process for the satisfaction of needs; process involving, in particular, the contribution of technological factors originating from the current cultural climate.

Opposite page: historical figures of 1936 that compares an 'industrialised' system of balloon frame to cars assembly line. See that the author calls 'disordered' the balloon frame system in 1936! (from: Bernis, 1936, p. 31)

1. The idea of *sustainability*, interpreted as reliability (Herzog, 2010), as intergenerational equity (Hausladen, Tucci, 2017), as durability (Jourda, 2010), was born in the '80s and it is now re-read within the processes of the circular economy (European Commission, 2017), in which what is waste for someone must be a resource for another, in the awareness that energy (but also polluting emissions, or any other parameter used to calculate impacts) must be calculated on the entire life cycle of the building, from the production of components to the disposal, passing from the management and the maintenance. From this approach the LCA (Hollberg 2016), LCEA (Cabeza, Rincón, Vilariño, Pérez, Castell, 2014; Carrara, Fioravanti, Loffreda, Trento, 2017), or building evaluation systems (Leed, Bream, PdR13, …) have evolved.

2. *Digitalization*, and therefore the possibility of monitoring every aspect of the production process and every aspect of each component of the building, sharing keeping and processing data and the possibility of creating networks of self-learning systems open up new scenarios with potentially infinite developments: smart building , smart cities (Terence, Sherratt et al. 2017), Internet of Things (Elkhodr, Shahrestani, Cheung, 2017), big data, BIM (Alreshidi, Mourshed, Rezgui, 2017), GIS. Also the next use of automated construction systems (Kasperzyk, Kim, Brilakis, 2017), such as 3D printers or machines that can autonomously build portions of buildings on site, are into this research line.

3. *Resilience* and the ability to manage (or at least deal with the minimum cost) uncertainty and risks are an interpretation of the current design issue. The resilient project must be able to deal with this uncertainty and must provide the system with tools to deal with unexpected changes and events.

Although having at least three approaches, design should always have a unitary view of the project that should precede the work of architecture. Factually, the culture, the place and exigencies have driven the choice of objects, that was tested by users monitoring, which had an intrinsic complex awareness of sustainability. The project was fully integrated between culture and practice, between idea and know-how. Today some authors (Heyes, John, 2014) have highlighted that buildings elements have an independent life, disconnected from the design system as a whole. From this consideration, this work identifies a kind of design[2] that could be 'independent' from objects. The cause of this contradiction could be born because of disconnection between design process and time, generating two opposing attitudes. Design just considers specific point of view on the project (energy, for example, or BIM or the logic of performance-based design) as the core of the building, fragmenting the design itself (Losasso, 2017) in its components without having a complete vision of it. On the other hand, buildings are just considered iconic landmarks to be shown without pondering social, economic and political features (Settis, 2017). On one hand, specific objectives such as energy efficiency are pursued unidirectionally by practicing the building/plant relationship or refined calculations are performed on the materials used to minimize risks or consumption, without however proposing organic design logic. On the other hand, marketing aspects (territorial or regional) overcome organic (global) sustainability.

Therefore the construction sector lives a fragmentation of knowledge which makes the project a mechanistic action. This annihilates the concept of

[2] See next chapter for a in-depth discussion in the concept of design inside construction process.

continuous improvement over time and therefore it lowers potential character of re-generation of value. This unbundling occurs when you lose connection between theory and practice, which leads to nihilism that eliminates the problem of meaning and the purpose to make architecture (Sichenze, 2011).

To avoid that *il digitale scolla l'intelligenza dall'azione*[3] (Floridi, 2017), it's mandatory that: «i) permanga una salda e condivisa guida culturale del progetto, in cui società e ambiente, idea e fattibilità possibile coesistano realisticamente, in una solidale sinergia tra aspetti ambientali, sociali, economici e istituzionali; per intravvedere strategie finalizzate all'equilibrio tra natura uomo e tecnologia; ii) si acquisisca conoscenza sulle potenzialità dello strumento digitale; iii) si forniscano norme di 'sistema' a supporto del dialogo tra i diversi aspetti della progettualità, secondo un approccio olistico che vede negli elementi culturali, naturali e tecnologici, un 'sistema complesso' che si integra e completa»[4] (Ferrara, Ginelli, Mocchio, Pozzi, 2020, p. 39).

For one vision of the design between temporality and anticipation overcoming deflections in theory and practice

Contemporary demands ask the architectural project for a change of paradigm, which finds its essence in the Technological Culture of Design. As Nardi expressed, «technological know-how is a method of design research that combines technical know-how and inventive capacity, which is therefore able to manage and orientate in a heuristic way technical solutions, rules and creativity» (Nardi, 2002, p. 24), It is the «the logical and cultural dimension within which the various manifestations and characteristics of planning are coordinated and brought into focus» (Hausladen, Tucci, 2017, p. 64).

This book falls under the context of design technological culture, which characterises methods, instruments, objectives and outcomes of design training, of design and the constructed architectural work. The architectural product is considered a resource offering the best performances in relation to usability and management over time of its own spaces and concrete technical elements; nonetheless, it needs to face feasibility and economic and financial management according to production criteria and objectives consistent with the achievement of a balanced relationship with the environment issue (Ciribini, 1984).

Therefore, technological culture is perceived as an intellectual instrument of design, and technology is interpreted in the sense of rationalising architectural imagination in the form of a new value for the art of building in a given present (Vittoria, 2008). It results in design principles giving direction to projects. Typo-technological flexibility becomes a vehicle for sustainability in its broadest meaning (environmental, economic, institutional, social, technical), paving the way for multifunctionality and resilience.

Design thus recovers its role of bringer of a strategic – but especially political, forward-looking and 'foreboding' – notion requiring bold and ineluctable solutions, able to trigger even profound changes in the current construction approaches and to envision building structures (Ginelli, Pozzi, 2017).

[3] *Digital divides intelligence from action.*
[4] i) a solid and shared cultural guide of the project remains, in which society and the environment, idea and possible feasibility coexist realistically, in a solid synergy between environmental, social, economic and institutional aspects to envision strategies that can regulate the balance between nature, mankind and technology; ii) to acquire knowledge on the potential of the digital tool; iii) 'system' norms are provided to support the dialogue between the different aspects of planning, according to a holistic approach that sees in the cultural, natural and technological elements a 'complex system' that integrates and completes.

The new paradigm (or the paradigm to be rediscovered) starts from the culture of the 'valorising' project: it's able to give to the used components (both material and immaterial) a real surplus value. Thanks to the relationships it is able to establish, it should not only maximize resources and minimize negative impacts, but should be able to generate potential energy, income, opportunities for development and improvement. This approach involves every aspect of the construction, in which the project is strategy oriented, as an action aimed at the sense of choices.

From a semantic point of view, the project should be predictive, not so much of the phenomenon, as a physical state, but predictive of changes. In other words, it must integrate the anticipation of the possible transformation of the building in order to get an adaptive and reactive answer to the transformative phenomenon.

The static nature of the construction must advance towards a dynamic spatial dimension, variable structure, supported by an articulated, open and multiple building system with a high level of variability of its technological elements (Ginelli, 2018). This idea of project must therefore assume some invariants, intended as essential cultural landmarks, such as: managing the variable *time*; controlled *transferability* of solutions with respect to the context and specific needs; design and production *innovation*; *qualitative multifunctionality* of the building system and its components; *adaptive* and *re-active* constructive system.

The project conditions, because of its process complexity, must constantly make specific aspects coherent and must help making pragmatic choices. For doing this, designers have to embrace a vibrant and organic tactic (Morabito, 2004) to define what and how the design should be. A definition of design that allows the designer «to design the plurality of points of view and to access the meta-point of view on all the different points of views…» (Morin, 1980, p. 179).

The 'Technological design of architecture' receives this method because it establishes its design as a permanent, feasible, research, expression of a wise management and, nowadays, including transformability and re-use, according to time, place and system variables.

The function of transformation is continuous and asks to consider the results over time, from time t_0 to $t_{0+x+y...z}$. This expansion allow to increase resilience and can introduce the concept of 'design for time' as a built-in feature of permanent mutation of design. As Ciribini said, mutation belongs to project, «in the current sense, it is a forward projection into the future, through action strategy, of a symbol-idea, original and unique in its being the image of a significant structure and at the same time the process of that structure's transformations, until it manifests itself in the form of a real object» (Ciribini, 1984, p. 50). This position considers time as a consequence of events, so that transformation develops from the understanding and the awareness of 'being'. For this reason, the project must include mixing variable functions, absorbing transformative coding. Following this logic, design needs to include transformational programming to obtain a mixture of variable functions, so that the project includes transformation in time, together with realisation and management. So design «acquires the specific connotations of a 'creation programme' […]» (Del Nord, 1988, p. 7).

Therefore, anticipation of decision becomes a key point and it asks to consider transformation phase in the building process. The design must assume an active role of a vector that can give an orientation to the plot of all the aspect of the project. The design should be able to place the project really inside circular economy at all scales at in all the stages of the process. This capacity introduces flexibility that «is not the exhaustive anticipation of every possible transformation. Many are unpredictable […]. Flexibility is creating a wide-margin capacity (degree of freedom) allowing for different and opposite uses and transformations» (Koolhaas, Mau, 1995, p. 37).

At the same way, other authors often use the words 'transformability' or 'reactive' to highlight the capacity of the project to embrace changes as chance of development, enhancing value and features in 'adaptive morphogenesis processes' (Mehaffy, Salingaros, 2015). 'Reversible' is another word-manifesto of contemporary research: authors (Mialet, 2017) and institutions (Construire Réversible by Canal Architecture[5]) are developing studies and reports that regive to flexibility in buildings a significant role in design process, especially in the early phases in which it can be more effective and beneficial. Then eventually flexibility is taking again the centrality in researchers' interest, above all regarding the end-of-life programming, in which it can help to fix sustainability from an economic and environmental point of view. Flexibility asks for systemic choices that involve, from the beginning, structures, plants, envelopes, access, movements, building proportions.

[5] https://canal-architecture.com/sites/default/filesystem/files/publications/construire-reversible-555/201704construirereversible.pdf (visited on 06/07/2021).

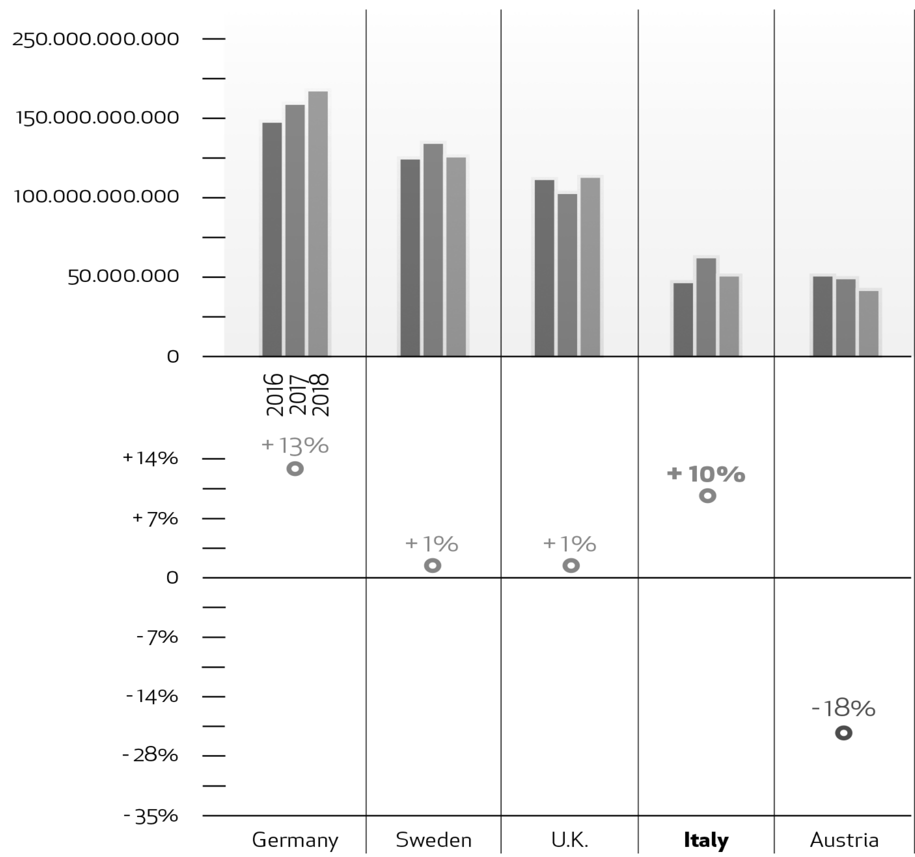
CONTEMPORARY HOUSING BETWEEN MARKETS, TRENDS, SCENARIOS AND CLASSIFICATIONS

What is the housing market asking for? There are many ironclad evidences that housing market has been asking for innovation for many decades (Losasso, 2010). This chapter analyses the innovation of industrialisation, its benefits and the barriers to its large-scale development.

Industrialisation in building construction is mandatory and inevitable to reach contemporary requirements and will give a reading key on the design to suggest which kind of industrialisation must be pursued today.

Here some facts are anticipated, especially related to residential market, concentrating on Italian market (usually considered very low industrialised) inserting some international data and considerations to clarify that possible role of the Industrialisation in building is a widespread and worldwide request.

Graph 1: Wood housing production (€ , var.% 2018/2016) (from: FLA, 2019)



Opposite page: cHOMgenius project prototype, Busnago MB Italy. Further information available at https://www.dabc.polimi.it/en/ricerca/ricerca-competitiva/chomgenius-prototypesystemsharedproject/

Official reports assert (confirming the tendency of previous reports) that Italy is in a new building cycle in which the demand for quality of constructions is increasing and in which around the 15% of new private residential buildings uses non-traditional techniques or components, such as plasterboard, pre-assembled counterframes and plants, pre-fab stairs,... (CRESME, 2020). Part of new houses are pre-finished with all-inclusive bathroom and often with finished kitchen: the tendency is certainly to increase the general quality, to facilitate the moving of the inhabitants, to keep high performances even thanks to an assisted maintainability.

This trend is confirmed by sector reports, fixing +10% (2016-2018) (FLA, 2019) the increase of economic amount of wooden house market (see graph 1 above), with an increasing prospect in next years (around +5% in 2024[1]). It's not a big market (630ml €/year) but it has been increasing despite any crisis and so can be a good litmus test to check the tendency of the future market. This market generates full-finished houses, most of time with pre-assembled elements, for which the owners ask for guaranteed quality, certified sustainability and definite short construction times. A look at the international situation not only confirms this tendency but shows that many Countries are supporting and funding innovation and industrialisation in housing market.

UK, for example, strongly supports[2] Modern Method of Construction as an answer to lack of poor quality of housing. Some guidelines are very interesting for this market trends: «step 2: Building homes faster; step 3: Diversifying the market, thanks to 'Boosting productivity and innovation by encouraging modern methods of construction (MMC) in house building'[3] and increase (1.49) 'Building good quality homes'» (Department for Communities and Local Government UK, 2017, pp. 18,19).

It appears clear from the graph 2 that the gap between the different trend of whole economy and construction: even in a country as UK considered 'industrialised' the construction market had a very few increase in 25 years,

Graph 2: Productivity indices (1990=100): whole economy vs. construction (from: Department for Communities and Local Government UK, 2017)

[1] Fact confirmed also by https://www.freedoniagroup.com/ quoted on 'Il Venerdì di Repubblica' of 03/07/2020.

[2] Such as (visited on 06/07/2021):
http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/housing-communities-and-local-government-committee/modern-methods-of-construction/written/101503.pdf.
http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/housing-communities-and-local-government-committee/modern-methods-of-construction/written/101438.pdf.

[3] 'Industry reports suggest homes constructed offsite can be built up to 30% more quickly than traditional methods and with a potential 25% reduction in costs' (from: Department for Communities, 2017, p. 54).

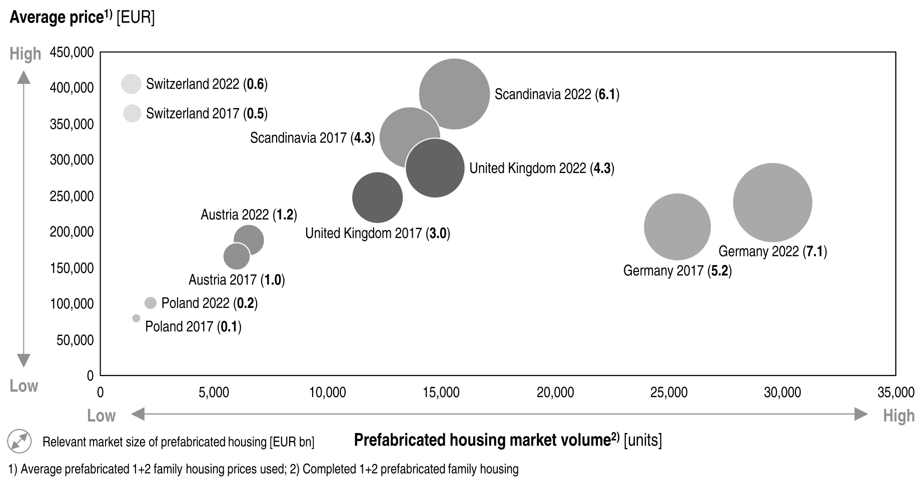
confirming the mandatory necessity of a change.

Around the world, all market's reports[4] confirm that Industrialisation processes are increasing for housing market, especially because «planning security and comfort level to be a key driver in the purchasing decision for prefabricated houses»[5]. The graph 3 well shows the consistency and the trends of prefabricated market.

The last confirm of this tendency can be found in France, where a recent report[6] (February 2021) commissioned by France's Government to Real Estech strongly confirms that off-site construction is the only possible solution to innovate a not-investing and not-innovating sector as constructions one.

The market is increasing in consistency and dimension in all considered European countries, confirming that this kind of innovation is affordable and competitive. Next chapters will propose interpretations of this success.

Beside independent reports, in the last years many associations have been born to study, promote and spread pre-fab systems. Here only two of them, from which this work has taken data and enlightenment: www.modular.org, www.prefabnz.com. They, of course, confirm the benefit of pre-fab and modular systems. They are interesting above all for market survey, new realisations, new products and techniques.



Graph 3: The market value of prefabricated 1+2 family housing is expected to grow across all focus regions between 2017 and 2022. Overview of market development, 2017 vs. 2022. From: https://www.rolandberger.com/publications/publication_pdf/roland_berger_prefabricated_housing_market_3.pdf p23 (visited on 07/06/2020)

The house between resilience and sustainability

Resilience and sustainability are two of the main research lines of technological culture in these years: in this book they are considered from the design process point of view, so giving them particular meanings strictly linking to industrialisation.

Sustainability is considered in its aspect of *durability*, intended as (Jourda, 2010) 'durable': in a complete circular economy conception, construction should be a sort of tank or bank [7] so that the material and components are just frozen for some years in a place, ready to be easily re-used somewhere else, or at least re-cycled and so they can live many decades and many lives.

[4] https://www.freedoniagroup.com/ https://www.fortunebusinessinsights.com/industry-reports/modular-construction-market-101662;https://www.grandviewresearch.com/industry-analysis/modular-construction-market;https://www.alliedmarketresearch.com/precast-construction-market;https://www.rolandberger.com/publications/publication_pdf/roland_berger_prefabricated_housing_market_3.pdf (both visited on 06/07/2021).

[5] https://www.rolandberger.com/publications/publication_pdf/roland_berger_prefabricated_housing_market_3.pdf p16.

[6] https://www.batiactu.com/edito/construction-hors-site-solution-un-secteur-qui-investit-61316.php?MD5email=29a48073748b8330ec53410002129671&utm_source=news_actu&utm_medium=edito&utm_content=article.

[7] See https://www.bamb2020.eu/ (visited on 25/05/2021).

This introduces *reversibility*, as the second aspect of sustainability, as some authors confirm (Bologna, 2002; Mialet, 2017). We do not consider other parameters of environmental sustainability (energy or Co2 emission in use, consumption, LCA, percentage of 'green' materials or renewable energy …) because these parameters can be applied almost to every 'good' and smart building. The work concentrates on durability and reversibility because they are the basis of a systemic approach to the project, especially for including buildings in 3Rs principles.

The approach to *resilience*, likewise, is a specific and non-common point of view, considering the concept of active-resilience, for which the right design can give value to buildings incorporating them into dynamism and flexibility able to predict changing disturbances and future requirements.

The relationship between resilience and sustainability is investigated by some researchers (Marjaba, Chidiac, 2016) who have an ecological/economic point of view. This approach can be summarised by the proportion (Faber, Qin, Miraglia, Thöns, 2017):

LQI: resilience = LCA: sustainability

in which LQI corresponds to the Life Quality Index, while LCA corresponds to the Life Cycle Assessment, and proposes, if not a summary, at least one possible methodology of comparison and comparative measurement. Other authors consider these two concepts very distant and difficult to approach, because the first is a dynamic system properties describing parameter (Derissen, Quaas, Baumgärtner, 2011); the second is a normative concept that is part of the idea of intergenerational justice.

Others add the concept of *adaptability* to the combination of *resilience* and *sustainability* (Carmichael, 2015). Adaptability is often understood (Pinder, Schmidt III, Saker, 2013) as the ability to change to 'pursue' an external change, often climate (Botti, Ramos, 2017) or catastrophic (in this case, adaptability is closely related to *resilience* (Fazey et al., 2007)).

It is also linked to the concepts of *maintainability* and *reliability* (Oliver, John, Sebastiano, Re Cecconi, Dejaco, 2017). In others, adaptability relates to the concept of *reuse* (Lovell, Smith, 2010) or to the concept of *easy demolition* and/or *deconstruction* (Webster Mark D., 2007). A special agreement exists between adaptability and *flexibility*[8] (of which adaptability is in some cases a manifestation), which often makes them privileged forms of resilience (Carmichael, 2015) and even of quality (Esin Altas, Özsoy, 1998), as well as sustainability (Gosling, Sassi, Naim, Lark, 2013).

Also from these last points of view, resilience and sustainability are strictly joint together, not only because of adaptability, but because they can have many aspects in common in innovative construction systems, for which sustainability and resilience are mandatory.

This approach comes from the necessity of welcoming complexity (Morin, 1980) even for building process, remembering that complexity asks for multi-approach, contamination and uncertainty, but that is fruitful and can enrich every project (Ceruti, Belluschi, 2020).

[8] Flessibilità progettuale: la capacità dell'idea-progetto a non esaurirsi in una risposta univoca (Mandolesi, Carrara, 1973) p. 30 (Design flexibility: the ability of the idea-project not to be exhausted in a single answer, ed.).

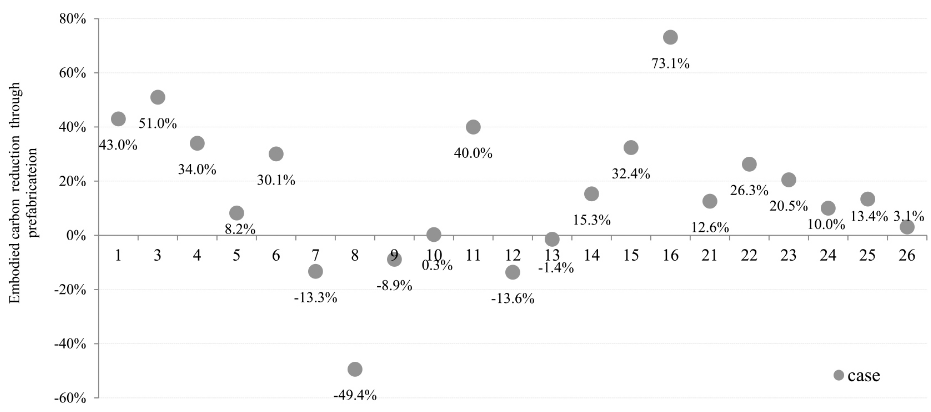
Sustainability

The contemporary direction of construction world (EU CPR[9] , UNI Pdr 13[10], CESBA[11] , EU SMART building[12]) asks for sustainability related to 3Rs' principle (Reduce, Reuse, Recycle). This requirements is necessary not only for each component, but also for the entire building, as end-of-life studies are highlighting. Industrialised Building System (IBS) can be an answer to this mandatory request and seems to be a good direction to get sustainability in constructions, from an economic, an environmental, a social and an institutional point of view, as the SWOT analysis of next chapter shows.

In addition, IBS strictly relates to the idea of module and it is currently strictly involved in BIM system approach, that is another recurring mantra in construction nowadays for sustainability and reliability. This assertion is clearly confirmed by many studies and reports. For example Frost&Sullilvan's Future of Construction, Global, 2030[13] affirms that prefabrication is one of the six top trends «that will shape the future of the construction industry. The study maps 6 trends and 20 sub-trends that will directly/indirectly impact the global construction forum while mapping a 5-10-year trend horizon which includes the market status, predominant opportunities, and key milestones».

The fourth trend Frost&Sullivan's report quotes is sustainability that can be split in 3 sub-categories «*standard*, *prefabricated*, *modular* concepts will enhance compatibility among building and infrastructure projects, improve economies of scale, enhance productivity, and accelerate the industrialization of the construction industry». AMC journal[14] has an in-depth dossier on IBS (Mialet, 2021) asserting, among other benefits, that IBS and its conception is strongly sustainable from many point of view. Other studies have made a deep review of scientific literature on reduction of carbon emission through prefabrication, compared to similar cases made by traditional/on-site process (Teng, Li, Pan, Ng, 2018). The results of their analysis confirm that IBS reduce, on average, embodied carbon by 15.6%, compared to traditional base case (see graph 4).

This study anticipates the benefits of IBS identified on next chapter, introducing metric comparison and highlighting some gaps in knowledge, including gaps in end-of-life of building and steel prefabricated housing analyses.



Graph 4: Embodied carbon reduction of prefabricated buildings compared with their traditional base cases. X=26 cases; Y=% of reduction. As confirmed by authors, negative cases are probably more related to lack of knowledge and assessment tools than to a real greater embodied carbon of IBS (from: Teng et al., 2018, p. 132)

9 Construction Product Regulation, REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.
It introduces this requirement: 7. Sustainable use of natural resources. The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:
- reuse or recyclability of the construction works, their materials and parts after demolition;
- durability of the construction works;
- use of environmentally compatible raw and secondary materials in the construction works.

10 Prassi di riferimento - Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità.

11 Common European Sustainable Built Environment Assessment – www.cesba.eu (visited on 12/03/2020).

12 DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

13 https://store.frost.com/future-of-construction-global-2030.html#:~:text=Frost20%26%20Sullivan's%20'Future%20of%20Construction,future%20of%20the%20construction%20industry.&text=Autonomy%3A%20The%20construction%20industry%20will,challenges%20for%20the%20construction%20industry (visited on 25/05/2021).

14 https://www.lemoniteur.fr/archives/amc/2021 (visited on 25/05/2021).

For filling the gap on end-of-life analysis and identifying possible features of innovative IBS, together to LCA and LCCa[15] indicators on sustainability, we can introducew 2 synthetic categories, Durability and Reversibility. Just remember that durability and reversibility are intrinsic asks of the UE 7th requirement for construction, as the aforementioned REGULATION (EU) No 305/2011 quoted above. They can be defined by 9 sub-categories (some of which are clearly in common to both categories and some can be related primarily to one category, even if it has some links to the other one), as the table below shows.

Durability is the capacity to maintain its own characteristic and performances during time[16].

Reversibility is the easy turning back of an action or intervention without damages[17].

In the following table, the left and right columns decline sustainability in durability and reversibility. Central grey column collects the sub-categories that can be referred to sustainability of materials, components or entire building.

Table 1[a,b]: Categories and sub-categories of sustainability for IBS. *materials: simple elements that make components, made by external market factories; ** components: parts of the buildings, assembled in external factory or in the off-site assembling point of building; *** building: combination of components in the off-site assembling point, generally an industrial warehouse. See beyond for definitions of sub-categories. 'X' in left and right columns under 'durability' and 'reversibility' indicates if the considered sub-category belongs to that category of sustainability.

Table 1[a]. Categories and sub-categories of sustainability for IBS

Categories of SUSTAINABILITY							
Durability		Sub categories					Reversibility
		Sub category related to:	Materials*	Components**	Building***		
Disassembly of components guarantee the easy replaceability of components for customisation or damages	X	Disassembly		X		X	Disassembly of components is a mandatory requirement for dis-assembly a building in its components, guaranteeing reversibility
		Dry clamping joints		X		X	Joints, made by dry clamping, assure a complete and easy dis-assemblability of components
		Easy assembly			X	X	Assembly should be easy and fast: this is the only way to guarantee quality and dis-assemblability
Long life for building and components is mandatory for durability and, consequently, for sustainability[18]	X	Long life guarantee		X	X	X	Long life guarantee is a pre-condition for reversibility because the investment on reversibility can be affordable only in long-life building and systems

15 Life Cycle Carbon.
16 See also Durability Implications, http://www.canadianarchitect.com/asf/enclosure_durability/durability_implications/durability_implications.htm; https://www.greenbiz.com/article/durability-key-component-green-building visited on 05/06/2018.
17 See UNI EN 15898:2019 _ Conservation of cultural heritage - Main general terms and definitions.
18 See (Jourda, 2010), considering that 'durable' is the French word for 'sustainability' in construction.

Table 1[b]. Categories and sub-categories of sustainability for IBS

Categories of SUSTAINABILITY							
Durability		Sub categories				Reversibility	
		Sub category related to:	Materials*	Components**	Building***		
Off-site assembly of components and building guarantees high quality level of industrial process that assures durability and long life to building	X	Off-site		X	X		
Easy maintainability is mandatory for durability of components and building	X	Maintainability		X	X		
		Recyclability	X			X	Easy recyclability is one of the possible strategies of reversibility: if materials are recyclable, the building components can return to their own raw materials
Re-use is a pillar of sustainability: if a component can be re-used, its life is longer and more sustainable	X	Re-usability		X		X	If you can re-use components using low energy and at low cost, building reversibility is more affordable and sustainable
		Separability	X			X	Turning back of components and buildings is affordable only if materials can be easily separated in their sub-elements and raw material.

These categories and sub-categories answer to contemporary needs of sustainability from the design and end-of-life point of view: they have a project and an orientation purpose for helping design strategy and building process. The table synthetizes the two main considered aspects of sustainability, such as durability and reversibility. Central grey column collects the sub-categories referred to sustainability of materials, components or entire building, marking with 'X' the correspondences between the sub-category and the two declinations of sustainability.

In order to clarify better these categories, this chapter uses the just finished project cHOMgenius as an example of an innovative industrialised building system for housing, taking its technical solutions as best practice demonstrating the feasibility and the validity of the proposal and the robustness of the methodology.

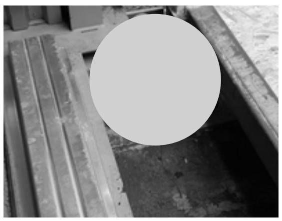
'cHOMgenius. PrototypeSystem and SharedProject. Extraordinary solutions for intelligent living' is a shipping container building (SCB), completely off-site, with dry clamping technologies, completely disassembling and morphologically flexible, focused on the reuse of dismissed modular elements, employing industrialized multifunctional components and products with environmental certification and solutions for the seismic control, thanks to a specially designed dissipation device.

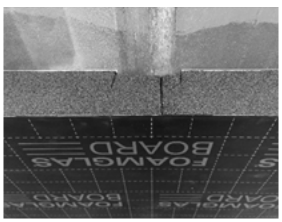
It was designed and built by department ABC of Politecnico di Milano, in partnership with BFC Sistemi srl and Whiteam srl, with the collaboration of UNI (Ente nazionale Italiano di Unificazione) and the fundamental support of 20 national and international companies. The project was partially funded by the Project Smart Living of Regione Lombardia. It is open and visitable in Busnago MB Italy (https://www.dabc.polimi.it/en/ricerca/ricerca-competitiva/cHOMgenius-prototypesystemsharedproject/). For these reason the following table gives definitions of categories together with images of the cHOMgenius's prototype that well esemplifies the considered category.

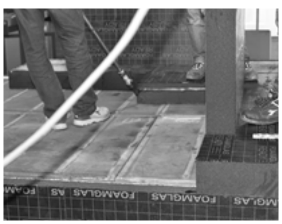
[19] https://www.lifecyclebuilding.org/docs/DfDseattle.pdf (visited on 03/06/2021).

Table 2[a,b]: Sub-categories of sustainability for IBS with definitions and examples from cHOMgenius project

Table 2[a]. Sub-categories of sustainability for IBS		
Sub-category	**examples from cHOMgenius project**	**Definition on-demand process**
Disassembly	Driving of the screw pole as foundation: no use of concrete, water or other systems requiring time and energy to be removed	«Maximizing materials conservation from building end-of-life management, and create adaptable buildings to avoid building removals altogether»[19] thanks to dry techniques and reversible joints
Dry clamping joints	Dry joint between external insulation (Foamglas – dry-laid) and window counterframe (Alpac) sealed with auto-blowing tape	Reversible joints made only by mechanical elements, without water, glue, welding (new definition)
Easy assembly	Intertwist dry joint that centres and fixes HC second floor	Easy assembly







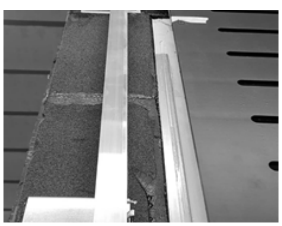


Table 2b. Sub-categories of sustainability for IBS

Sub-category	**examples from cHOMgenius project**	**Definition on-demand process**
Off-site	HC preparation in workshop	Off-site is a process that incorporates prefabrication and pre-assembly [...] involves the design and manufacture of units or modules, usually remote from the work site, and their installation to form the permanent works at the work site (Gibb, 1999)
Long life guarantee	Use of corten, stainless and magnesite steel, dry joint in workshop	Ability of a component or a building to perform a required function for a planned long time (depending on components, even hundreds of years) (ed.)
Maintainability	Seismic system inspectable from above and outside the building, with easy replaceable damageable components [obscured because patent pending]	Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources[20]
Recyclability	Foamglas vertical insulation dry joint to the vertical externa wall of the container: all the components are completely recyclable	Ability of an item, product or system to be recyclable, becoming a second raw material (ed.)
Re-usability	Re-use of the floor of the container as rooftop of the second floor container	Ability of an item, product or system to be used after its useful life in a building, without using energy or with no transformation processes (ed.)
Separability	Vertical wall external covering: insulation (Foamglas), under-structure (Etancò) and external panels (SIL lastre) completely dry joints and easy dismountable	Ease of decoupling any homogeneous material constituting a part or a whole.[21] It is guaranteed by the use of materials that are not coupled, fixed together only by dry tightening systems. All components are traceable to their initial state.

The table shows the highlighted sub-categories of sustainability, related to the concepts of durability and reversibility. These nine features can also be considered as design strategies to deal with the project: each one can be considered as a status of the project and can have a design impact, driving every choice of the design from the initial concepts of the building.

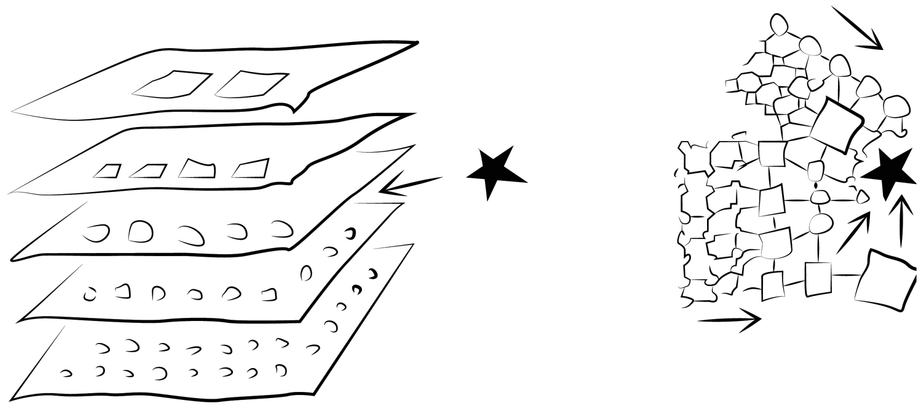
Resilience(s)

This research introduces the idea of resiliences, instead of resilience. It starts from the assumption that resilience for builgings is in the project, especially in the design phase, more than in the objects or of the objects. The word 'resilient' does not have a univocal definition within the scientific community and perhaps it will never have because its definition structures more deeply itself in individual applications from time to time. If we want to give a feature to resilient technology, this is certainly the word 'simple': even if the project will undoubtedly deal with complexity, the objects that implement the resilience are simple objects, easy to realize, low-cost, durable, reliable, easy to repair, that do not require heavy maintenance. An example can be the so-called 'semicomponenti (semi-components)' (Ginelli, 2002), objects that have a high functional value, but a low technological level. Among others, there are four line of investigation in which a system based on resilience approach could be very effective and productive: the management of water at big scale (hydrogeology and control of the territory), management of big data, as collection, processing and storage of information; involvement of finance for rapid and shared reply to events; engagement of local communities for participation in control and restoring thanks to new tech-nologies and grid of contacts (Da Silva, 2017).

The economic, the social, the organisational and the technical dimensions of the resilience can be associate to four properties (resistance, speed, redundancy and resourcefulness) and three effects (higher reliability, faster recovery and fewer consequences) (Bruneau et al., 2003). This is the starting point to analyse the connections between resilience, design and housing. Products and process resilient must be economically sustainable, inclusive and open. For doing this R&S should be increased thanks to university research and public investments. Companies should give up programmed obsolescence logic in favour of long term, upgradeable systems that also use redundancy ac-cumulating resources and information in a network grid fast to respond to changes or perturbations.

The three basic characteristics of resilience - absorptive, adaptive, transformative - are all fundamental, interrelated and reciprocally decisive. Because of this, in the definition and measurement of resilience, it is necessary to consider simultaneously all of them. The dynamic nature of resilience compels a dynamic measurement, in which the frequency of measurement is itself a planned decision (Gregorowski, Dorgan, Hutchings, 2017): these three versions of resilience coexist constantly at different scales and reinforce each other (Jeans, Castillo, Thomas, 2017). For this reason, the only key to interpret and correctly support resilience is the implementation of collaborative interactions between all sectors at all levels, as the below image shows.

[20] UNI EN 13306:2018 - Maintenance - Maintenance terminology.
[21] ISO 20887:2020 _ Sustainability in buildings and civil engineering works - Design for disassembly and adaptability - Principles, requirements and guidance.



A complex resilient system coordinates its response to a disturbance phenomenon, and this response involves every single dimensional scale, from the smallest to the largest (from: Mehaffy, 2015, p. 6)

Resilience asks for complexity, especially for buildings, in which physical and structural elements work together with human and social (Villanueva, Gould, Pichon, 2016) activities. Eco-system are connected in a non-linear network, almost instable and uncontrollable: every project should be aware of this interdependence and must be able to create new connections, adaptable and open, that can accept transformation as an opportunity.

In addition, considering the institutional dimension of resilience, flexibility and openness of stakeholders are mandatory prerequisite for organising active grid and adap-tive systems. This should be pursued at all the scale of control, by which the level of resilience directly depends: rigid and slow control process do not allow high level of resilience (Folke et al., 2002). Forecasting settings and scenarios, on the contrary, could involve complementary prospects, if they are flexible and open to changes from the first steps of the process. This institutional dimension of resilience is deeply jointed to the social and political decision making systems, that are often not ready to manage resilience (Eakin et al., 2017). They do not involve an adequate number of stakeholders and do not have models and tools for making the right choices, also because they often think that changing due to uncertainty is a cost and not an opportunity.

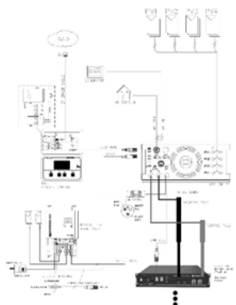
With this background and evaluating resilience with the paradigm of complexity, we can entrust resilience with a more active role. Usually, in fact, the factors that indicate resilience are related to the capacity to resist/adapt/react to any negative perturbation. The resilience we want to pursue is an 'active resilience', defined as «the intrinsic capacity of the project to generate active value within the building system» (Ginelli&Pozzi, 2019, p. 538).

An active-resilient project is able to anticipate change, rather than implementing reactions to events. This is possible because an active-resilient project create a network between the components (material and immaterial), aware that changing is an intrinsic characteristic of every open system, especially buildings that are exposed to climate conditions, degeneration due to time and use, functional and normative obsolescence. The active-resilience can also be the junction point between resilience and sustainability, because active-resilient project can be driven to a specific direction as, in this, case, sustainability.

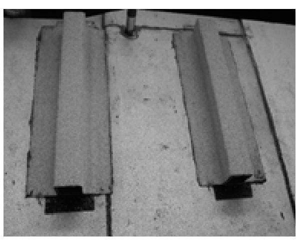
The following table synthetises, with examples and definitions, the resilience requirements for the project, using, as before, cHOMgenius project as an example.

Table 3[a,b,c]: Active resilience elaboration, definitions and realised example from cHOMgenius project for validating the theoretic point of view

Double-height floor made by overlapping an overturned HC on a base HC, demonstrating the high flexibility and spatial and structural potentiality of the system (it is the first example of this use of HC)



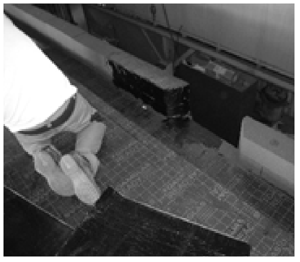
Part of the 'energetic network' of the system, with self-learning and predictive algorithms



An easy and certified system for fixing solar-cells support bars to the cover, using the same super-reflex white membrane (Index) of the cover: this guarantees no piercing of the cover, durability of the membrane and easy re-use or modification of the above plants and supports

Table 3[a]. Resilience requirements for the project

Technological-functional requirements	**Examples of object requirements**
Flexibility	Convertibility
This design invariant facilitates the enhancement transformation, synonymous with architecture and bâtiment durable, whose value is determined by the ability to change quickly at a low cost (Ginelli, 2010)	It is the constructive process that indicates the concrete possibility of activating - once the temporary function of the artefact is exhausted - an inverse process of de-construction through which it's possible to 'free' the material and the spatial resources engaged to allow the re-integration into the environment from which they have been taken or the re-introduction into a further production cycle (Bologna, 2002)
Predictive and adaptive project	Smart object
Forecasting and anticipating decisions are essential to strongly characterize the project as 'predictive'. This quality does not refer so much to the phenomenon, as a physical state, but refers to all acceptable changes, integrating the anticipation of the possible transformation up to arrive at a resulting systemic adaptive and reactive to the transformative phenomenon design	The use of 'self-learning' systems, which 'learn on their own over time', allows us to better react to external stimuli and user needs. Networking ensures a continuous and coordinated monitoring and evaluation of the performances (example: appliances able to 'choose' the best time to turn on - when, for example, there is more availability of solar energy)
Reactive project	Durability re-functionalization
It is the ability to facilitate the material and functional adaptation of the building components to new circumstances, exploiting changes (physiological or unexpected) as an opportunity to increase their performance	Durable and certified products should be preferred, in order to be used in specific times and, at the end of their life, they must be reused as a primary resource and recyclable as a second resource (Jourda, 2010)



Roof gutter made by Foamglas, without metal flashing: insulated, waterproof, durable, efficient and easy. As a further and double protection, there is above a white super-reflex membrane (Index)

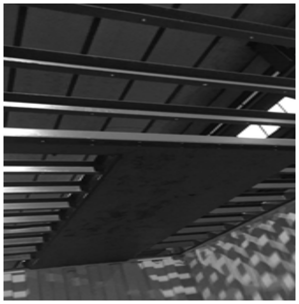
The HC container as the most replicable and industrialised component of the prototype

The energy core of the system: an integrated skid for energy and environmental management. Low voltage heat pump integrated to a bio-ethanol co-generator, automatically regulated

Table 3[b]. Resilience requirements for the project

Technological-functional requirements	**Examples of object requirements**
Redundancy of systems	Multifunctionality reliability fault tolerant design
The duplication of critical components and / or key functions of a system increases its reliability and availability. This can guarantee the safety of people and facilities or the continuity of production in case of an event or unexpected changes. Redundancy can be a key strategy for the success of a project, even from the point of view of the built-in energy as it can increase the useful life of the building and significantly reduce repair and / or restoration costs	Redundancy can be declined in object requirements that can guarantee reliability and fault tolerance: circular routes, for example, can improve the reliability of the entire system. Furthermore, the use of undifferentiated components (no component must have a specific function that makes it unique) can guarantee low intensity and low repair and / or modification costs. These, and other requirements, contribute to the global multi-functionality of the building
Replicability	Industrialization and prefabrication
Strategies for a resilient project must be replicable strategies for other projects. Replicability should not lead to standardization or non-personalization of the final product	Replicability can be achieved through production in workshop and easier installation phases, the use of prefabricated elements and clamping technology solutions, leaving only the installation and assembly operations to the construction site (Ginelli, Pozzi, 2017)
Sharing	Guarantee of communication
The sharing of information, energy, space, etc. presumes a sharing of information, interaction with the project as well between the technological components of the building and between the operators/users, in a co-design approach	Sharing presumes a guarantee of communication between the actors of the project, between the components/ systems of the building and between users/ planners/maintenance technicians, ensuring remote and automatic controls through the identification of the components/elements at risk

Table 3c. Resilience requirements for the project	
Technological-functional requirements	**Examples of object requirements**
Soft approach	Continuous / discrete Small network elements and accumulations
From a functional point of view, a resilient approach rather than opposing a 'force' to perturbative events, must provide a strategy based on the absorption and distribution of perturbations and the facilitation of transformation	The soft approach can be declined in objects and continuous systems, which do not have a step or a preordained scheme, but can be modified without interruption (spatial, energetic, aggregative, etc.). These systems involve the use of 'smart' components, small and networked and part of a grid, rather than large, robust and very expensive components and must be aimed at the intelligent management of accumulations (of meteoric water such as the green roof, of mass for hot climates, of hot water in tanks or electricity in batteries)
Technological flexibility	Accessibility, maintainability, substitutability, equipment and transformability
Characteristic of the technological nodes and/or parts of them (products, components, etc.) to be able to adapt, modify, integrate, replace, maintain over the lifetime of the building. It represents the ability of the building organism to facilitate the work of maintenance, requalification, reuse in the logic of the circular economy	These requirements are understood as: inspection of each sensitive component, disassembly and substitutability of parts that can be worn and / or damaged, with consequent transformability to achieve upgrading


The HC container as a continuous structural hyperstatic steel box, instead of one-dimensional resistant elements

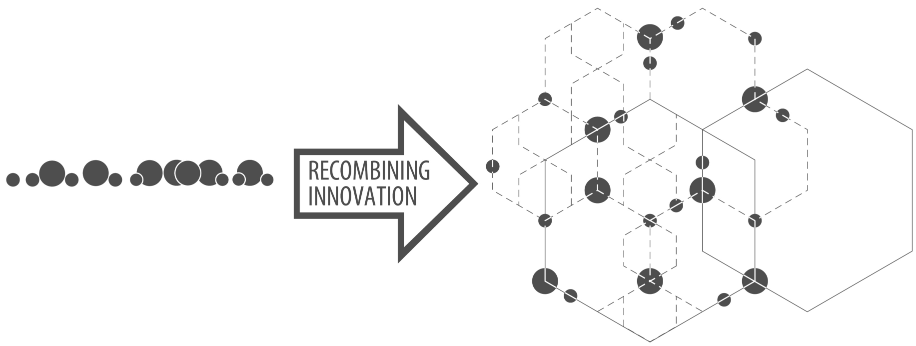

All electric plant is at sight, easy transformable, inspectable and upgradable

As the table 2 for sustainability, the above table 3 shows possible sub-categories of resilience as technological-functional requirements, giving possible explanation and examples and associating an illustrative image of cHOMgenius. These design suggestions can drive project choices for elements, components and technological solutions. cHOMgenius does not aim to be the right solution: it just exemplifies that easy and affordable solutions are possible and feasible.

Within such scenario, the discussion about design is taking over the concept of 'resilience'. We intend hereby to include this quality by considering resilience design as a strategy, which assumes both uncertainty and change as fundamental elements (Perriccioli, Ginelli, 2018). This entails bold choices in terms of building and management, which are defined by 'predictive' design absorbing transformation more as an intrinsic characteristic, and less as simple anticipation of potential phenomena. Hence the idea of an 'adaptive/active' resilience, i.e. capable to provide adequate responses to change, not so much through immediate physical reactions as through our own systemic nature reacting to transformation.

Design thus becomes a means of valorisation, turning from a condition of pre-established plot to one of transformational vector wherein resilience and adaptation get imprinted on the system, which is the pivotal forum for investments of time and resources.

This Active Resilience can give value to the project thanks the appropriate design.



The VALUE-GIVING recombining Innovation role of the design (original elaboration)

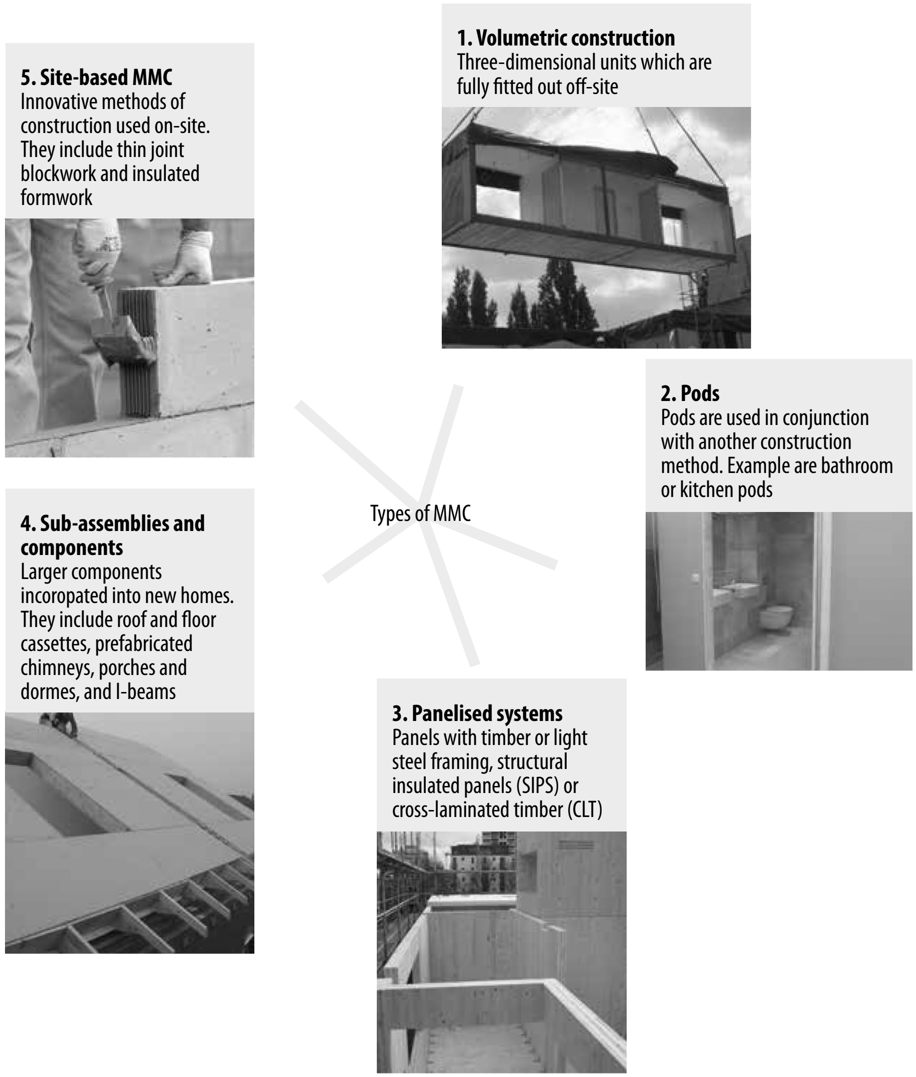
The above image visually explain this concept: black globes are components, which can be material (objects) or immaterial (knowledge, techniques, software …) and could have their own resilience. Thanks to design they can be combined and re-combined giving a new 'structure' of connections. Recombining innovation is defined as the capacity to create value connecting in a smart way products and knowhow, since this project could create the right conditions for companies and designers to let their ideas and outputs being 'better' thanks to the network they create with others. In addition, the new structure has, also figuratively, a more 'resilient' geometry, able to afford negative events or environmental changes.

Elements for a contemporary glossary: a proposal of a fluid classification system

Industrialised Building System (IBS) is one of the most explored topics in construction. From building like Paxton's Crystal Palace (year 1851), the scientific community has been investigateing this topic in thousands of projects and papers, exploring its potentials and its possible development.

However, the boundaries of industrialisation in building construction are not clear or conclusive still nowadays.

This uncertainty depends on one hand on the inner fluidity of the market itself and on the other hand on a terminological ambiguity. As an example of this ambiguity, we can introduce seven categories to classify IBS: 1 Frame System (pre-cast or steel), 2 Panellised System, 3 Onsite fabrication, 4 Sub-assembly and components, 5 Block work system, 6 Hybrid System, 7 Volumetric and Modular System (Mohamad Kamar, Hamid, M.N.A, Ahamad, 2011). Its proposal, borrowed from scientific papers, certainly works well in Malaysia where it is applied, but it seems generally uneven because Onsite fabrication could use Hybrid System or some prefabricated components.



Example of possible conventional classification based on components: MMC - Modern Method of Construction (from: NHBC, 2008, p. 8)

This problem has become more evident in the last decades, in which together to ‘traditional’ techniques many advanced systems were invented (3D printing, light buildings,...). Furthermore, even entire Countries (e.g. Malaysia) invested many resources for developing IBS in its building asset, increasing systems, techniques, tools and knowledge in this field.

Even though inside a dynamic and fluid system that cannot be fixed once and forever, the purpose of this chapter is the collection of the most effective and used classifications and definitions on these semantic topics. It proposes classification systems that, starting from the role of the design inside project process and from scientific literature can help the scientific discussion and the market develop and in which each technique (even the ones not yet invented) could find its place.

As anticipated above, one of the biggest problem of the scientific research on industrialisation is the semantic ambiguity. For defining 'industrialisation' and proposing interpretative categories on the design and project, the research needs to define boundaries of the terms.

Many authors (Hosseini et al., 2018; Jin, Gao, Cheshmehzangi, Aboagye-Nimo, 2018; Kamar, Anuar, Zuhairi, Azman, Mohd Sanusi, 2011; Lawson, M., Ogden, Goodier, 2014; Li, Shen, Xue, 2014; Pan, 2019; Smith, 2010) made deep and comprehensive reviewing works on the last decades Pre-fabrication and Industrialised building systems. They adopted three principal methodologies:
- a collection and a systematic comparison of definitions (Kamar et al., 2011); these works provide a list of definitions and papers, and usually propose their own specific definitions;
- a holistic research, starting from bibliometric research, followed by a scientometric analysis and a qualitative discussion (Jin et al., 2018); this kind of work can classify very well authors, journals, words, citations, places and relations between them;
- a deep and complete review using scientometric analysis (as the previous one) but including books and manuals, and introducing construction components (Hosseini et al., 2018); same results of the previous with some more indicators on techniques.

All of them are very effective to find papers containing definitions on IBS. Unfortunately, they could not avoid ambiguities in some definitions. They identified and collected, thanks to one of the methodologies above described, what existing papers described on this topic in general or in a specific context. As a result, sometimes, the same word has different meaning or applications. The word 'prefabrication', for example, is sometimes used only for buildings, sometimes also for industrialised components, sometimes only for big industrialised elements.

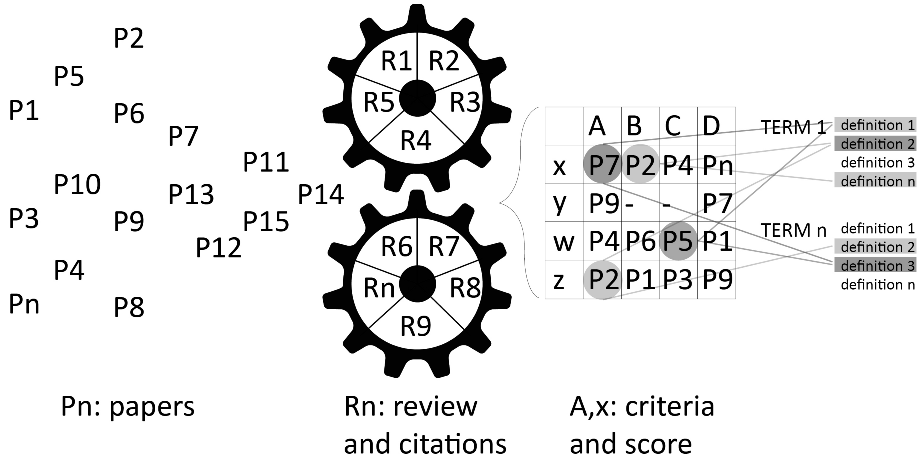
One aspect they have in common is that most of them identify Gibb's work (Gibb, 1999) as a starting point for the classification of these systems (he is one of most cited author). For this reason, this work starts from his classification of industrilised systems.

This book introduces a new point of view on classification: it starts from existing literary review that should have already done part of the comparison work, rather than starting from the general or specific papers on IBS. To find this reviews, we start from a double list of key words: one related to the word 'subject' and one associated to the word 'review':
- *Subject*: IBS, Off-site construction, off site construction, prefabricated construction, industrialized building, panelis(z)ed construction, modular construction, modern method of construction, offsite construction, precast construction, off-site manufacturing, prefabrication construction.

- *Review*: review, holistic, literature, comparison, definitions, concepts, new direction, characteristic.

A first screening of papers (around 150 papers) has been obtained by means of the scientific search engines key-word search function using different combinations of two lists terms (subject_*nn* + review_*nn*). The list of articles has been refined removing articles that were not really a review, the ones with a short or inadequate bibliography, articles considered not updated for the focus of this research (more than 15 years old) or articles not relevant detected through keywords in different semantic meanings. After this process the research selected 15 papers that were the basis for exploring the papers on this subject. They were used to identify the most cited papers, journals and authors, which have been used for the following steps of the research.

The following figure shows the methodology for the selection of papers and definitions.



Methodological path of the research of the terminological counterframe of the research: from papers (Pn), through review (Rn) to definitions adopted by the research (new elaboration). Some inspirations of this part of the research have been developed with prof. P. Beccarelli at University of Nottingham

Because this proposal wants to be productive, the starting point are scientific papers and reviews, but the results are more planning drive.

For this reason, rather than beginning from an extended analysis of a large amount of papers (Pn in figure aboive), the research acknowledged the conclusions of many reviews (Rn in figure 19) (Hosseini et al., 2018; Jin et al., 2018; Kamar et al., 2011; Lawson, M. et al., 2014; Li et al., 2014; Pan, 2019; Smith, 2010) which already investigated these aspects, using scientific and bibliometric methodologies that, although different, provide comparable results.

Thanks to their analysis, and thanks to the criteria and score they used to weigh considered papers, it has been possible to identify which words and definitions are more common and widespread in the scientific community and the papers in which these definitions are. Table 4 presents the definition retrieved from those papers. These are not all the terms inside all the papers cited by the reviews: as mentioned before, the research made a choice rejecting incoherent meaning (different to most other papers) or meaning appearing only in one paper.

Table 4[a,b,...l]: Definition of IBS semantic field, from literature review

Table 4[a]. Definition of IBS semantic field, from literature review

Word alphabetic order	Definition / specification	Source
Automated Construction	Constructions using Re-fabrication and RPS (Robotic Prefabrication System).	(Kasperzyk, Kim, Brilakis, 2017)
DFMA – Design For Manufacture	The term 'design for manufacture' (DFMA) is used to describe the philosophy of designing with factory production in mind. The design is tailored for ease of manufacture, transport, assembly, and at a point in the future, disassembly and materials recovery. This concept tends to rely on the use of standardised components and methods as part of a mass customisation process. Mass customisation is central to the realisation of competitive prices and short lead times from design approval (design freeze) to site delivery. Manufacturers' standardised component parts will be contained in a CAD or BIM library to help guide designers. This is referred to as a product family library.	(Emmitt, 2018)
IBS - Industrialised Building System	An innovative process of building construction, using concept of mass-production of industrialized systems, produced at the factory or onsite within controlled environments, it includes the logistic and assembly aspect of it, done in proper coordination with thorough planning and integration.	(Mohamad Kamar et al., 2011)
IBS - Industrialised Building System	A combination of factory-based manufacturing with site based building. Industrialised construction combines off-site and on-site construction.	(Matt, Hess, Benlian, 2015)
IBS - Industrialised Building System	IBS is a method of construction developed due to human investment in innovation and on rethinking the best ways of construction work deliveries based on the level of industrialization. The level of industrialization in IBS can be classified as pre-building system, modern construction, advance automation and volumetric construction.	(Abdullah, Egbu, 2009)
IBS - Industrialised Building System	IBS is as an organizational process-continuity of production implying a steady flow of demand, standardization, integration of the whole production process, a high degree of organization of work, mechanization to replace human labour.	(Salihudin, Jaafar, Sazalli, 2009)
IBS - Industrialised Building System	IBS is as a mass production of building components either in a factory or at site with dimensions, standard shape and transport to the construction site to be re-arranged with certain standard to form a building.	(Chung, 2006)

Table 4b. Definition of IBS semantic field, from literature review		
Word **alphabetic order**	**Definition / specification**	**Source**
IBS - Industrialised Building System	IBS is as a construction system using pre-fabricated components. The manufacturing of the components is systematically organize using machine, formworks and other forms of mechanical equipment. The components are manufactured in the factory and once completed will be delivered to construction sites for assembly and erection.	(Rahman, Omar, 2006)
IBS - Industrialised Building System	IBS is as an integrated manufacturing and construction process with well-planned organization structure for efficient management, preparation and control over resources used, activities and results supported by the used of highly developed components.	(Lessing, 2006)
IBS - Industrialised Building System	The term is also defined as a new construction method that can improve the quality and productivity of work through the use of better construction machineries, equipments, materials, and extensive project planning.	(Haron, Hassim, Kadir, Jaafar, 2005; Marsono, Tap, Ching, Mokhtar, 2006)
IBS - Industrialised Building System	In the Malaysian context, Construction Industry Development Board (CIDB) has defined IBS as a construction technique in which components are manufactured in a controlled environment (on or off site), transported, positioned and installed into a structure with minimal additional site works.	(CIDB, 2003)
IBS - Industrialised Building System	IBS is defined as a concept of mass production of quality building by using new building systems and factory produced building components. It is as a system which use industrialized production method either in the production of component or assembly of the building or both.	(Badir, Kadir, Hashim, 2002)
IBS - Industrialised Building System	IBS is as a system in which concrete components are manufactured at site or in factory are assembly to form the structure with minimum in situ construction.	(Trikha, 1999)
IBS - Industrialised Building System	IBS is as continuum beginning from utilizing craftsmen for every aspect of construction to a system that make use of manufacturing production in order to minimize resource wastage and enhance value end users.	(Esa, Nuruddin, 1998)
IBS - Industrialised Building System	IBS is a total integration of all subsystem and components into overall process fully utilizing industrialized production, transportation and assembly methods (Dietz, 1971), Improved by (Junid, 1986) adding the structured planning and standardization. The system includes balance combination between software and hardware component.	(Dietz, 1971) (Junid, 1986)

Table 4[c]. Definition of IBS semantic field, from literature review		
Word **alphabetic order**	**Definition / specification**	**Source**
IBS - Industrialised Building System	OS: Offsite Production (OSP) - Offsite manufacturing (OSM) - Offsite Fabrication (OSF) - Offsite Construction PRE: Pre-assembly – Prefabrication - Prefab MM: Modern Methods of Construction (MMC) - Modern Methods of House Construction - Modern Methods of House Building BUILDING: System Building - Non-traditional Building - Industrialized Building.	(Pan, 2019)
IBS - Industrialised Building System	IBS could be either the product or process […] if IBS is a product, process or system is heavily dependent on its context and unit analysis of the observer. In general, a review on IBS definitions classified IBS into two categories; IBS as a method, approach and process and IBS as a product, system and technology. Based on the literature search, the majority of scholars defined IBS as a method, approach and process. However, there are also authors who defined IBS as a product, system and technology particularly from an earlier scholar in this field. Therefore, IBS can be a product, process and system based on the research context and observer's perspective.	(Sarja, 1998; Warszawski, 1999)
IBS - Industrialised Building System	A change of thinking and practices to improve the production of construction to produce a high quality, customized built environment, through an integrated process, optimizing standardization, organization, cost, value, mechanization and automation.	(CIB, 2010)
IBS level and definition	-Level 0 - Basic Materials: With no preinstallation assembly aspect -Level 1 - Component sub-assembly: Small sub-assemblies that are habitually assembled prior to installation -Level 2 - Nonvolumetric pre-assembly: Planar, skeletal or complex units made up from several individual components, and that are sometimes still assembled on-site in traditional construction - Level 3 - Volumetric pre-assembly: Pre-assembled units that enclose usable space can be walked into, installed within or onto other structures, usually fully finished internally - Level 4 - Modular building: Pre-manufactured buildings - volumetric units that encloses usable space but also form the structure of the building itself, usually fully finished.	(Gibb, 1999)

Table 4[d]. Definition of IBS semantic field, from literature review		
Word **alphabetic order**	**Definition / specification**	**Source**
IBS level and definition	1) Frame System (pre-cast or steel) 2) Panellised System 3) Onsite fabrication 4) Sub-assembly and components 5) Block work system 6) Hybrid System 7) Volumetric and Modular System.	(Mohamad Kamar et al., 2011)
Industrialisation	Industrialisation in construction is a change of thinking and practice to improve the production of construction to produce a high quality, customised built environment, through an integrated process, optimising, standardisation, organisation, cost and value, mechanisation and automation.	(Gibb, 1999)
Industrialisation	Production that makes use of equipment and technologies in order to improve production, reduce cost associated with manual labour (if this is what costs more) and consequently improve the quality of final product.	(Warszawski, 1999)
Interface for IBS	- Physical interfaces between different elements. - Managerial/contractual interfaces: interfaces caused by the way that the work content of the project has been subdivided. - Organisational interfaces: relationships between the various parties involved in the contract.	(Gibb, 1999)
IPD - Integrated Project Delivery	Integrated Project Delivery (IPD) is an approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.	(Nawi, Lee, Azman, Kamar, 2014)
MMC - Modern Method of Construction	HYBRID CONSTRUCTION. Volumetric units integrated with panellised systems. Hybrid construction is also referred to as semivolumetric construction. Highly serviced areas such as kitchens or bathrooms can be constructed as volumetric units, with the rest of the dwelling constructed with panels.	(NHBC, 2006)
MMC - Modern Method of Construction	Sub-assemblies and components. Larger components that can be incorporated into either conventionally built or MMC dwellings. These items are not full housing 'systems' and are usually factory made or, occasionally, site-assembled. Sub-assemblies and components in this category are: Pre-fabricated foundations - Floor cassettes - Roof cassettes Pre-assembled roof structure - Pre-fabricated dormers - Pre-fabricated chimney stacks - Wiring looms; Pre-fabricated plumbing - Timber I beams - Metal web joists.	(NHBC, 2006)

Table 4[e]. Definition of IBS semantic field, from literature review		
Word **alphabetic order**	**Definition / specification**	**Source**
MMC - Modern Method of Construction	VOLUMETRIC CONSTRUCTION. Three-dimensional units produced in a factory, fully fitted out before being transported to site and stacked onto prepared foundations to form the dwellings Volumetric construction is also referred to as modular construction. These units can be made from most materials including light gauge steel frame, timber frame, concrete and composites. The units are sometimes used alongside panels (ready made walls, floors and roofs) in hybrid construction. 'PODS' are another type of volumetric unit usually used. Volumetric construction is most efficient when used for large numbers of identical units, as may be found in flats. A house is typically made up of four units plus roof (which can be either pre-fabricated or conventional). A flat usually comprises one, or more commonly two units.	(NHBC, 2006)
MMC - Modern Method of Construction	PANNELISED CONSTRUCTION SYSTEM. Flat panel units built in a factory and transported to site for assembly into a three-dimensional structure or to fit within an existing structure Systems can include wall, floor and roof panels to create the complete structural shell. Factory-made structural floor and roof panels are known as 'cassettes' (these are considered in the subassemblies category on page 10). There are many different types of panel, the main types are: - Open panels: panels delivered to site where insulation, windows, services and linings are fitted. All structural components are visible. Panels can be structural (transmitting load to the foundations) or non-structural (used as non-loadbearing separating walls and partitions). - Closed panels: panels based on a structural framing system (such as the type used for open panel systems), which can have factory fitted windows, doors, services, internal wall finishes and external cladding. The internal structural components can only be seen around the perimeter of the panel. - Concrete panels: structural wall panels, which can include cladding (often bricks or brick slips), insulation materials, windows and doors. - Composite panels: panels made from a combination of different materials that act together to provide structural support. Structural insulated panels are a specific form of composite panel. - Structural insulated panels (SIPS): sandwich construction comprising two layers of sheet material bonded to a foam insulation core. (continues)	(NHBC, 2006)

Table 4[f]. Definition of IBS semantic field, from literature review

Word **alphabetic order**	**Definition / specification**	**Source**
	Used primarily as wall and roof panels. - Infill panels: non-loadbearing panels inserted within a structural frame. Any type of panel can be used although framed panels are more common. Masonry can also be used. - Curtain walling: vertical building enclosure system that supports no loads other than its own weight and the environmental loads that act upon it.	
MMC - Modern Method of Construction	MMC can be divided in 7 categories - Pre-manufacturing (3D primary structural systems) - Pre-manufacturing (2D primary structural system) - Pre-manufacturing components (non-systemised primary structure) - Additive manufacturing (structural and non structural) - Pre-manufacturing (non structural assemblies and sub-assemblies) - Traditional building product led site labour reduction / productivity improvements - Site process let site labour reduction productivity / assurance improvements.	(Housing Communities and Local Government Committee, 2019)
Modular Architecture	It is an overall framework that specifies all known component interfaces. It is developed in advance of development efforts (developing architectures thus depend on the ability to foresee product and process interdependencies). It results in a codified, organisational asset (as opposed to tacit, private knowledge).	(Worren, 2002
Modular Architecture	M.A. minimises interdependencies between different modules by having only one (or a very low number) of functions per module.	(Ulrich, Eppinger, 1995)
Modular Architecture	M.A. contains standard interfaces that allow changes in modules within a range of variation that has been specified.	(Sanchez, 1995)
Modular Architecture	M.A. allows component reconfigurability, in that components can be substituted with other components as long as they conform to interface specifications.	(Worren, 2002)
Modular Construction	M.A. is a three-dimensional volumetric units that are generally fitted out in a factory and then delivered to site as the main structural elements of a building.	(Lawson, M. et al., 2014; Smith, 2010)
Modular Design	The depiction of artefact variants based on a defined set of modules leading to reductions in complexity and reductions in cost.	(Meehan, Duffy, Whitfield, 2007)
Module	Functionally or structurally independent components that are clustered so that interactions are localised within each module and interactions between modules are minimised.	(Meehan et al., 2007)

Table 4[9]. Definition of IBS semantic field, from literature review		
Word **alphabetic order**	**Definition / specification**	**Source**
Off-site fabrication	Off-site fabrication is a process that incorporates prefabrication and pre-assembly. The process involves the design and manufacture of units or modules, usually remote from the work site, and their installation to form the permanent works at the work site. In its fullest sense, off-site fabrication requires a project strategy that changes the orientation of the project process from construction to manufacture and installation.	(Gibb, 1999)
Off-site fabrication	The term 'offsite' construction refers to the process of producing buildings, or parts of buildings, in factories remote from the building site. The manufacturing process is usually highly automated, resulting in prefabricated and preassembled components, panelised units (2D) and modular (3D, volumetric) systems. The prefabricated and preassembled units and modules are transported to site when required and craned into position on prepared foundations or slotted into a structural frame. This is primarily a dry method of construction, although some wet trades may be employed to complete the building in some circumstances.	(Emmitt, 2018)
Off-site fabrication	'Offsite' is a term used to describe the preassembly of buildings and building components at a location, or locations that are remote from the building site. A wide range of terms are used to refer to offsite, ranging from offsite manufacturing (OSM) and offsite production (OSP) to industrialised building, prefabrication and modern methods of construction (MMC).	(Emmitt, 2018)
Off-site production	Off-site production is used to describe the manufacture of a prefabricated building. The manufactured building or building parts are then delivered to the site and assembled in their final position.	(Emmitt, 2018)
Open building	The open building concept aims to provide buildings that are relatively easy to adapt to changing needs, with minimum waste of materials and little inconvenience to building users. The main concept is based on taking the entire life cycle of a building and the different service lives of the building's individual components into account. Since an assembly of components is dependent upon the service life of its shortest-living element, it may be useful to view the building as a system of time-dependent levels. Terminology varies a little, but the use of a three-level system, primary, secondary and tertiary, is common. Described in more detail, the levels are:	(Emmitt, 2018)

Table 4h. Definition of IBS semantic field, from literature review		
Word **alphabetic order**	**Definition / specification**	**Source**
	- The primary system. Service life of approximately 50-100 years. This comprises the main building elements, such as the loadbearing walls and roof or the structural frame and floors and roof. The primary system is a long-term investment and is difficult to change without considerable cost and disruption. - The secondary system. Service life of approximately 15 – 50 years. This comprises elements such as internal walls, floor and ceiling finishes, building services installations, doors and vertical circulation systems such as lifts and escalators. The secondary system is a medium-term investment and should be capable of replacement or adaptation through disassembly and reassembly. The shorter the service life of components, the greater the need for replacement, hence the need for easy and safe access. - The tertiary system. Service life of approximately 5 – 15 years. This comprises elements such as fittings and furniture and equipment associated with the building use (e.g. office equipment). The tertiary system is a short-term investment and elements should be capable of being changed without any major building work.	
OSC - Off-site construction	OSC offers a new construction approach by moving the building construction process away from the jobsite into a controlled factory environment.	(Jiang, Mao, Hou, Wu, Tan, 2018)
OSC - Off-site construction	OSC involves the modularity of construction products, which is related to design, manufacture, supply chain, and the life cycle assessment.	(Sonego, Echeveste, Galvan Debarba, 2018)
OSC - Off-site construction	OSC does not simply refer to the assembly of building components at site, but involves early stages such as project design and planning.	(Choi, O'Connor, Kim, 2016)
OSC - Off-site construction	Offsite encompasses the whole process including the design, manufacture/ production of assemblies away from the place of installation, and the installation of these manufactured assemblies on site.	(Gibb, Alistair GF, 1999)
Pre-assembly	Pre-assembly is a process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit. It is generally focused on a system.	(Tatum, Vanegas, Williams, 1986)
Pre-assembly	For a given piece of work, the organisation and completion of a substantial proportion of its final assembly work take place before installation in its final position. It includes many forms of sub-assembly. It can take place on or off site and often involves standardisation.	(Atkins, 1998)

Table 4[i]. Definition of IBS semantic field, from literature review

Word alphabetic order	Definition / specification	Source
Pre-assembly	With the aim of controlling the working environment, preassembly is the assembly of components into subassemblies, either offsite in a factory or onsite prior to final installation in place.	(Winch, 2010)
Pre-design	A design for re-use.	(Anderson, M., Anderson, P., 2007; Lawson, B., 2006)
Pre-design	A design that uses a set of concepts and common solutions for systematic variant design.	(Meehan et al., 2007)
Prefabrication	Prefabrication is a manufacturing process that is generally conducted at a specialised facility where various materials are joined to form a component part of the final installation; it is the transferring stage of construction activities from field to an off-site production facility.	(Tatum et al., 1986)
Prefabrication	Prefabrication is the making of construction components in a place that is different from the point of final assembly, and it may lead to better control of the inherent complexity within the construction process.	(Björnfot, Sardén, 2006)
Prefabrication	A manufacturing process, generally taking place at a specialised facility, in which various materials are joined to form a component part of the final installation.	(Gibb, Alistair GF, 1999)
Prefabrication	P. is a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation.	(Tatum et al., 1986)
Prefabrication	P. is a manufacturing and pre-assembly process that makes construction components in a place that is different from the point of final assembly under specialised facilities with different materials used to produce both prefabrication structure and the production facility.	(Senaratne, Ekanayake, 2011)
Prefabrication	P. is a term used to describe the construction of buildings or building components at a location, usually a factory, remote from the building site.	(Emmitt, 2018)
Re-fabrication	Flexibility can thus be further improved if it becomes possible to automatically disassemble a prefabricated structure and reconstruct it according to a new design - a concept which shall be referred to from here onwards as 'refabrication'.	(Kasperzyk et al., 2017)
RPS - Robotic Prefabrication System	A new concept and demonstrates the idea to increase the flexibility of prefabrication through the early development of a refabrication system using robotics. A Robotic Prefabrication System (RPS) that employs a new concept 'refabrication' is presented here. The RPS consists of a software module and a hardware module.	(Kasperzyk et al., 2017)

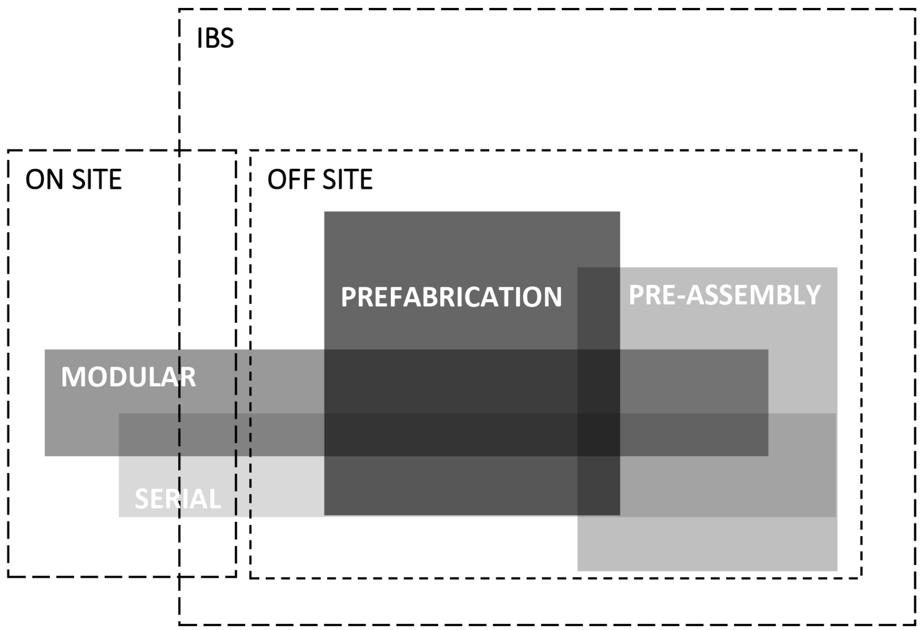
Table 4[I]. Definition of IBS semantic field, from literature review		
Word **alphabetic order**	**Definition / specification**	**Source**
Standardisation	The use of standard components or modules. In construction the aim of standardisation is to increase numbers of identical elements so that economies of scale can be achieved, moving production more towards mass or lean methods. The limiting factor is the extent of market; and conception may limit the amount of elements that can be standardised.	(Winch, 2010)
Tolerance, joint	Joint tolerances will be determined by a combination of the performance requirements of the joint solution and the aesthetic requirements of the designer. Functional requirements will be determined through the materials and technologies employed. Aesthetic requirements will be determined by building traditions, architectural fashion and the designer's own idiosyncrasies.	(Emmitt, 2018)
Tolerance, manufacturing	Manufacturing tolerances limit the dimensional deviation in the manufacture of components. They may be set by a standard (e.g. ISO), by a manufacturer and/or the design team. Some manufacturers are able to manufacture to tighter tolerances than those defined in the current standards. Some designers may require a greater degree of tolerance than that normally supplied, for which there may well be a cost to cover additional tooling and quality control in the factory.	(Emmitt, 2018)
Tolerance, positional	Minimum and maximum allowable tolerances are essential for convenience and safety of assembly. However, whether the tolerances are met on site will depend upon the skills of those doing the setting out, the technology employed to erect and position components, and the quality of the supervision.	(Emmitt, 2018)

The research has extracted the words repeating in many definitions. They are: assembly, automat(ion/ed), construction(s), control, controlled environment(s), coordination, factory, function(s), integration, interface(s), join(t/ed), manufacture, mass customisation, mass production, method, modul(e/es/arity), off-site, optimisation, pre-assembly(ing/ed), pre-fabricat(ion/ed), process, production, refabrication, remote location, standard(ised)(isation), system, tolerance. These words can be collected in some semantic area of the building system:

- the place: controlled environment(s), factory, manufacture, method, off-site, remote location
- the action: assembly, construction(s), mass customisation, optimisation, pre-assembly(ing/ed), pre-fabricat(ion/ed), production, refabrication, standard(ised)(isation)
- the features: automat(ion/ed), control, coordination, integration, join(t/ed),

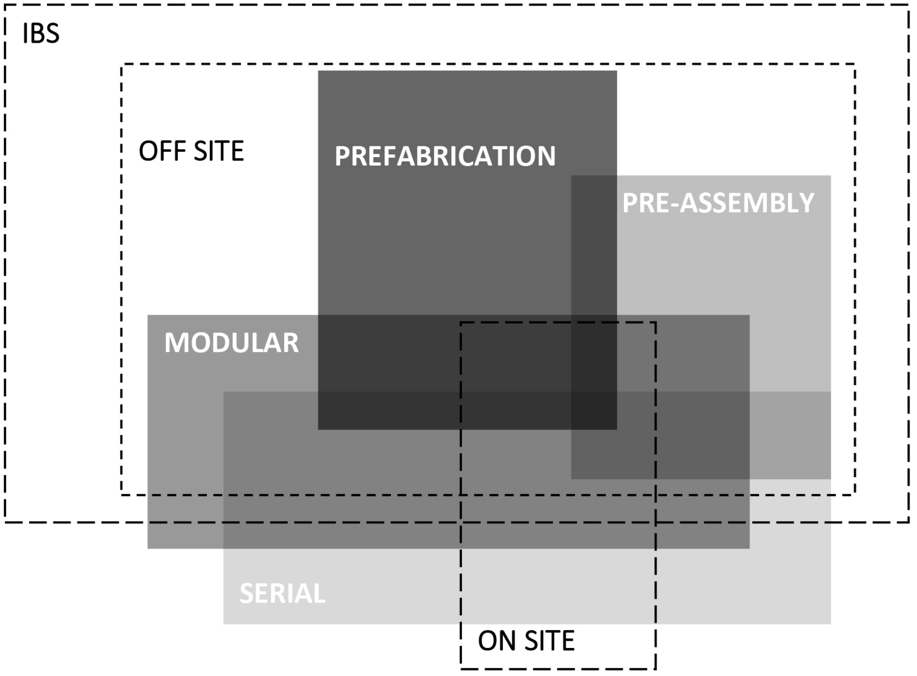
mass customisation, modul(e/es/arity), standard(ised)(isation), tolerance
- the elements: function(s), interface(s), join(t/ed), modul(e/es/arity).

Some words appear in more than one category because they can represent contemporary more than one category. For example, 'standardisation' represents an action if referred to the modification or production of an element due to a norm but it can represent a feature if referred to the specific characteristic of the project that need a standard for its intrinsic coordination of all elements Two words are outside these categories – system and process – because they represent the general category in this fiel. The next step was the comparison of these definitions, in order to find homogeneous possible semantic areas which could re-organise all (or at least most) of them. This proposal does not aim to classify construction techniques starting from the components or the techniques as does, for example, (Housing Communities and Local Government Committee, 2019): it aims to give a semantic framework that could go beyond single elements and aspires to be general and universal. The following two schematic sets are the first attempts of this process.



First hypothesis for the classification of semantic areas of the topic of the research (original elaboration)

The scheme avove starts from two big categories ON-SITE and IBS, because some authors separate IBS from traditional on-site. However, this classification does not include the concept of 'hybrid buildings' and does not consider that most of on-site buildings (actually the largest part of buildings) are made by IBS components, even if the on-site assembly technique is more hand-made and very little 'industrialised' (bricks, for examples, are IBS standardised components but they are used almost only on-site). The scheme also introduces OFF-SITE category inside IBS and pre-fabrication and pre-assembly inside it, because they appear many times in the cited definitions. It also introduces two concepts (modular and serial) introduced by some definitions and which role



Second hypothesis for the classification of semantic areas of the topic of the research (original elaboration)

this research clarifies in the following paragraphs. However, as mentioned before, this classification, based on some definition, does not work for all of them and is in contrast to some construction market evidences. For this reason, a second scheme (above) was generated.

This second version provides a more effective overlay of the IBS and the On-site areas. It also includes all the categories already introduced in the first version. The aim of this scheme is the creation of crossing zones that could help to insert those definitions that cannot be inserted only in one category but that are simultaneously in more than one category. However, it is possible to notice intermediate empty sections and the relation between categories cannot find a real correspondence in the actual building market. At the end of these attempts (and after the proposal of many other different 'boxes' scheme) it became obvious that with schemes based on 'boxes' it was impossible to fill each area and avoid 'holes' of meaning and undefined zones. This approach has too many uncertainties left and some category could belong to different disjointed sets. This often happens in most of papers that do not provide defined boundaries and sometimes use different words for the same category. The proposal tried to overcome this gap. It has been suggested that this might be because technological building systems cannot easily be fractioned. The reality is more fluid and blurry than the rigid classification provided defined 'boxes'. Moreover, although the onsite techniques are still manual, it is difficult to find construction sites whose basic products do not come from an industrialized production: from bricks to concrete, from finishings to coatings, the vast majority of components are produced in series in a factory.

The discriminating factor cannot be based on the production technique.

For this reason, the research abandoned this fixed and strict model and it adopted a model based on trends and tendencies, an original outcome of the methodology adopted. In addition, we suggest an original and innovative approach where the focus has been shifted from single building products or techniques to functions and requirements of the building systems. This approach overpasses single specific objects and can include all building systems, even eventual ones.

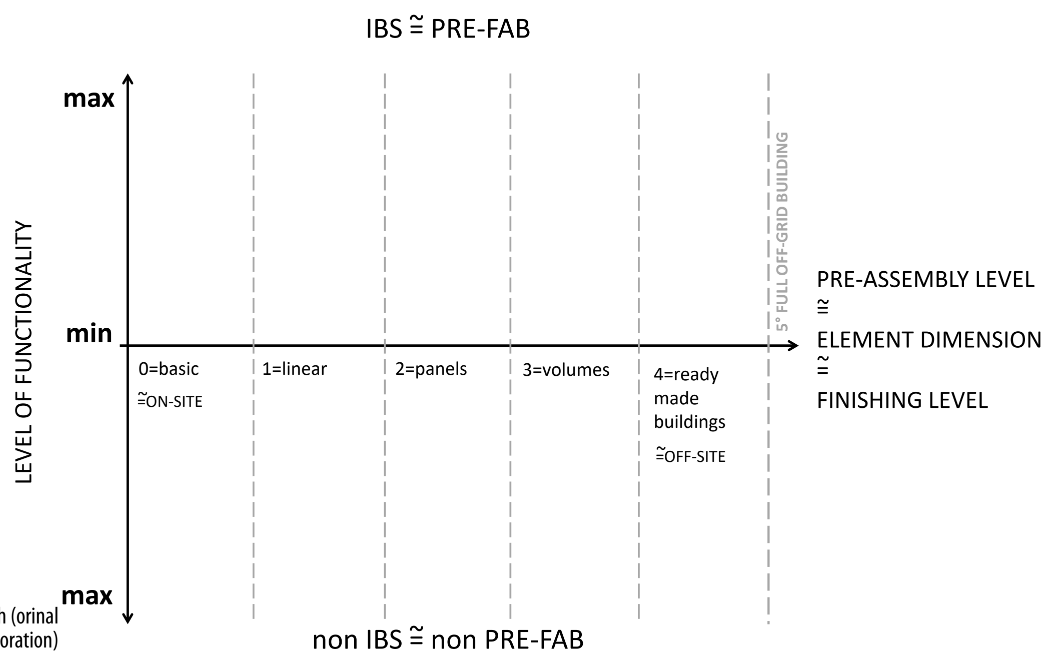
The work proposes a possible interpretation of Building Technological Systems, which can be considered flexible and open, because of its 'fluid' approach. It hasn't got fixed boxes or boundaries, it starts from requirements (functionality, dimension, level of…) and not from techniques or objects: so it could be universal and adaptable, depending on market or times or development level (a sort of Kant's analytic a priori judgments).The new classification is also designed to help the positioning and the research of scientific papers related to construction building systems. A sort of visual 'glossary' that can lead throughout semantic research fields for a better and faster identification of interesting and targeted papers, product, or technique.

The basic graph

As a result of the methodological path, the research developed the following scheme which classifies the Building Systems on the basis of definitions available in literature.

The scheme (graph 5) includes papers gathered through an accurate research based on semantic issues.

Next paragraphs explain the graph.

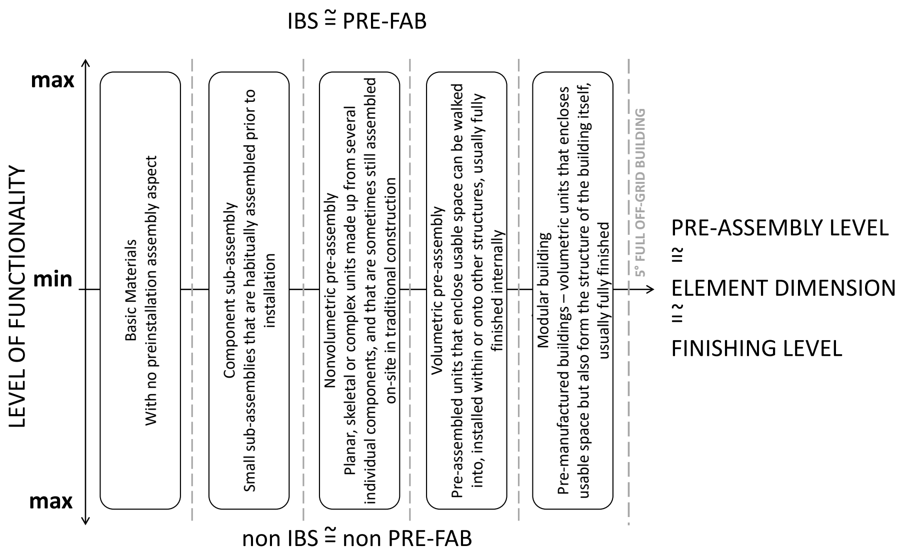


Graph 5: Basic classification graph (orinal elaboration)

The X axis

The X axis represents the dimension of components: from small (basic) to entire buildings. This feature, on the basis of the work of (Gibb, A., Pendlebury, Goodier, Ashley, Taylor, 2015), can be divided in 6 macro-categories[22]:
0-1 Basic Materials. With no preinstallation assembly aspect.
1-2 Component subassembly. Relatively small scale items that are invariably assembled offsite.
2-3 Non-volumetric preassembly. A large category covering items which the designer opted to assemble in a factory prior to installation. This type of units do not enclose usable space. Applications may be skeletal, planar or complex.
3-4 Volumetric preassembly. Units which enclose usable space and are then installed within or onto a building or structure. Typically fully finished internally.
4-5 Complete buildings. Units which enclose usable space and actually form part of the completed building or structure (units may or may not incorporate modular coordinated dimensions). Typically, fully factory finished internally (and, possibly, also externally).
>5 Complete full off-site and full off-grid buildings.

[22] For another possible classification of IBS techniques, but not so coherent with the aims of this research, you can also see the definitions of MMC in https://www.gov.uk/government/publications/modern-methods-of-construction-working-group-developing-a-definition-framework.



Graph 6: Definitions of X categories of basic classification graph. Definitions in boxes taken (from: Gibb, A. et al., 2015)

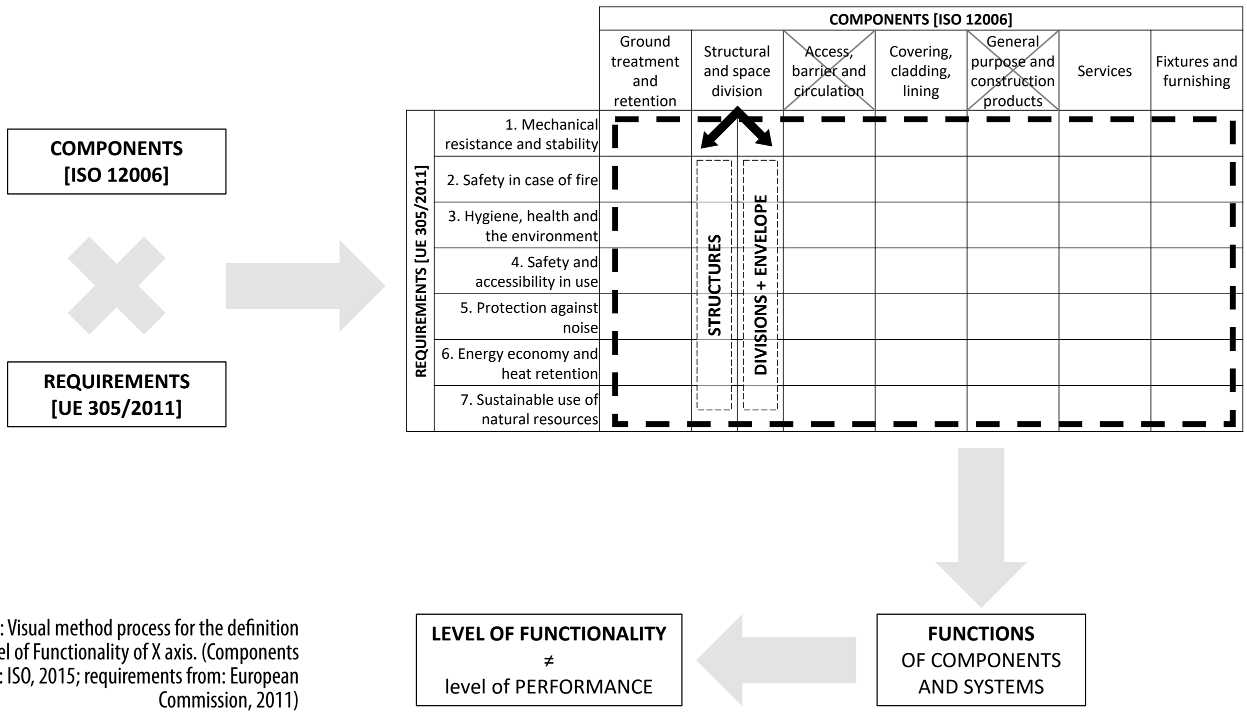
The X value also corresponds to the level of Pre-assembly of the component or building. It also corresponds to the level of finishing. *Therefore, the research assumes that the more a component (or building) is pre-assembled, the more it is also pre-finished*. This is not always true everywhere, but for this specific work that is the starting point. This working hypothesis depends on some factors:
- the graph should be two-dimensional: introducing other different variables would have made the graph unreadable;
- pre-assembly and finishing level are easily overlapping: the level of dimension could seem extraneous to these level, though here the term 'dimension'

is not assumed as absolute, but it is relative to the five categories of X axis and represents the 'level of space' a component embeds compared the components of the other categories[23].

The Y axis

The Y axis represents the *level of Functionality*. This value is about *function and it is not related to the performance*: for this reason the research considered the number of functions provided by each building system and not the level of performance achieved. Positive values of Y corresponds to IBS components and negative to non-IBS. Because the definition of IBS is still unclear and all embracing, this research, in this classification, overcomes the problem of its definition using pre-fab and non-pre-fab categories to explain the concept. Using this research question, all the components related to a factory (from bricks to modules) are on positive value of Y; all the components that are hand-made (from adobe bricks to self-made building with natural or waste material) are on negative values. Examples on nest chapters will better explain these categories and confirm that this division works well in this case.

The following scheme shows how the level of function has been defined:



Graph 7: Visual method process for the definition of the level of Functionality of X axis. (Components from: ISO, 2015; requirements from: European Commission, 2011)

The level of functionality corresponds to the number of functions each component can provide. These functions are limited and elementary in order to maintain a reduced number. They are designed to 'answer' to easy and simple questions.

[23] For example a steel beam could be longer and heavier than a pre-fab bath cell, but they belong to different categories, so the beam is nearer to 0 than the cell.

To identify these functions the research criss-crossed components of the building system from BS ISO 12006-2:2015 (ISO, 2015) and building requirements from EU 305/2011 (European Commission, 2011). Components not relevant to the research (such as 'Access, barrier and circulation' and 'General purpose and construction products') have been eliminated and the 'Structural and space division' has been divided into 'Structures' and 'Divisions and envelope' for a more effective classification of the system.

The following table 5 is the result of the matrix described above.

Table 5: Matrix of Functions of the Building Systems (Elaboration based on European Commission, 2011; ISO, 2015)

Table 5. FUNCTIONS OF BUILDING SYSTEM _ Components X Requirements matrix							
		COMPONENTS according to BS ISO 12006-2:2015					
		Ground treatm. & retention	Structural & space division		Covering, cladding, lining	Services	Fixtures and furnishing
			Structures	Divisions			
REQUIREMENTS according to 305/2011	1. Mechanical resistance and stability	Stabilise	Resist and Keep resilience	Resist and Keep resilience	Resist and Keep resilience	Keep resilience & efficiency	Keep resilience & efficiency
	2. Safety in case of fire	Separate	Resist	Keep safe	Keep safe	Keep safe	Keep safe
	3. Hygiene, health and the environment	Insulate	Keep safe	Keep safe and healthy	Keep safe and healthy	Keep safe and healthy	Keep safe and healthy
	4. Safety and accessibility in use	Retain	Ease use	Keep safe and Ease use	Keep safe and Ease use	Keep safe and Ease use	Keep safe and Ease use
	5. Protection against noise	Disjoint	Protect	Protect	Separate	Keep noise low	Keep noise low
	6. Energy economy and heat retention	Insulate	Separate	Separate and Insulate	Insulate	Keep efficiency	Keep efficiency
	7. Sustainable use of natural resources	Reduce, Reuse, Recycle	Reduce, Reuse, Recycle	Reduce, Reuse, Recycle	Reduce, Reuse, Recycle	Reduce, Reuse, Recycle	Reduce, Reuse, Recycle

In this matrix, the building system is divided in six sub-systems, according to BS ISO 1200-2:2015. The left columns introduce seven requirements, according to EU 305/2011. Each sub-system intersects each requirement and generates a function, expressed by a verb.

Each component and system identified was tested in the matrix and a point has been assigned in case of a positive answer to each question.

The sum of the points provides the level of functionality considered for the positioning of the item on the graph. The result is the table 6 on p. 52, in which:

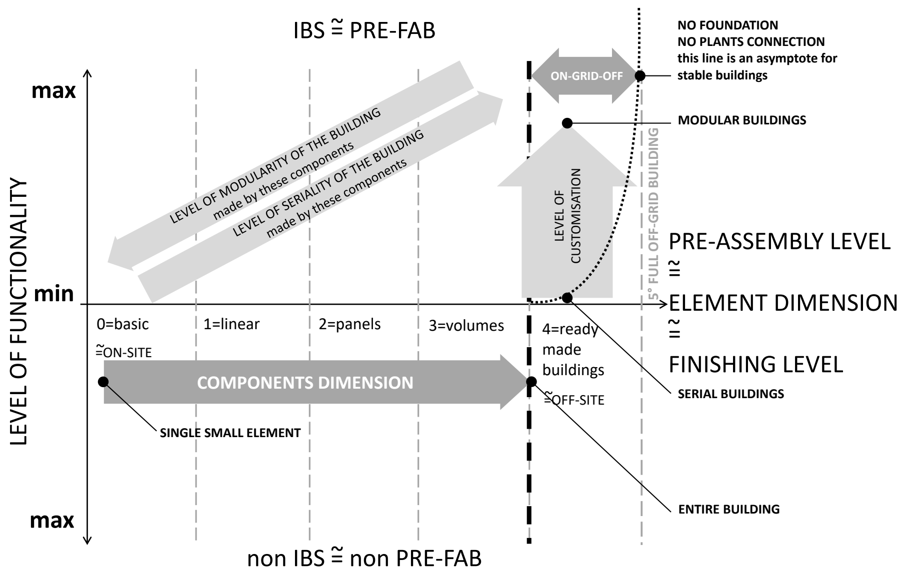
- the level of pre-assembly is one of the five categories of graph 6;
- IBS/non IBS depends on Y axis positivity or negativity (see above definition of Y axis);
- components are elements of the building system representative of each pre-assembly level category;

- components, sub components and questions come from table 5;
- the level of functionality is the number of 'X' of each components:
- a 'X' is set in every intersection the component has a positive answer to the requirement question.

The results of table 6 will be used to fill the graph 10 on p. 51 with examples that helps to understand better the proposed classificational system.

Tendencies and regions of the graph

Considering the general classification graph, it is possible to identify some tendencies and homogenous regions, as the following graph (graph 8) shows.



Graph 8: Explanation of the basic graph (orignal elaboration)

This work has assumed four categories to define the classification of the building systems: basic, linear, panel and volume (Gibb, 1999). These categories have dashed boundaries because the limits between them are not always so clear and fixed (see methodology chapter). A new category (4: ready-made building) has been added because in the last few years this kind of systems is getting more common and widespread on the market.

On ready-made building, in turn, different degrees of evaluation can be applied. This research focused on two: the level of off-grid and the level of customization.

- Considering *off-grid level* (X axis), the graph shows, on the left, buildings that need foundations, sewer, water, energy to work. On the right it collects buildings completely off-grid, without foundations and with no connection to the utilities: surely they are very uncommon for permanent buildings, except for some extreme research centres or holiday lodges. This explains why there is an asymptote (dashed curve line) that shows how buildings usually need physical connections for utilities and for fixing to ground.

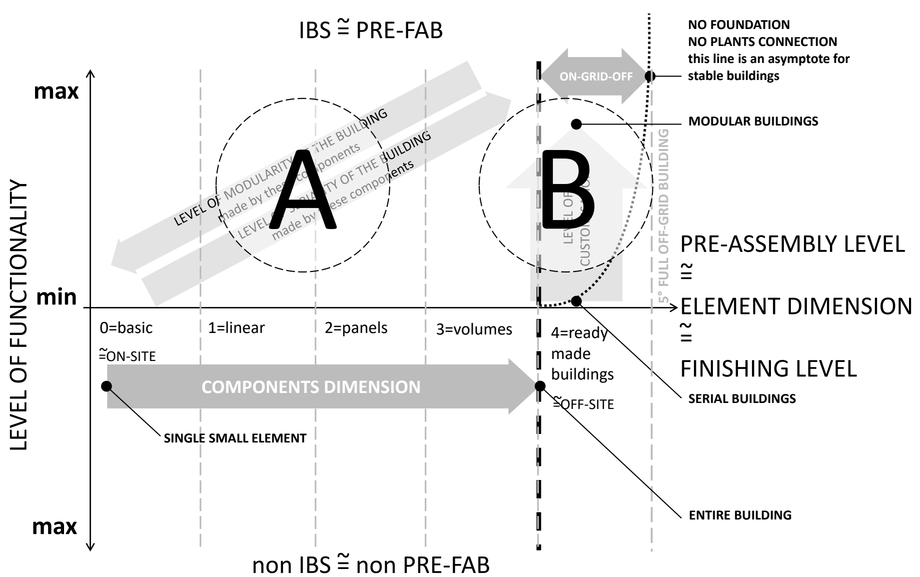
- Considering the *customisation level* (from bottom to top), it is possible to notice that this trends is related to the Level of Functionality (Y axis): starting from the definitions of (Sanchez, 1995; Ulrich, Eppinger, 1995; Worren, 2002), in which the authors combine components and buildings, the research tried to separate modular buildings from its modular components. It is possible to find two trends in buildings using modular elements: buildings can be *modular* or buildings can be *serial*. As the vertical blue arrow shows, this classification is valid for the 4th category but also for the end of the 3rd (volumes assembled on-site).

Both, modular and serial buildings use modules as defined by those authors, but the level of possible customisation (corresponding to the level of Functionality of Y axis for this column) could be very different and introduces new categories.

Serial buildings are buildings made by individual identical and replicated parts (for examples dormitory or emergency houses, made using boxes or containers), in which duplicated 3D complete elements are juxtaposed together. Serial buildings could be also ready-made canopies, usually mobile, such as tents or inflatable buildings (e.g. available off the shelf). Serial buildings could also be found in other areas of the graph (traditional/hybrid - non IBS, for example English terraced houses), but they are not ready made, so not included in this 4th category).

Modular buildings are buildings with high level of customisation and flexibility, made by modular components (not only 3D) easily and usually dry joined together, in which each part needs others to work as a building and that does not necessarily shows its modular nature.

Related to the previous definition of Modular and Serial, and considering the first four columns and the Y positive area of the graph (sector marked with 'A' in the graph 5), it is possible to find a trend that goes from high value of Modularity of the building and low components dimension and functionality

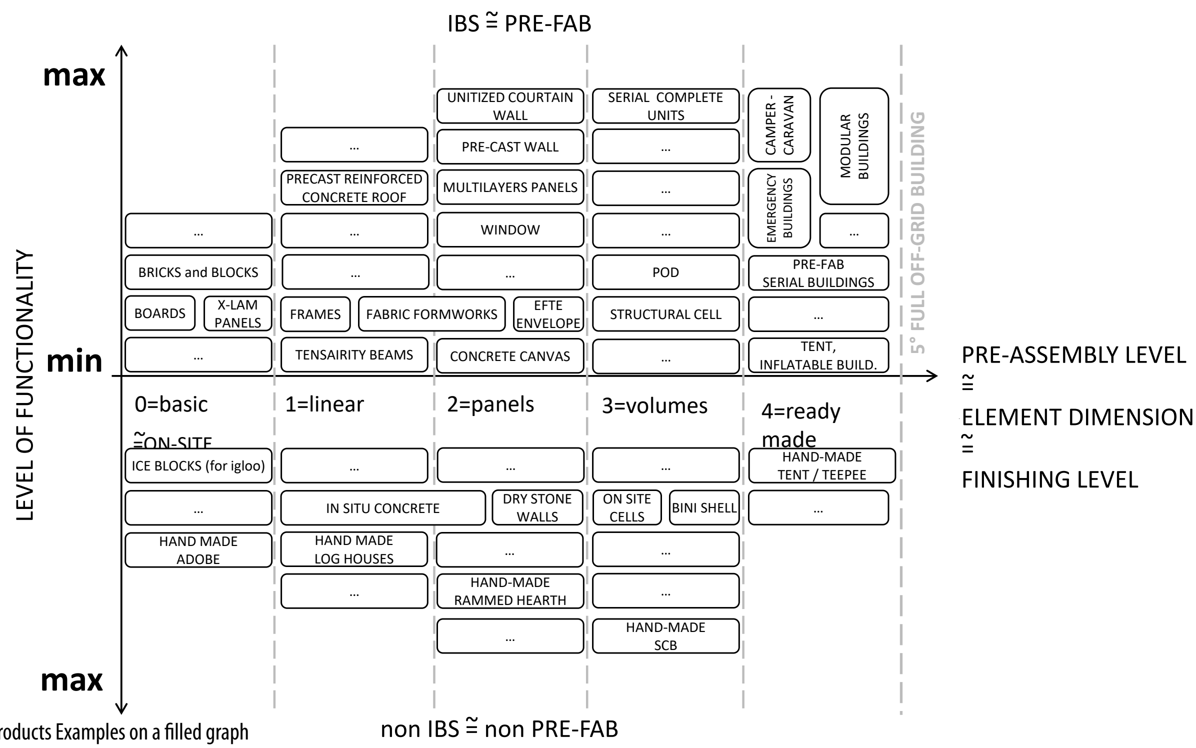


Graph 9: Sector A and B on positive Y (IBS ≈ PRE-FAB)
(orinal elaboration)

(low value of X,Y) to low level of Modularity of the building and high components dimension and functionality (high value of X,Y). This trend is opposite to the Level of Seriality of the Buildings. Following the same line of thinking of the 5th column (marked with 'B'), according to many authors (Worren, 2002; Ulrich, Eppinger, 1995; Sanchez, 1995), the simplest a component is and less functions it has, the more possibilities it has to be used in a modular building. Complex and bigger components with a lot of functions can be used for modular buildings with less ease, because of the univocal place and use they are designed for.

Graph 10 provides a visual help to better explain the categories described above. The graph has been populated with the most common building systems according to their level of functionality.

The classification scheme does not start from products or techniques but provide a flexible approach where products and techniques can easily be inserted on the graph. Here some examples are proposed (with many intentionally empty spaces, depending on the value from table 6, for showing the proposal is not exhaustive and many other products can be inserted) meant as suggestion for better understanding the scheme itself . The graph suggests one of the potential arrangements of the examples which, however, can be placed between two columns or overlapped to others, but here are separated to improve clarity and readability. The small or empty cells depend on table 6 score and the cells between columns depend on the positioning referring to the X categories (some components can belong to two categories).



Graph 10: Products Examples on a filled graph

Table 6[a,b]: Functions of building system table (*REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC)

Table 6[a]. Functions of building system table

			Ground treatment & retention							Structures			
			Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use
level of pre-assembly	IBS/ nonIBS	component	Stabilise	Separe	Insulate	Retain	Disjoint	Insulate	Reduce, Reuse, Recycle	Resist and Keep resilience	Resist	Keep safe	Ease use
0=basic	non IBS	hand made adobe								X	X	X	X
0=basic	non IBS	ice blocks								X		X	
0=basic	IBS	bricks and blocks		X						X	X	X	X
0=basic	IBS	x-lam panels								X		X	X
0=basic	IBS	boards											
1=linear	non IBS	hand made log houses								X		X	X
1=linear	non IBS	in situ concrete	X							X	X	X	X
1=linear	IBS	precast concrete roof								X	X	X	X
1=linear	IBS	fabric formworks								X		X	X
1=linear	IBS	frames								X	X	X	X
1=linear	IBS	tensairity beams								X		X	X
2=panels	non IBS	rammed earth	X							X	X	X	X
2=panels	non IBS	dry stone walls	X							X	X	X	X
2=panels	non IBS	in situ concrete								X	X	X	X
2=panels	IBS	unitized curtain wall								X	X		
2=panels	IBS	pre-cast wall								X	X	X	X

			Divisions (+ envelope)							Covering, cladding, lining							Services							Fixtures and furnishing							
Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	
Protect	Separate	Reduce, Reuse, Recycle	Resist and Keep resilience	Keep safe	Keep safe and healthy	Keep safe and Ease use	Protect	Separate and Insulate	Reduce, Reuse, Recycle	Resist and Keep resilience	Keep safe	Keep safe and healthy	Keep safe and Ease use	Separate	Insulate	Reduce, Reuse, Recycle	Keep resilience and efficiency	Keep safe	Keep safe and healthy	Keep safe and Ease use	Keep noise low	Keep efficiency	Reduce, Reuse, Recycle	Keep resilience and efficiency	Keep safe	Keep safe and healthy	Keep safe and Ease use	Keep noise low	Keep efficiency	Reduce, Reuse, Recycle	level of functionality [Σ X]
X	X	X	X	X	X	X	X		X																						-13,00
	X	X																													-4,00
X	X	X	X	X	X	X	X		X																						14,00
X			X	X	X		X																								8,00
			X	X	X	X	X	X	X																						7,00
X	X	X	X		X	X			X																						-10,00
X																															-6,00
X										X	X		X	X	X																10,00
			X		X	X																									6,00
		X																													5,00
		X																													4,00
X	X	X	X	X	X	X	X	X	X																						-15,00
X	X	X																													-8,00
X	X																														-6,00
			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X		X	X	X	X				24,00
X	X	X	X	X	X	X	X	X	X								X	X	X	X	X	X	X								21,00

Table 6[b]. Functions of building system table

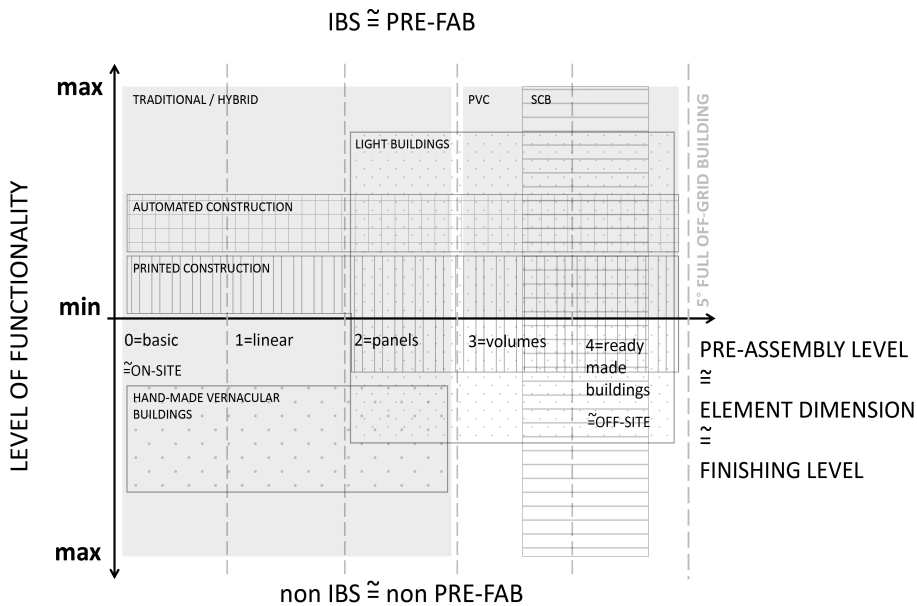
level of pre-assembly	IBS/ nonIBS	component	Ground treatment & retention							Structures			
			Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use
			Stabilise	Separe	Insulate	Retain	Disjoint	Insulate	Reduce, Reuse, Recycle	Resist and Keep resilience	Resist	Keep safe	Ease use
2=panels	IBS	multilayers panel											
2=panels	IBS	window											
2=panels	IBS	efte envelope											
3=vol	IBS	concrete canvas	X		X	X				X			
3=vol	non IBS	hand-made scb								X	X	X	X
3=vol	non IBS	on site concrete cell								X	X	X	X
3=vol	non IBS	bini shell								X	X	X	X
3=vol	IBS	serial units								X	X	X	X
3=vol	IBS	pod											
3=vol	IBS	structural cell								X	X	X	X
4=building	non IBS	hand-made tent / teepee								X	X	X	X
4=building	IBS	serial buildings								X	X	X	X
4=building	IBS	modular buildings								X	X	X	X
4=building	IBS	camper-caravan								X	X	X	X
4=building	IBS	emergency buildings								X	X	X	X
4=building	IBS	tent, inflatable buildings								X	X	X	X

			Divisions (+ envelope)							Covering, cladding, lining							Services							Fixtures and furnishing							
Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	Mechanical	Fire	Health Hygiene	Use	Noise	Energy	Resources	
Protect	Separate	Reduce, Reuse, Recycle	Resist and Keep resilience	Keep safe	Keep safe and healthy	Keep safe and Ease use	Protect	Separate and Insulate	Reduce, Reuse, Recycle	Resist and Keep resilience	Keep safe	Keep safe and healthy	Keep safe and Ease use	Separate	Insulate	Reduce, Reuse, Recycle	Keep resilience and efficiency	Keep safe	Keep safe and healthy	Keep safe and Ease use	Keep noise low	Keep efficiency	Reduce, Reuse, Recycle	Keep resilience and efficiency	Keep safe	Keep safe and healthy	Keep safe and Ease use	Keep noise low	Keep efficiency	Reduce, Reuse, Recycle	level of functionality [Σ X]
			X	X	X	X	X	X	X	X	X	X	X	X	X	X															14,00
					X	X	X	X	X	X		X	X	X	X	X															11,00
			X		X	X		X	X																						5,00
																															4,00
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-35,00
X	X	X																													-6,00
X	X																														-5,00
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	35,00
			X	X	X	X	X		X								X	X	X	X	X	X	X								13,00
X	X	X																													7,00
		X	X	X	X	X			X	X	X	X	X	X	X	X															-17,00
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	35,00
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	35,00
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	35,00
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	35,00
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	35,00

A possible synthesis of components

Starting from graph 10 that introduces some possible examples inside basic graph and that analyses the components and elements arranged in the graph, it is possible to identify some homogenous areas that, on the basis of the definitions from the literature, could be outlined on the graph.

These macro-areas represent techniques and tendencies of the actual market. They are just examples and they do not pretend to be exhaustive or complete. However, they show how the graph could be an useful tool for identifying and explaining building system tendencies. The graph 11 shows some homogeneous area of possible concentrations of techniques.



Graph 11: Trend macro-areas and polarization of building construction system (original elaboration)

Traditional and Hybrid buildings are positioned on the left side of Graph 11, with a level of dimension which varies from 0 (basic) to 2 (panels). This category effectively describes an heterogeneous group of building systems which, however, are based on the common approach of using small construction elements, such as bricks (level 0) or sandwich roof panels (level 2), to deliver more complex constructions which can achieve high levels of functionality just adding and integrating relatively small and simple building components. Historically, this type of constructions could be based on several components manufactured on site, such as handmade adobe bricks. In current years, only low-tech constructions make extensive use of building components made onsite.

Hand Made Vernacular Buildings are probably the only building category which does not use prefabricated building components. Despite the relatively inefficient and labour intensive building method, this building systems are becoming a niche in the current building sector, however, they are particularly interesting if assessed from the environmental point of view due to the fact that they are generally based on locally sourced materials which can be disposed easily due to the absence of industrial chemicals.

Automated Constructions is an interesting category which is showing a growing interests in recent years due to the availability of robots at more accessible prices. The use of robots allows the handling of components larger in dimension but the level of functionality is currently relatively limited due to a technology which is still at the early stages of its development.

Printed Constructions show a substantial overlap with the classification of automated constructions with the only exception that the technology can also include tasks carried out on site, such as the 3D printing of entire houses. 3D printing technologies, despite the exponential growing interest in the last decade, is still at its beginning in the building sector and the level of functionality achievable is relatively low at the moment.

Light Buildings are characterised by an efficient use of materials which leads to buildings with an overall self-weight which is lower than other building methods. Building components are mainly based on engineered industrialized materials such as composites, extruded aluminium or membranes which only in few applications are based on natural alternatives such as w, timber or natural fibres. Due to the intrinsic lightweight, these building methods can use large elements and the combination of several advance materials can allow high level of functionality.

Prefabricated Volumetric Constructions are based on free-standing 3-dimensional modules with internal finishes, fixtures and fittings added during the off-site fabrication before the final delivery and installation in the building site. They are positioned in the top left area of Graph 11 due to the intrinsic size related to the components and the high level of functionality that can be achieved in the most advanced examples. If the access to the site allows the handling of the weight and size required for the PPVC module delivery, the systems have the potential of ensuring an improved productivity, a safer, offside, construction environment and an improved quality control.

Shipping Container Buildings are an extreme in the current panorama of the building industry. They are based on relatively large structural units which can be customized in order to achieve any level of functionality required. The retrofitting of existing container can be done with an industrialized offsite approach but there are also examples of shipping containers transformed on site with low-tech materials and techniques. This category is introduced, even if very specific, because the research will highlight potentialities and limits of this kind of system.

These are only some of the possible homogenous macro-areas that collect the components filling the graph. These categories come from literature (Basmara Putra, Susanto, 2018; Goulding, Pour Rahimian, Arif, Sharp, 2015; Housing Communities and Local Government Committee, 2019; Lessing, Brege, 2018; Luther, Moreschini, Pallot, 2007; Peltokorpi, Olivieri, Granja, Seppänen, 2018) or from building market experience. The macro-areas cross each other because some techniques and components belong to more than one.

The outlines are not fixed because there is not a clear boundary, but they can change depending on the building market or country scenario. The flexibility of these macro-areas demonstrates the universality of the classification system: it can be re-arranged and new macro-areas could be inserted.The classification is designed to provide a framework for further reflections and analyses on Building Technological Systems.

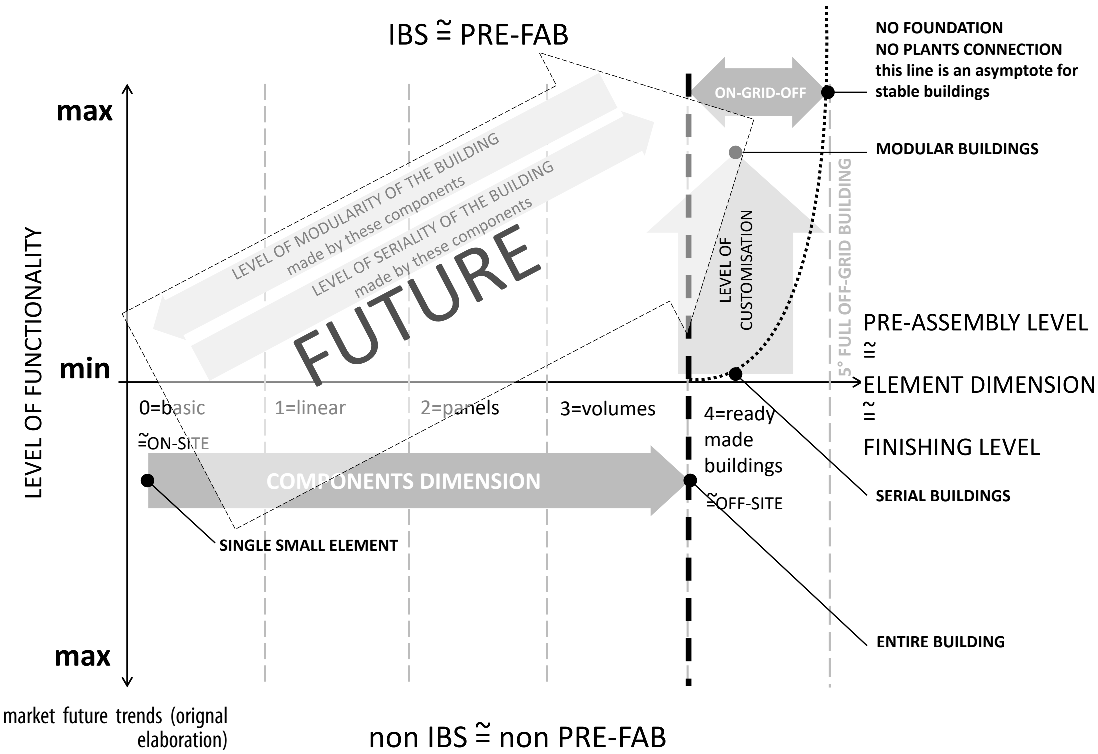
It is a flexible tool: in the previous setup, we presumed that incoming new tools show as the paradigm of change is real. We have now «[…] tools for implementing design in physical space (Arduinos, 3D printers, CNC mills); and the means – financial or manpower – to make it happen. These constitute the engine that will drive the accelerating force of collective production» (Ratti, Claudel, 2015, p. 98). As predicted in 2010 (CIB, 2010), and as all the scientific works on this issue confirm in these years, IBS has had a huge growth in the last decades. In some markets (e.g. Malaysia), government has consciously decided to support this sector with a lot of funding and research (Abdullah, Egbu, 2009).

The proposed classification system can accommodate these new possible scenarios in building techniques: most of the new techniques and tools would find their place in the upper right part on Graph 12, as suggested by many authors (Arashpour et al., 2017; Azam Haron, Abdul-Rahman, Wang, Wood, 2015; Basmara Putra, Susanto, 2018; CRESME, 2019; Department for Communities and Local Government UK, 2017; Emmitt, 2018; Ginelli, Pozzi, 2017; Hamid, Foo, Rahim, 2017; Jaillon, Poon, 2009; Lessing, Brege, 2018; Lu, Chen, Xue, Pan, 2018; Luther et al., 2007; Navaratnam, Ngo, Gunawardena, Henderson, 2019; Peltokorpi et al., 2018; Powell, Monahan, Foulds, 2016; Qays, Mustapha, 2010; Švajlenka, Kozlovská, 2017) and confirmed by many reports on market trends[24]. This zone *identifies in system with a high level of functionality and high level of pre-assembly one of the few way to get quality and performance in building*. It is not the only possible way, but in the scenario descripted above, for this reason, it is possible to identify a trend that from the bottom left indicates the future to upper right, as shown in the graph below.

Moreover, the graph is an open tool: it can be re-arranged for different contexts or different needs, expanding some parts and reducing others.

This proposal should be tested in different contexts for different techniques: the introduced categories are just a possible example. This tool needs further studies from researchers or companies that could test new (or old) systems and components. It clarifies semantic ambiguity inside IBS and prefabrication systems thanks to a visual classification system that transcends fixed categories and definitions. It is a fluid and flexible tool, that could help the classification of current techniques and products but also open to incoming new products. Using the visual classification graph it is possible to find over-categories and trends that can explain, or even predict, actual and future scenarios in the building sector. It works as an open tool: it can be arranged for different purposes in different settings; it can be implemented with new techniques and products. Another interesting and positive aspect is that the proposed visual map can also be used to classify scientific works on these issues.

[24] https://www.freedoniagroup.com/ https://www.fortunebusinessinsights.com/industry-reports/modular-construction-market-101662 (visited on 06/07/2021). https://www.grandviewresearch.com/industry-analysis/modular-construction-market (visited on 06/07/2021) https://www.alliedmarketresearch.com/precast-construction-market (visited on 06/07/2021). https://www.rolandberger.com/publications/publication_pdf/roland_berger_prefabricated_housing_market_3.pdf (visited on 06/07/2021). https://www.batiactu.com/edito/construction-hors-site-solution-un-secteur-qui-investit-61316.php?MD5email=29a48073748b8330ec53410002129671&utm_source=news_actu&utm_medium=edito&utm_content=article (visited on 06/07/2021).



Graph 12: Building market future trends (orignal elaboration)

BUILDING INDUSTRIALISATION BETWEEN CULTURAL BONDS SYSTEMIC OBSTACLES AND NEW PROCESS VIEWS

There are a lot of studies and papers on IBS, in the last decades[1]. But there is not a unique and homogenous data-base: each research and paper has different points of view and considers different data. This paragraph collects many of them, at the beginning as a miscellaneous of data and graphs. Only at the end there is a critical and reasoned synthesis.

This research has equated the different words used in different data-bases and survey. These words are: pre-fabrication (pre-fab, prefabrication), off-site (offsite, OSC), pre-assembly (pre-assembled), MMC.

The three steps of this analysis can be summarised:
- *previous studies*, dealing with the theme from 5 points of view, that address different questions: 1. Diffusion and market: what is the amount and the widespread of IBS? Which techniques are more used than others? 2. Awareness and knowledge: why choosing IBS or why not? 3. Perception: which are the advantages/disadvantages using IBS? 4. Costs: which are the variables linked with economic aspects of IBS? 5. Time: which is the relationship of IBS with time?
- *swot analysis on 4 dimensions*, facing the theme using a four dimensional SWOT analysis: all the features and factors highlighted are arranged and compared together to other aspects and factors borrowed from scientific literature, following the economic, environmental, institutional and social dimensions of sustainability.
- *swot analysis for inside and outside conditions*, is a synthesis that faces IBS from the point of view of the design: it isolates the factors outside building market, the external factors of the design phase and the internal of design. This research aims to compare only with the factor strictly linked to this last category, which is maybe the small one, but it is the only one that design can effectively influence.

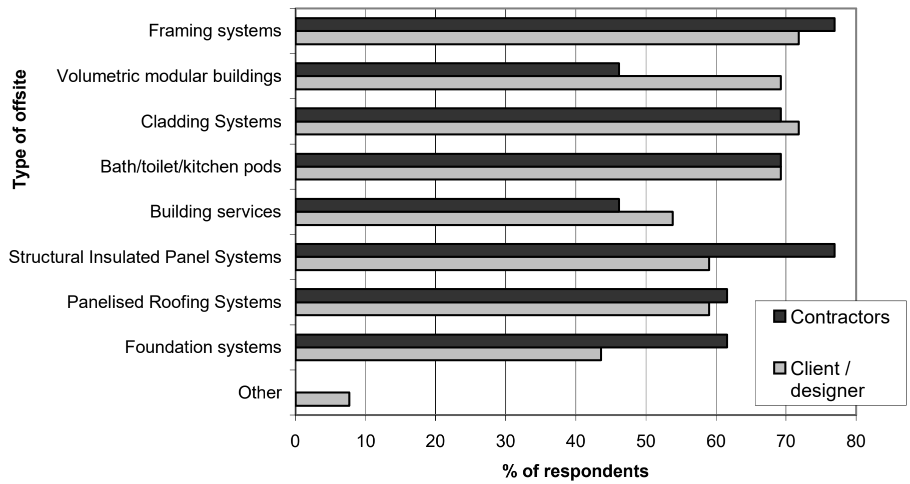
Traditional and industrialised systems: a possible comparison

Until 2005 in UK 97% of clients/designers and 92% of contractors have used offsite on any of their projects (Goodier, Gibb, 2005).

Most of suppliers agree IBS is an increasing sector in building construction (Bildsten, 2011; Blismas, Wakefield, 2009; Nadim, Goulding, 2011; CRESME, 2019; CRESME, 2020; Samuelsson Brown, Parry, Howlett, 2003). Anyway, compared to other high-technological sectors[2] the building industry has been the slowest to modify over the decades (Boafo, Kim, Kim, 2016).

[1] Some inspirations of this chapter have been developed from a conversation with prof. Alistair Gibb of Loughborough University UK, occurred the 27th of January 2020.
[2] Automobile, shipbuilding or aerospace.

Opposite page: cHOMgenius project prototype, Busnago MB Italy. Further information available at https://www.dabc.polimi.it/en/ricerca/ricerca-competitiva/chomgenius-prototypesystemsharedproject/



Graph 1: Type of offsite most commonly considered for project. Percentage respondents that have used OSC at least once in their projects (from: Goodier, Gibb, 2005)

Despite this expansion, there is still a problem with builder companies' structure that does not allow a large spread of these systems. There is actually a huge discrepancy in the development between building and other industries (Horden, 2001).

In UK, but also in Italy, no company has the power or the purpose to invest in research for private residential buildings:

1. Small and very small companies have no economic strength and no management structure to invest their own capital. They are just hand-worker with no risk appetite.
2. Big companies are usual services companies: they have few employers and they usually have a lot of small sub-contractor companies that materially make hard work. Their issue is to maximise profit and their big dimension does not allow them to invest in small[3] or non-sure projects.
3. Builders are not specialised for a technique or a place: pre-fabrication asks specialised skills and clear and constant environmental conditions.
4. If builders outsource construction system, their profit decreases: they cannot buy ready-made buildings from other companies because it should be too expansive for them and they do not have the structures to produce their own system.
5. Building workers are usually low trained and skilled. Offsite system should increase simplicity in on-site operations. Therefore, a construction market with a general workers' lack of skills should ask and increase IBS demand. Whereas a skilled workforce is mandatory to ask and accept any kind of innovation, included offsite IBS (Clarke, 2002).

From a *historically point of view*, pre-fab IBS companies were born and increased only if they were strictly joined to big real estate assets (Akmam Syed Zakaria, Gajendran, Rose, Brewer, 2018). An example of this is the Unite Modular Systems (UMS) of Stonehouse[4]. The company was founded in 2002 and made modules for building sites including fully-fitted and furnished bedrooms, studios and kitchens. This company was created by United Students for its new building assets and produced hundreds of buildings for almost ten

[3] Only-residential private buildings are usually small or small/medium size.

years. In 2012 United Student[5] policy changed and decided to stop using UMS system and to spin off UMS from United Students and open it to the market: in few years the company went bankrupt. This clearly shows that the first sustainability to consider, even for IBS, is the institutional one[6] and shows that supply and demand in IBS should be strictly joined.

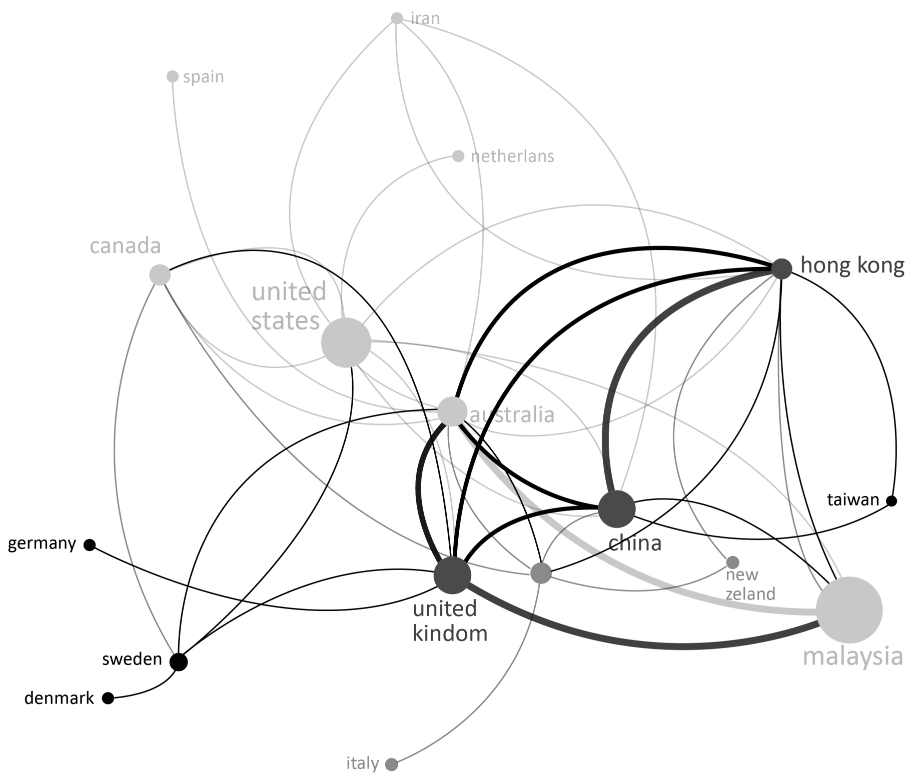
Looking at IBS-OSC research map (see below image) two groups of countries can be highlighted. One is the Anglo-Saxon (USA, Canada, Australia, UK, …) (Zhang, Skitmore, Peng, 2014) and the other one is the East/South East Asian group (with Malaysia and China in front).

IBS is a tradition in Anglo-Saxon Countries so their interest is expected. The last decade news is the second group (above all Malaysia) in which there is a very strong public control on residential sector. he government consciously has been driving this change with a strong policy and a lot of public investments (Akmam Syed Zakaria et al., 2018; Qays, Mustapha, 2010). And again the institutional aspects strongly emerge.

[4] https://www.bbc.co.uk/news/uk-england-gloucestershire-17258331.

[5] The UNITE Group Plc is a service company that provides (year 2020) accommodations for more than 50,000 students every year in circa 130 properties across 22 leading university towns and cities in the UK. http://www.unite-group.co.uk.

[6] See specific next chapters for in-depth analysis of institutional analysis.



Mapping of Countries where OSC (Off-Site Construction) research were located (elaboration from: Jin, et. al., 2018, p. 1212)

It appears clear that the most powerful driver for an increase of IBS is the public push. Countries with a big public residential asset or with important public incentive in the residential market can bring IBS to be strongly competitive to traditional market.

Awareness, knowledge and drivers' choice

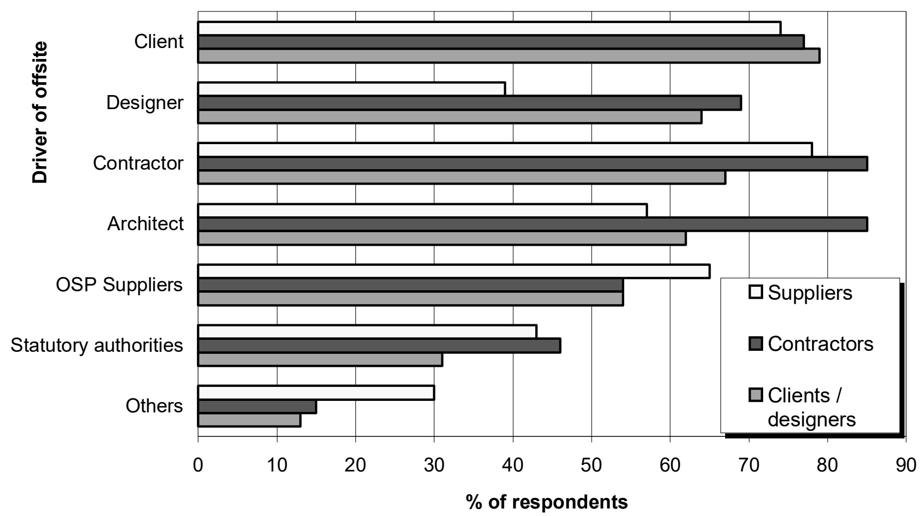
«The majority of clients and designers surveyed (73%) claimed that they were sufficiently aware of the relative advantages and disadvantages of offsite over traditional construction, compared with just over half (54%) of the contractors surveyed. However, less than a third (30%) of the suppliers questioned thought that their customers were aware of the relative advantages and disadvantages of offsite over traditional construction» (Goodier, Gibb, 2005, p. 151).

Supplies always report that customers are sure they know about IBS, but this is a false awareness: most of times, they know few about these products and sometimes they use them without knowing they are offsite (pre-cast concrete as an example example).

Who decides the use of IBS in a project? Even the answer to this question is complex for the residential private market[7]. Next graph well shows how each stakeholder thinks that the main driver is someone else: for designers and clients the drivers are the clients. Instead, the contractors think themselves and architects to choose the construction systems. Suppliers think clients and contractors to have the choice.

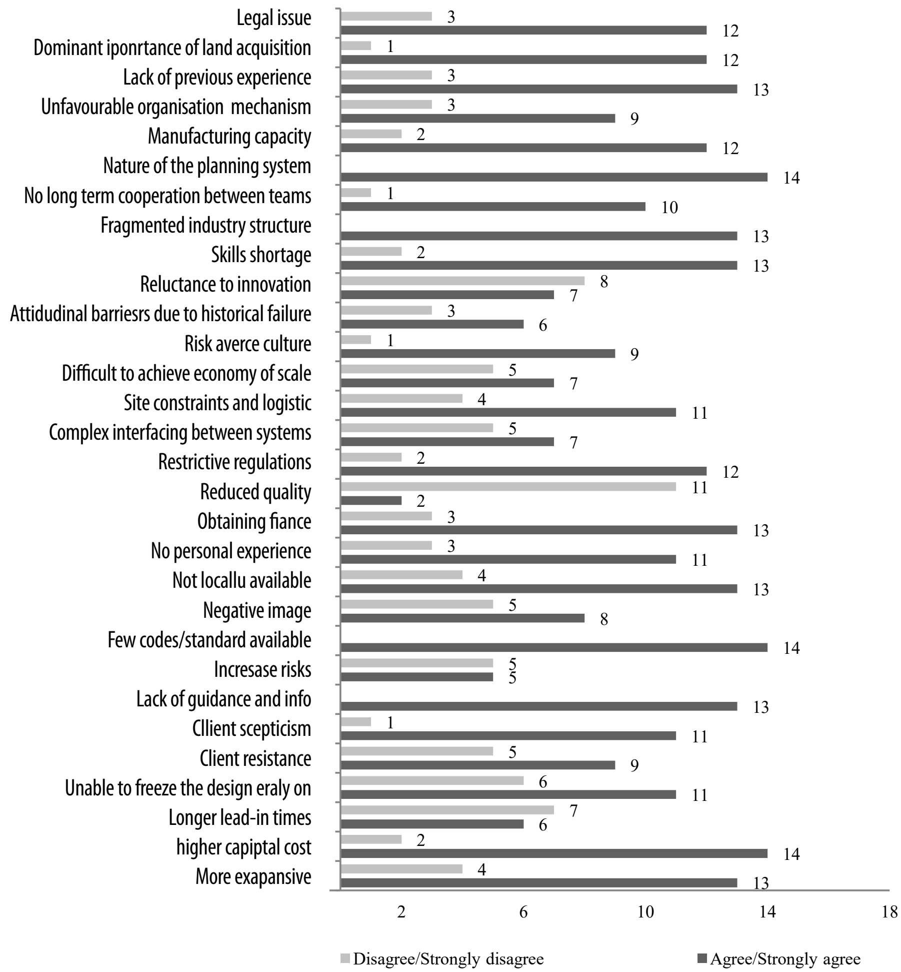
Next graph shows this uncertainty and decision-making confusion.

[7] For other sectors (offices, services, collective housing, …) the property has much more control on decisions and big contractor can wise and efficaciously decide which system using.



Graph 2: Main driver of offsite on a project. Who thinks can decide for IBS (from: Goodier, Gibb, 2005)

The results of this decision-making uncertainty is that nobody, really, takes responsibility to use IBS in a large-scale (Goodier, Gibb, 2005), even because there are a lot of factors (real or perceived) that scare stakeholders and decision-makers (see graph 3). «Change in building construction technologies, in most countries, is generally slow and rarely noticeable. When people think of a house, they are influenced by what already exists. The sense of familiarity is greater than the desire of experiment. Most people are looking for a home which is not the same as a product. They haven't accepted the idea of a home being modular or prefabricated. For an office block or an airport this concept is perhaps more acceptable» (Horden, 2001, p. 615).



Graph 3: Barriers against the use of offsite techniques in India (from: Arif, Bendi, Sawhney, Iyer, 2012)

Perception of advantages and disadvantages

Real and statistic data can be found in the next paragraphs. Here this work underlines the perception that stakeholders have about IBS and offsite systems.

As already said, most of the problems in choosing to use IBS come from misrepresented image society (expert and not) has of them.

Starting from perceived advantage, it is clear that benefits of IBS are well understood, as the following table shows, especially compared to the data of the next chapters.

Most of stakeholder in UK is aware that IBS are faster, with more quality, more consistent and increase value and sustainability in general. Even in South East Asia the reduction of costs and construction times are a plus of IBS, as better environmental performances, with more integrity of the buildigs and more aestethic quality.

Surprisingly, early freeze disegn is not perceived as a problem, even if it is often cited as one of the principal factor against IBS.

Table 1. Perceived advantages of offsite in UK (from: Goodier, Gibb, 2005)

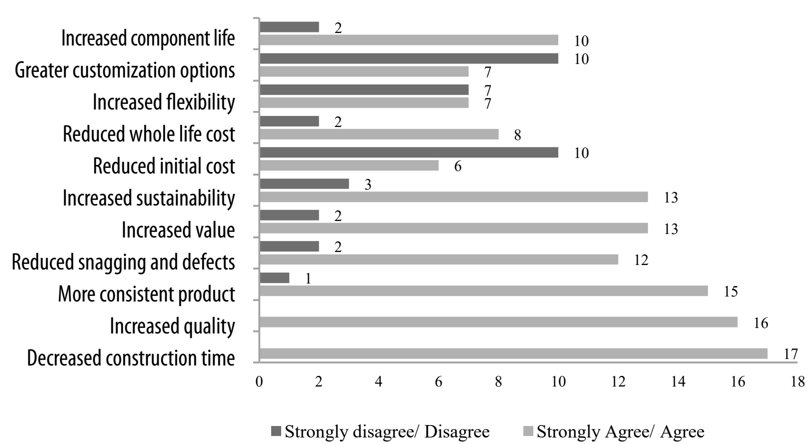
Table 1. Perceived advantages of offsite in UK

Perceived advantages	Clients/designers		Contractors	
	% of respondent	% as 1st choice	% of respondents	% as 1st choice
Decreased construction time	87	38	92	69
Increased quality	79	28	77	15
More consistent product	77	18	54	0
Reduced snagging & defects	79	8	69	0
Increased value	51	5	23	0
Increased sustainability	49	3	31	0
Reduced initial cost	44	3	15	8
Reduced whole life cost	41	0	15	0
Increased flexibility	33	0	15	0
Greater customisation options	33	3	0	0
Increased component life	28	0	15	0
Other	18	15	8	8

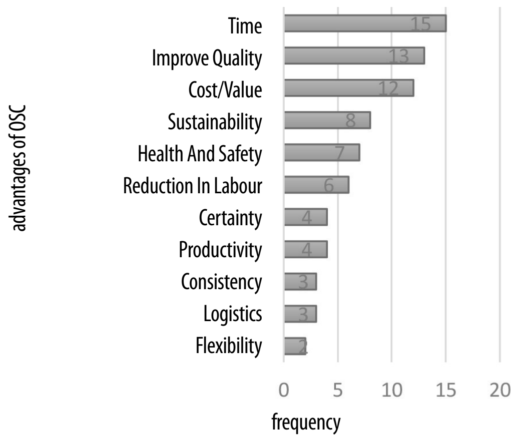
Table 2: Perceived advantages of prefabrication in South East Asia (from: Tam, et. al., 2007)

Table 2. Perceived advantages of prefabrication in South East Asia

Perceived advantages	Least significant (%)	Fairly significant (%)	Significant (%)	Very significant (%)	Extremely significant (%)	Average value
Frozen design at the early stage	3	3	16	56	22	3.91
Better supervision	0	3	6	69	22	4.09
Reduce construction costs	0	16	22	47	16	3.63
Shorten construction time	6	13	22	44	16	3.50
Improve environmental performance	16	59	13	13	0	2.22
Integrity of the building	9	16	16	50	9	3.34
Aesthetic issues	6	6	31	56	0	3.38



Graph 4: Perceived advantages of offsite construction in India (from: Arif et. al., 2012)



Graph 5: Advantages of off-site construction (from: BSI, 2019)

The perceived disadvantages, instead, show some surprises, because they contradict the previous data, although the representative sample of the survey was the same. This clearly shows all the unawareness on this topic. For example, the first perceived disadvantage is 'more expansive' even if one of the first perceived advantage is the reduction of initial and whole life cost, as well as increase of value of the building. In the same way seems that 'increase of risk' is a disadvantage, even if 'increase quality' and 'reduce snagging & defects' is one of the advantage.

This clearly confirms that the core of the choice for IBS should be left to perception of stakeholders and that the discernment of these systems is one of the more sensitive aspect of the question.

Table 3: Perceived disadvantages of offsite in UK from: (Goodier, Gibb, 2005)

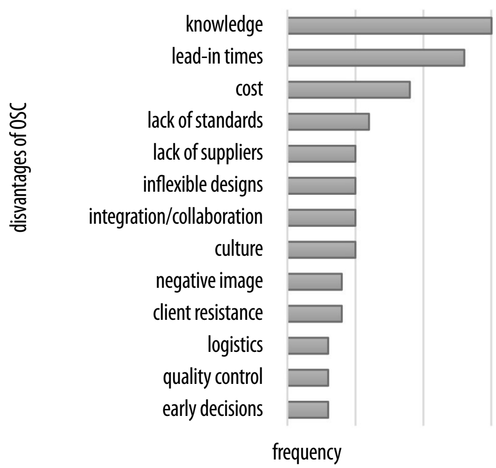
Table 3. Perceived disadvantages of offsite in UK

Perceived disadvantages	**Clients/designers**		**Contractors**	
	% of respondent	% as 1st choice	% of respondents	% as 1st choice
More expensive	67	54	77	38
Longer lead in times	46	8	62	8
Client resistance	38	13	31	23
Lack of guidance and information	33	5	46	0
Increased risk	36	0	15	0
Little codes & standards available	33	3	23	0
Other	31	18	15	8
Negative image	28	0	46	8
Not locally available	18	5	15	0
No personal experience of use	18	3	38	15
Obtaining finance	18	3	8	0
Insufficient worker skills	21	0	23	0
Reduced quality	13	0	15	0
Restrictive regulations	13	0	31	0

Table 4: Perceived disadvantages of prefabrication in South East Asia from: (Tam et al., 2007)

Table 4. Perceived disadvantages of prefabrication in South East Asia

Perceived disadvantages	Least significant (%)	Fairly significant (%)	Significant (%)	Very significant (%)	Extremely significant (%)	Average value
Inflexible for design changes	0	10	28	52	10	3.62
Higher initial construction cost	2	19	19	58	2	3.39
Lack of research information	0	12	40	40	8	3.44
Time consuming	2	25	20	48	5	3.29
Conventional method	8	10	40	39	3	3.19
Limited site space	0	28	34	35	3	3.13
Leakage problems	3	37	28	32	0	2.89
Lack of experience	3	46	23	23	5	2.81
Monotone in aesthetics	3	38	28	28	3	2.90
No demand for prefabrication	0	52	35	8	5	2.66



Graph 6: Disadvantages of off-site constructions from: (BSI, 2019)

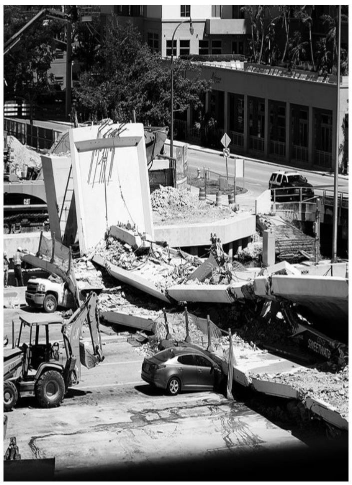
Some studies show as house buyers are very bad influenced by negative perceptions of post-war prefabrication (Robert Gordon University, 2002).

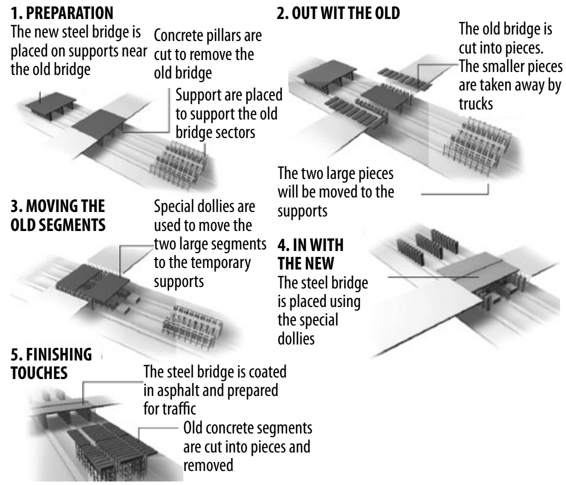
Others underline that the idea that the use of pre-fab is a barrier to designers' creativity and clients' customisation is false: it just depends on the kind of design process the stakeholders employ (Benros, Duarte, 2009; Noguchi, Hernàndez-Velasco, 2005).

From a cultural point of view, only few countries (e.g. Scandinavian countries or Japan)[8] have a real cultural approach for pre-fabrication and pre-assembly. Their vernacular buildings come from wooden dry-jointed structures: they are very easily dismountable and repairable and, above all in Japan, they are based on strictly modular system. Other countries approach of vernacular buildings is based on bricks or stones, joined with cement. Cultural background is very hard to be replaced and new positions can be easily wiped out.

[8] USA has IBS tradition in balloon frame, but although it is an IBS system, it is not pre-assembled and it requires a lot of manpower on site for building. See chapter 6. for in-depth analysis and definitions on this topic.

At the end of the Seventies and the beginning of the Eighties in the UK the timber frame was catching as an inner counterpart of bricks or for internal walls. In 1983 a ITV documentary made by World In Action «caused the timber-frame housing market to crash. It alleged that timber-frame construction could not produce houses that would last, citing rot in the frames of nine-year-old homes on a Cornwall estate. It also said timber framing was at the heart of a fire in a Barratt home in the Midlands»[9]. The system, in few days, fell out of the market – even though the claims were widely discredited and it could recover only after no less than after 16 years.
In 2018 in Florida a prefabricated pedestrian bridge of the Florida International University collapsed. «A Prefabricated Tragedy. The collapse of a super-bridge in Florida shows how an entire philosophy of building can go wrong»[10]. Some in-depth analysis[11] demonstrated that there was a flawed design and incorrect calculations, but still nowadays prefabricated bridges are considered untrustworthy, despite any evidences. The images below show the pedestrian bridge collapsed, compared to succesful prefabricated off-site Sanyuanqiao overpass in Beijin, a huge vehicular bridge replaced in 43 hours.





Pedestrian bridge of the Florida International University after the collapse (left), from: https://slate.com/business/2018/03/the-florida-bridge-collapse-shows-how-accelerated-bridge-construction-can-go-wrong.html (visited on 07/07/2021);
schematic render of the Sanyuanqiao overpass in Beijing (right), from: https://www.chinadaily.com.cn/china/2015-11/11/content_22425536.htm (visited on 07/07/2021)

Another consideration, which starts from the previous point, is that if there are problems in a traditional building, the reason is the builder. If there is a problem in a prefab or MMC system, the reason is the system itself. It seems that the common perception (and so the stakeholders' perception) is that IBS is a monolithic system and the fault of one is the fault of all. This is obviously a cultural preconception, irrational but very rooted. See (Zhang et al., 2014) on this subject.

If you type 'dream house' in a whatever search engine, the images that will appear will be a villa, usually old style, in the countryside. People's ambition for living if they were reach or retired (or better if they were both) is an old cottage in the countryside, but with all comforts. It is not a new modern flat in a city. This consideration closes every possibility that an IBS house would be the most wanted. It could only be for temporary use (e.g. student dormitory)

[9] https://www.building.co.uk/news/timberand8217s-back-in-the-frame/4474.article (visited on 07/07/2021).
[10] https://slate.com/business/2018/03/the-florida-bridge-collapse-shows-how-accelerated-bridge-construction-can-go-wrong.html (visited on 07/07/2021).
[11] http://happypontist.blogspot.com/2018/03/the-collapse-of-fiu-sweetwater.html (visited on 07/07/2021).

or for disadvantaged people (and this was at the beginning the idea of Jean Nuovel's Nemausus).

In crisis times, 'ancient times are always better'. This statement is related to people's perception, but it is also linked to the concept of conservation: old is, most of time, just and venerable. This could be right, but it could have, as a consequence, that new and innovation are at first glance bad.

Speaking of non-acceptance, it clearly emerges that the non-acceptance is most of the time a question of bad perception. Some authors suggest some possible strategies to overcome this lack of awareness (Dainty, Moore, Murray, 2005). Good examples and viva voce, together with collaboration and dissemination of information, seem to be the right way. The below table shows some of these possible strategies.

Table 5: Possible overcoming clients' resistance to offsite (from: Goodier, Gibb, 2005)

Table 5. Possible overcoming clients' resistance	
Means of overcoming resistance	% of respondents
Provision of examples / case studies	68
Client experience	55
Increased partnership arrangements	55
Increased marketing / information	50
Price reductions	27
Other	23

So training, education and increase of awareness of IBS appear to be the most useful strategies. Education is needed at all levels, from school to University (Dainty et al., 2005). Also Government training grants were asked by many stakeholder (Clarke, 2002).

Other authors introduce the idea that «failures in modular building have resulted from a vicious co-dependency on public acceptance, volume production, and distribution infrastructure. None of these attributes can successfully exist without the presence of the others. The public was looking for cost reduction and availability, while such reductions, in turn, depended upon mass production, and high public demand, offering little flexibility» (Luther, Moreschini, Pallot, 2007, p. 158).

The costs

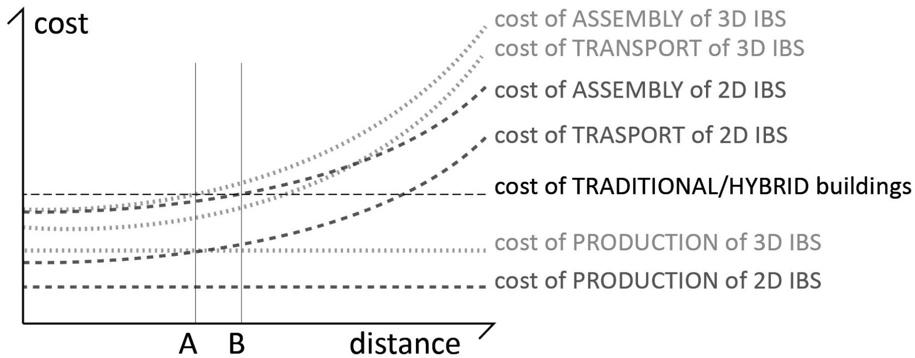
Despite some perceptions, IBS is not more expensive than traditional. Many papers clearly and extensively demonstrate that considering all time and costs variables, offsite is cheaper than other systems (Venables, Barlow, Gann, 2004), especially introducing quality and performance variables[12] (Benros, Duarte, 2009; Haas, O'Connor, Tucker, Eickmann, Fagerlund, 2000; Kamali, Hewage, 2016; Kozlovská, Kaleja, Struková, 2014; Lawson, R., Ogden, Bergin, 2012; Navaratnam, Ngo, Gunawardena, Henderson, 2019; Noguchi, Hernàndez-Velasco, 2005; Pasquire, Gibb, 2002; Paya-Marin, Lim, Sengupta, 2013). Some authors estimated that the total cost of the labour can be reduced to the 25% compared to traditional (Haas et al., 2000; Quale, et. al. 2012).

[12] An interesting and very useful tool to analyse IBS costs is IMMPREST (Interactive Method for Measuring PRE-assembly and STandardisation benefit in construction) tool developed by Loughborough University, which 'seeks to provide a framework for comparing solutions in a holistic manner' https://offsite.lboro.ac.uk/proj-immprest.php.

The *price* of the land is high, compared to the total amount of the building. The construction system must be cheap and quick. These seem to be reasons supporting IBS, but, because of the market structuring and because the other points of this list, every building is a sort of prototype (so expensive and with a long design phase) and builders do not risk their capital or image in it.

Considering *space*, catchment area leads the economical sustainability of IBS (especially the 3D systems): distance is a factor of great impact on total cost for IBS systems. The more a system is pre-assembled and the more the transport costs and becomes a possible reason of extra-cost towards on-site construction. 2D IBS include less air than 3D IBS and are usually smaller and more packable: their transport costs less than 3D ones. On-site constructions use small, easy transportable and local-available components: their transport cost is very low, considering the whole amount of building cost.

The following graph shows the relations between cost and distance, regarding 2D IBS and 3D IBS and traditional/hybrid buildings.



Graph. 7: IBS cost towards traditional, considering distance from IBS production factory. There are no complete or verified data in literature, but jus many sentences from many sources: the graph is a synthesis of them (qualitative original elaboration, having the only purpose to make 'visible' the concept introduced before)

The cost of a traditional/hybrid buildings is not strictly related to the distance from the production factories of components (except if the site is very far from civilization or in very hard physical conditions). Building components are widespread and similar in most part of the world.

2D and 3D IBS have production cost lower than traditional, but they need to be transported, often with high costs. Because of this, 2D and 3D IBS systems are affordable in a limited range distance from production units.

Relating to previous graph, after A point for 3D (B for 2D), IBS is affordable and sustainable only if:

- it's for an emergency use: you have a ready stock and no time for other solutions;
- special needs: very light or very high performance buildings or temporary buildings (for 3D IBS);
- use of current production market, maybe taken from naval or industrial equipments, ready made and transferred in building sector, e.g. Jean Nuovel's Nemausus[13]. This building has always been very controversial: already in 2000[14] there were a lot of problems, above all due to consensus, design bugs and costs. This could be one of the reason this kind of IBS approach was no more pursued.

[13] See http://www.jeannouvel.com/en/projects/nemausus/ for details.

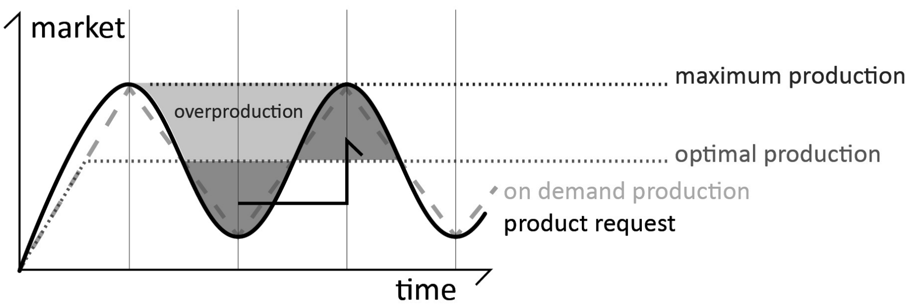
[14] https://www.liberation.fr/societe/2000/03/15/nemausus-un-paquebot-a-vau-l-eau-deficitaire-et-critique-l-immeuble-nimois-construit-en-1987-est-mis_318175 (visited on 31/03/2020).

The time(s)

The time variable can heavily influence the choice between IBS and traditional.

Considering time, IBS and prefabrication ask ready-stock to be competitive on the market. This factor heavily limits the possible use of prefab technology for the open and aggressive market and a large scale diffusion:
- stock is against customisation that is one of the most required need for private residences;
- stock mandatory needs fixed and constant assets to be economical sustainable. Actually, if a company invests for a big stock, it must be sure this stock will be sold and used in a guaranteed and limited time, otherwise the company would over-product and start losing money;
- on-demand production is against IBS because one of the plus of IBS is the possibility to reach an optimal and constant production. However, building market is never constant. Therefore, a big stock is required. This stock immobilises a huge amount of money and forbid personalisation of components.

The graph below visually shows these conditions.



Graph. 8: IBS market considering time and stock. There are no complete or verified data in literature, but jus many sentences from many sources: the graph is a synthesis of them (qualitative original elaboration, having the only purpose to make 'visible' the concept introduced before)

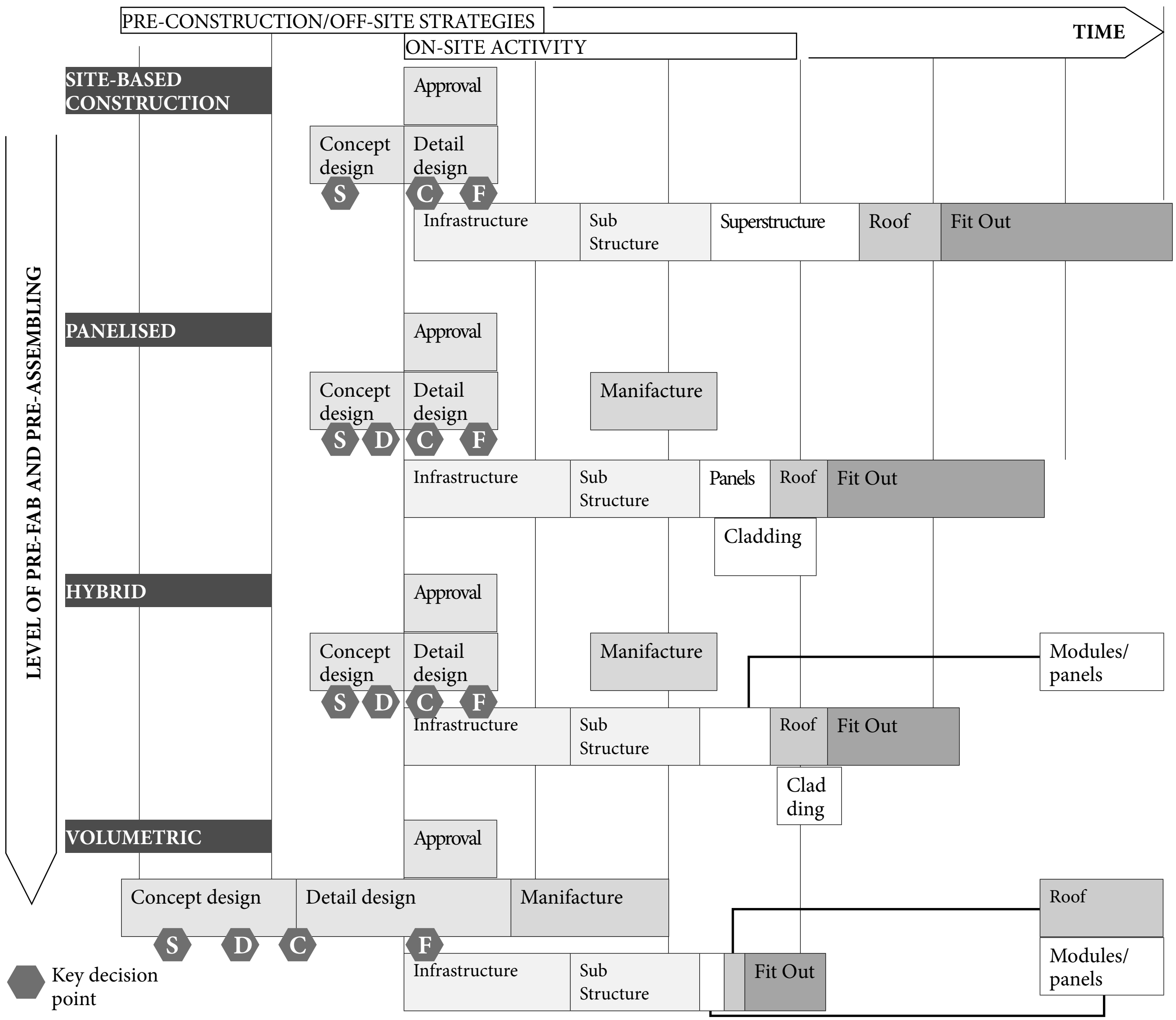
The case of UMS of Stonehouse cited before is a perfect example of this condition. If on one hand fully-operational and large-scale offsite system are certainly faster than other systems, on other hand IBS have usually longer lead-in times because the use of IBS generally delays the start of the working phase on site.

Land usually does not belong to builders: constructors are asked to build quickly and at minimum cost, as soon as possible the project starts. So builders have no time for an appropriate design phase, which should be long and expansive for them, to support pre-fab IBS, as the following image well shows. The more pre-fab and pre-assembled system you consider, the more anticipated must be the decisions phases and so the longer it takes to finish the building. This usually happens because IBS system need a long time to be designed and it is usual a mass-product and serial system. This means that if a contractor or a client ask for a custom project, traditional/hybrid systems are certainly faster.

The image below shows the differences between traditional (site-based) and IBS (off site and pre-assembled), showing the concept of anticipation of decision for IBS, in which the critical design milestones must be anticipated and the starting of the site postponed. This is called by scientific literature 'freeze design'.

Opposite page: time referring to project and realisation phases, elaboration (elaboration from: NHBC, 2006)

Concept design	**Approval**	**Detail design**	**Infrastructure**	**Manifacture**	**Substructure**	**Superstructure**	**Roof**	**On-site fit out**
Brief core team system S appraisal design team D	Planning permission building regulations	construction C appraisal project team design F freeze production schedule	roads services	modules pods panels factory-installed services	foundations slabs	shell panels cladding modules	structure cover	services fixture finish



As the previous image shows, the preparation of the site (Infrastructure in in the image) is the first construction phase for a site-based construction and other phases must wait this to be completed (in series production). Instead, for a pre-assembling system, the preparation phase can be simultaneous to manufacture and detailing phases, with an evident economy of time (Haas et al., 2000; Kamali, Hewage, 2016; Kawecki, 2010).

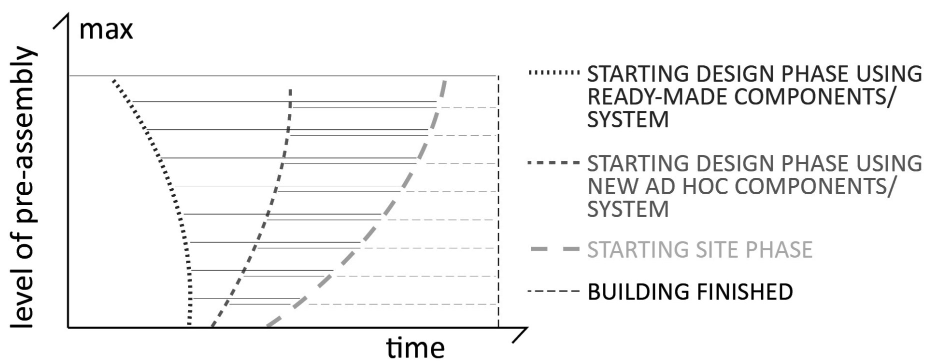
«In Australia, the prefabricated building system (i.e. pre-cut, panelised, modular, and mobile home building system) has been recognized as one of the alternative solutions to changing the speed of conventional construction methods at a fast rate» (Navaratnam et al., 2019, p. 2).

IBS is generally faster compared to traditional systems (Haas et al., 2000; Kamali, Hewage, 2016; Kozlovská et al., 2014; Lawson, R. et al., 2012; Navaratnam et al., 2019; Pasquire, Gibb, 2002; Paya-Marin et al., 2013): this rapidity can save up to 40% of traditional process.

However, design phase requires more time, accuracy, energy and more skilled labourers than traditional because of their degree of complexity and innovation.

This complexity is due to many factors (Ahn, Kim, 2014):
- design phase anticipates the decisions a traditional process spreads also in realisation phases;
- IBS are lifted and transported, so the components must have structural resistance and specific hooks for these operations;
- they are placed on a foundation system, so the joint must be designed accessible, easy to be used, with the right tolerances;
- pre-assembled elements must be joined together on-site, so this joint must be designed, calculated and realised.

Due to this increase of time for the complexity of design phase, and considering the previous image, it is possible to examine in depth the question 'time' introducing the following graph.



Graph. 9: The project' duration and phases, considering the level of pre-assembly of the components There are no complete or verified data in literature, but jus many sentences from many sources: the graph is a synthesis of them (qualitative origianal elaboration, having the only purpose to make 'visible' the concept introduced before)

The above graph links the starting phase of the project with the level of pre-assembly of the components. 0 (zero) on the Y axis means a traditional construction, in which most of the time is occupied by the site construction phase.

A high level of pre-assembly (at the top of the Y axis) means a project that uses 3D IBS pre-fab components.

In addition to the figure on p. 73, this graph introduces differences if a project uses systems and components ready-made and available on the market (first left curved line) or if it uses new systems/components purpose-built (second curved line).

For a project that uses ready-made components, the dashed line is similar to the tendency of the figure on p. 73: the more the system is pre-assembled, the faster is the entire process (design + realization).

Instead, if you consider the possibility to design a new system or some new components (it's true both for traditional and for pre-assembled systems) it's clear that the total time of the entire process is longer than any other prospects.

Other benefits

The table below collects a list of benefits and the author(s) who highlighted them. In the SWOT paragraph from p. 79 they are analysed and compared.

Table 6: List of benefits and author

Table 6. List of benefits and authors

Benefit	**Reference**
Improve performances and general efficiency of construction	(Hampson, Brandon, 2004; Luther et al., 2007; Matoski, Ribeiro, 2016)
Easy disassembly	(Lawson, R. M., Ogden,, Bergin, 2012)
Easy re-usability	(Gunawardena, Ngo, Mendis,, Alfano, 2016)
Reduction of construction waste, because a factory produces less waste and control, reuse and recycle it[15]	(Gibb, Isack, 2010; Haas et al., 2000; Jaillon, L., Poon, 2014; Kamali, Hewage, 2016; Kawecki, 2010; Lawson, R. et al., 2012; Luther et al., 2007; Pan, W., 2019; Quale et al., 2012; Tam et al., 2007)
Reduction of construction CO2 emission	(Jaillon, L., Poon, 2014; Kamali, Hewage, 2016; Kamali, Hewage, 2017)
More safety[16] for workers (up to 80%)	(Arif, Egbu, 2010; Haas et al., 2000; Lawson, R. et al., 2012; Luther et al., 2007; Pan, Wei, Sidwell, 2011; Quale et al., 2012)
Consistent production, because of repetitive and automatic process	(Arif, Egbu, 2010; Benros, Duarte, 2009; Cartz, Crosby, 2007; Lawson, R. M. et al., 2012; Noguchi, Hernàndez-Velasco, 2005)

[15] Total volume, mass and embodied energy of concrete and prefabricated steel and timber building scenarios, with percentage of potential savings achieved from the reuse of materials through Modular Construction (from: Aye, et. al., 2012).

[16] In terms of less incidents and problems occurring to workers.

Table 7: Difference of wastage between cast in situ and prefabrication (from: Tam et al., 2007)

Table 7. Difference of wastage between cast in situ and prefabrication

Trades	Average wastage level (%) Conventional (A)	Average wastage level (%) Prefabrication (B)	Percentage of waste reduction % [(A-B)/A]
Concreting	20	2	90
Rebar fixing	25	2	92
Bricklaying	15	–	–
Drywall	–	5	–
Plastering	23	0	100
Screeding	25	–	–
Tiling	27	7	74

Table 8: Other benefits of IBS

Table 8. Other benefits of IBS

Less affection to neighbouring buildings and surroundings, in term of less noise and less disruption (up to 50%)	(Lawson, R. et al., 2012)
Improve the quality of buildings	(Luther et al., 2007; Matoski, Ribeiro, 2016; Musa, Mohammad, Mahbub, Yusof, 2014; Tam et al., 2007)
Enhance the flexibility of usage	(Luther et al., 2007)
Enhance the maintenance	(Luther et al., 2007)

The data and concepts collected in previous paragraphs seem to be uneven and disorganised. This is due to the starting reference sources that collect different IBS techniques, different sources (surveys, statistical data, market analysis) and show how complex and non-linear is the perception and the decision making process fro IBS. Next paragraph, thanks to a SWOT analysis will give order and management, analysing all the aspects separately and using dimensions and categories to extarct factors and aspects comparable and uniform.

Meanwhile an early synthesis can be deduced: it seems that some kind of IBS can be suitable for house building, but the principal obstacle to their diffusion are the knowledge and the perception of them, together with the builders structure that does not allow the mandatory investments for some kind of IBS.

IBS works well. This is beyond doubt. You have only to consider the enormous investments that a lot of countries (UK, Malaysia, China, New Zeeland,…) are supporting in these years.

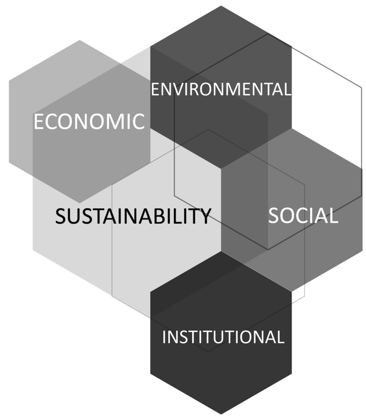
Some barriers can be overcome by the correct role of the design. Some others are external to design or to building market itself, and are out of the control of the design as the last chapter will show.

A multidimensional view on industrialisation: a SWOT analysis for housing

This chapter analyses IBS systems from a multi-dimensional point of view, using a SWOT analysis, starting from all the points of view and all the data and the categories revealed in the paragraphs above. It takes all the aspects and gives them a methodical structure for the purpose of a critical analysis and a weighted judgement.

After an analysis dividing the different factors by the four dimensions of sustainability, the last paragraph re-orders all the factors in external to the market, internal the market and specific of the design.

The IBS system is analysed starting from each of four dimensions of sustainability, as defined by UN DPSCD[17].



The four dimensions of sustainability (orignal elaboration)

Starting from official definitions[18], this book assumes specific definitions that could better express the goal of the research itself and that can be more useful to analyse IBS in a SWOT analysis.

Economic dimension: this dimension considers the economic and business aspects of IBS, including global cost, profit and value.

Environmental dimension: considers the aspects related to quality, answer to requirements, available resources, ...

Institutional dimension: evaluates the standpoint of the involved stakeholders. They can be private (owner, companies, trade association) or public (public Institutions or Department,…). In this dimension, you can also find rules, laws and regulations.

Social dimension: considers the inhabitants' point of view, whether people living inside IBS buildings or people leaving around them.

SWOT analysis is an analysis technique that places an argument in its contexts and analyses it from different points of view, underlining positive and negative aspects, and giving the basis for an improvement of a product or a technique or a sector.

Even for IBS theme (Jiang, Mao, Hou, Wu, Tan, 2018; Li et al., 2016) this techniques was useful and here this research collects SWOT analysis on these topics from scientific literature.

[17] UNDPSCD - United Nation Department of Policy Coordination and Sustainable Development https://sustainabledevelopment.un.org/.

[18] Official definition from UNDPSCD of the four dimensions of Sustainability:
- economic sustainability as an ability to generate income and work to support the population;
- environmental sustainability, as an ability to maintain quality and reproducibility of natural resources;
- institutional sustainability, as an ability to ensure conditions of stability, democracy, participation, justice;
- social sustainability, as an ability to guarantee conditions of human well-being (safety, health, education) equally distributed (by class and gender).

Table 9: SWOT analysis for IBS

Table 9. SWOT analysis for IBS			
SWOT- analysis		Internal Analysis	
		Strengths	Weaknesses
External Analysis	Opportunities	Areas IBS is well or has advantage on competitors	Areas to be improved
	Threats	External factors that may contribute to IBS and can build up IBS strengths	Potential problems/risks caused by external factors IBS may faces

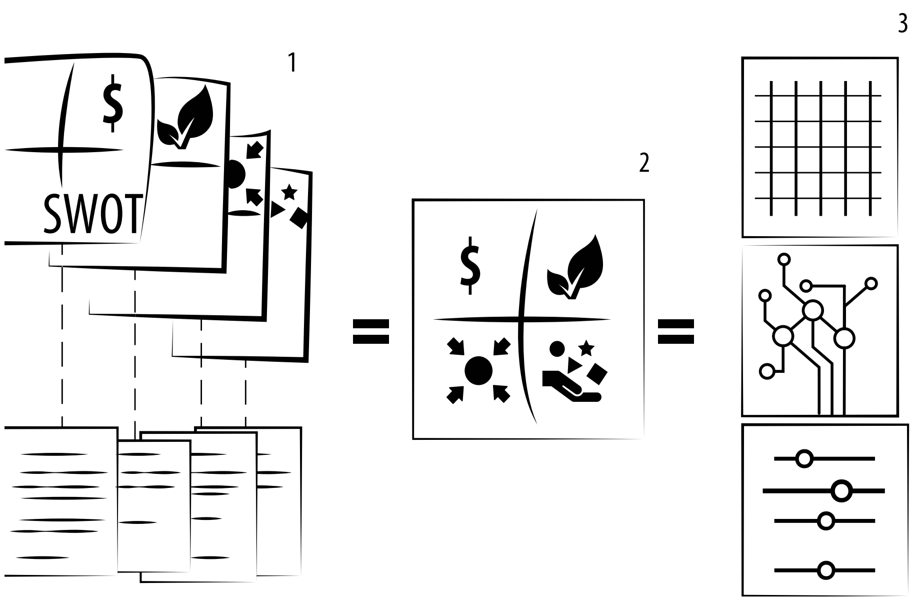
This research assumes the validity of the SWOT analysis, without entering the debate[19].

The SWOT analysis will be done four times, one for each sustainability dimensions.

The factors in the tables below are taken from literature (Abanda, Tah, Cheung, 2017; Goodier, Gibb, 2005; Jiang et al., 2018; Jin et al., 2018; Li et al., 2016; Pan, W., 2019), from interviews and from transversal analysis of texts.

At the end of the four SWOT analysis there is a synthesis that collects and synthetically recapitulates the results.

[19] Regarding SWOT analysis methodology in general, a starting point can be (Bell, Rochford, 2016), where you can find a history, together to pros and cons points of view.



Schematic methodology of the double SWOT analysis: 1. four dimensions SWOT, 2. comparison and interaction of negative factors, 3. three levels of ability to act of the project

Table 10: SWOT analysis Economic dimension

Table 10. SWOT _ Economic dimension			
SWOT – analysis ECONOMIC DIMENSION		Internal Analysis	
		Strengths CS1. Reduced construction time and labour requirement CS2. Increase Quality CS3. Defects reduction CS4. Minimisation of Life Cycle Costs CS5. Minimisation of site cost CS6. Minimisation of uncertainty CS7. Increase production quantity	**Weaknesses** CW1. Higher upfront cost CW2. Use of heavy machinery CW3. Insufficient industry investment in R&D CW4. Costs are distance-based CW5. Low tolerance interface even on site CW6. Lack of knowledge about durability CW7. Necessity of a stock production system
External Analysis	**Opportunities** CO1. Productivity-driven new urbanism CO2. Reducing reliance on manpower CO3. National economic growth driver CO4. Faster construction improves financial performances	From an economic point of view IBS is theoretically one of the best solutions	IBS needs: - the right scale and place - more studies - more education for companies and workers
	Threats CT1. Immature OSC development conditions CT2. All the future use must be design-in-advance projected (early freeze design) CT3. IBS stock necessity and cyclic market CT4. Non cost-effectiveness for not specialised companies	IBS needs the right external conditions (not only the economic ones) to improve and grow	Public support is mandatory: - as a driver - for infrastructures - as incentives and examples

From an Economic point of view, IBS is theoretically one of the best solutions because it reduces times, labour and costs, as all the sources affirm undoubtedly. It also can be a driver for all districts and for national economy too. However, it needs the right scale (of companies and of site) and place to be competitive, more research and more education for companies and workers. IBS needs the right external conditions (not only the economic ones) to improve and grow, including public support as a driver, incentives, examples and the right infrastructures.

Table 11[a,b]: SWOT analysis Economic dimension, main factors and definitions

Table 11[a]. SWOT _ Economic dimension, main factors and definitions		
factor	**definition**	**sources/insight**
CO1. Productivity-driven new urbanism	In China and Malaysia new town (or big part of towns) are growing up only using IBS/OSC systems.	(Akmam Syed Zakaria et al., 2018; Jiang et al., 2018)
CO2. Reducing reliance on manpower	Years ago, work force was very poor and under-paid in China. Today salary are increasing. Also outside China, this can be an opportunity to reduce cost of components.	(Jiang et al., 2018)
CO3. National economic growth driver	[…] the use of offsite technologies in construction has been recognised as one of the key factors contributing to national economic growth and recently has been part of the 'knowledge-based economy'.	(Ozorhon, 2013)
CO4. Faster construction improves financial performances	Long time on site means loss of money and less gains.	(Elnaas, 2014)
CT1. Immature OSC development conditions	[In China, but universally true] …the immaturity of development conditions of the OSC market is mainly revealed from two aspects, one is the dependence on the government, and the other is the less developed supply chain.	(Chao, Qiping, Wei, Kunhui, 2015; Jiang et al., 2018)
CT2. All the future use must be design-in-advance projected (early freeze design)	Anticipation of needs and uses is a key to make IBS economically sustainable.	(Elnaas, 2014)
CT3. IBS stock necessity and cyclic market	IBS need a steady and regular production system.	(Tam et al., 2007)
CT4. Non cost-effectiveness for not specialised companies	IBS need medium-big companies. Big companies are only service companies with a lot of sub-contractors. Outsourcing the construction system reduces companies profit.	(Chao, Qiping, Wei, Kunhui, 2015; Jiang et al., 2018)
CS1. Reduced construction time and labour requirement	IBS can reduce from 15 to 30% of time and around 16% of labour.	(Goodier, Gibb, 2005; Haas et al., 2000; Housing Communities and Local Government Committee, 2019; Jaillon, Lara, Poon, 2008; Jiang et al., 2018)
CS2. Increase Quality	IBS can improve quality and so they can lead the reduction of maintenance and utilities costs.	(Goodier, Gibb, 2005; Jaillon, Lara, Poon, 2008; Jiang et al., 2018; Tam et al., 2007)

Table 11b. SWOT _ Economic dimension, main factors and definitions		
factor	**definition**	**sources/insight**
CS3. Defects reduction	Components made in factory has a higher level of control.	(Elnaas, 2014; Jaillon, Lara, Poon, 2008)
CS4. Minimisation of Life Cycle Costs	Each component of cost is under control, including maintenance and dismantling.	(Elnaas, 2014; Goodier, Chris, Gibb, 2007)
CS5. Minimisation of site cost	Site requires accurate project that reduces costs and troubles.	(Elnaas, 2014; Goodier, Chris, Gibb, 2007)
CS6. Minimisation of uncertainty	IBS need a steady and regular production market.	(Elnaas, 2014; Goodier, Chris, Gibb, 2007; Pan, 2019)
CS7. Increase production quantity	As all productive companies, an IBS company needs to constantly increase the production to be performative.	(Benros, Duarte, 2009; Noguchi, Hernàndez-Velasco, 2005)
CW1. Higher upfront cost	«Higher initial costing is the most noticeable barrier to the use of OSC in China. Research works indicated that OSC […] is circa 20% higher than conventional design and construction methods […]. Besides, mechanised construction will incur a roughly 7% additional cost compared to conventional construction. However, this could be addressed with the growing applications of OSC that could hitherto bring down the component fabrication cost.»	(Chao et al., 2015; Chiang, Hon-Wan Chan, Ka-Leung Lok, 2006; Jiang et al., 2018; Xiao, Li, Zheng, Jin, Wang, 2015)
CW2. Use of heavy machinery	Heavy (especially 3D) IBS need big and expansive machinery to be moved and positioned on-site.	(Elnaas, 2014)
CW3. Insufficient industry investment in R&D	The core of IBS must be the investments in R&D.	(Elnaas, 2014)
CW4. Costs are distance-based	Costs depend on distance more than tradition systems. Affordability is a function that links the place of the factory and the site.	(Elnaas, 2014)
CW5. Low tolerance interface even on site	IBS has low tolerance interface. This could be a problem with the ground and foundation interface, which usually are not pre-fab.	(Elnaas, 2014; Goodier, Gibb, 2007)
CW6. Lack of knowledge about durability	IBS system have been used for housing by few decades and there is not knowledge about long-term performances and intervention possibility.	(Housing Communities and Local Government Committee, 2019)
CW7. Necessity of a stock production system	As highlighted in the previous chapter, most of IBS needs stock and constant production to be competitive.	(Elnaas, 2014)

Table 12: SWOT Environmental dimension

Table 12. SWOT _ Environmental dimension

SWOT – analysis ENVIRONMENTAL DIMENSION		Internal Analysis	
		Strengths NS1. Improved environmental sustainability NS2. Ensure building quality NS3. Control on dangerous substance	**Weaknesses** NW1. Lack of research and development practices NW2. CO2 production increase in case of site long distance from factory NW3. Difficult long-distance transport for large, heavy loads NW4. Use of heavy machinery NW5. Ground ad hoc interface required
External Analysis	**Opportunities** NO1. Sustainability-driven new urbanism NO2. Reduce local environment impact reducing working onsite time	Absolute control of the components and the environment	IBS needs: - more R&D - diffusion of the production site - the right scale of application - right scale for the system and company
	Threats No threat has emerged from literary review. A possible threat, even if no specific for IBS, could be the un-detachability of some layers and a difficult disassemblability of some pre-assembled components		A public control and incentive to the diffusion of production site

From an Environmental point of view, IBS certainly improves sustainability, quality and control on buildings and building process, creating new urbanism and reducing pollution and disturbance in general, thanks to an absolute supervision of the components and the production environment. The work on site is shorter and more controlled, so that troubles for neighbourhood linked to noise, handling and encumbrance of machinery and scaffolding are reduced in term of time and perturbation. IBS needs more R&D focused on targeted systems, more diffusion of production sites (to reduce distances between production and building site), the right scale of application and the choice of the right system for each building. It may be considered more experienced public control and incentive for increasing production and diffusion of companies involved in IBS.

Table 13: SWOT analysis Environmental dimension, main factors and definitions

Table 13. SWOT _ Environmental dimension, main factors and definitions		
factor	**definition**	**sources/insight**
NO1. Sustainability-driven new urbanism	China is planning to build 6 million dwelling units using IBS as the main way to get sustainability in new towns.	(Akmam Syed Zakaria et al., 2018; Jiang et al., 2018)
NO2. Reduce local environment impact reducing working onsite	A short duration of on-site working can reduce pollution (air, noise, energy, traffic ….) in the site area.	(Elnaas, 2014)
NS1. Improved environmental sustainability	IBS have a lot environmental benefits: - from 65 to 100 % reduction of waste; - from 30 to 40% reduction of carbon footprint; - 35 to 45 reduction of water consumption; - around 30 % plastering reduction; - around 50 % concrete reduction; - reduction of air pollution (more control); - reduction of transport pollution (if the distance between factory and site is affordable).	(Elnaas, 2014; Jaillon, Lara, Poon, 2008; Monahan, Powell, 2011; Poon, Yu, Jaillon, 2004; Tam et al., 2007)
NS2. Ensure building quality	Thanks to its accuracy, research has proven that IBS buildings are superior to the site-built ones, thanks to controlled environment of the factory.	(Arif et al., 2012; Jaillon, Lara, Poon, 2008; Jiang et al., 2018; Pan, Wei, Sidwell, 2011)
NS3. Control on dangerous substances	Factory process controls used components and reduces unknown substances.	(Elnaas, 2014)
NW1. Lack of research and development practices	«The Chinese construction sector has been long plagued with a deficiency of research and development practices and motive. Although China is promoting OSC mainly through three types of structure, namely, prefabricated concrete, steel and timber structures, there still lacks a national standard that justifies the techniques and processes regarding how to design, fabricate, assemble and demolish these structures».	(Chao et al., 2015; Jiang et al., 2018)
NW2. CO2 production increase in case of site long distance from factory	The distance between production and building site is one the biggest brake on development of IBS.	(Elnaas, 2014)
NW3. Difficult long-distance transport for large, heavy loads	The distance between production and building site is one the biggest brake on development of IBS.	(Elnaas, 2014)
NW4. Use of heavy machinery	Increasing of energy consumes and surrounding influences.	(Elnaas, 2014)
NW5. Ground ad hoc interface required	In some case, the ground interface can be a problem, especially because IBS requires low tolerance that must be well managed and coordinated.	(Elnaas, 2014)

Table 14: SWOT Institutional dimension

Table 14. SWOT _ Institutional dimension			
SWOT – analysis INSTITUTIONAL DIMENSION		Internal Analysis	
		Strengths IS1. Enhanced maintenance IS2. Increase Quality	**Weaknesses** IW1. Lack of OSC expertise and stakeholder coordination IW2. Lack of research and development motive IW3. Lack of understanding of local authorities IW4. Lack of understanding of national authorities IW5. Lack of regulations IW6. Lack of customisation IW7. Barrier to creativity
External Analysis	**Opportunities** IO1. Top-to-down policy support	IBS can guarantee: - more control on quality - assurance for times - certainty of results for the collectivity - reduction of building site threats for neighbourhoods	The OSC implementation requires key stakeholders to be involved from the start of the project and to work closely to implement specific workflows that cover design, construction and operation and maintenance tasks (Jiang et al., 2018). Designing with prefab components is not a barrier to creativity (Noguchi, Hernàndez-Velasco, 2005)
	Threats IT1. Incomplete policies and standards	IBS need - ad hoc rules and regulatory system, also for public procurements - more public incentives	«Government incentives: granting relaxation to the gross floor area for projects employing prefabrication elements will encourage the use of prefabrication. Moreover, tighter control on workmanship, allowable tolerances, homogeneity, and allowable rework will favour the adoption of prefabrication» (Tam et al., 2007)

From an Institutional point of view, IBS can guarantee certainty of quality, times and costs and can assure reduction of threats on site for neighbourhoods. To be competitive and accepted, all the stakeholders must be involved from the start of the project: by doing this quality is assured as well as a high level of customisation (often cited as on the biggest limit of IBS). IBS needs adequate regulatory systems and incentives and more workers training.

Table 15: SWOT analysis Institutional dimension, main factors and definitions

Table 15[a]. SWOT _ Institutional dimension, main factors and definitions		
factor	**definition**	**sources/insight**
IO1. Top-to-down policy support	Policy-making is the first and foremost opportunity: the example of China and Malaysia, in which public investments strong push the market, well show how a strength policy can drive a huge development.	(Akmam Syed Zakaria et al., 2018; Jiang et al., 2018)
IT1. Incomplete policies and standards	«Although numerous OSC-related policies and regulations have been introduced [in China], the majority of them are seen as general implementation frameworks and incentive mechanisms, rather than specific decision-making guidance, effective working procedures, detailed goals, steps and measures». In other Countries, there are even fewer policies and standards.	(Jiang et al., 2018)
IS1. Enhanced maintenance	IBS guarantee adequate level of maintenance.	(Luther et al., 2007)
IS2. Increase Quality	IBS can improve quality and so they can lead the reduction of maintenance and utilities costs.	(Goodier, Gibb, 2005; Jaillon, Lara, Poon, 2008; Jiang, 2018)
IW1. Lack of OSC expertise and stakeholder coordination	«However, the lack of coordination and collaboration among stakeholders clearly reflects the fragmented nature of the industry» of buildings.	(Chao et al., 2015; Jiang et al., 2018)
IW2. Lack of research and development motive	«The Chinese construction sector [but even other counties, including Italy (ed)] has been long plagued with a deficiency of research and development practices and motive».	(Chao et al., 2015; Jiang et al., 2018)
IW3. Lack of understanding of local authorities	Local and national authorities are often afraid of IBS, because they do not understand enough them.	(Elnaas, 2014)
IW4. Lack of understanding of national authorities	Local and national authorities are often afraid of IBS, because they do not understand enough them.	(Elnaas, 2014)
IW5. Lack of regulations	New technologies (especially transferred ones) can find many difficulties in a right classification and/or acceptability in regulation categories.	(Elnaas, 2014)
IW6. Lack of customisation	In some cases, IBS could be a barrier for customisation.	(Boafo et al., 2016)
IW7. Barrier to creativity	In some cases, IBS could be a barrier for creativity.	(Boafo et al., 2016)

Table 16: SWOT Social dimension

Table 16. SWOT _ Social dimension			
SWOT – analysis SOCIAL DIMENSION		Internal Analysis	
		Strengths SS1. Ensure work safety SS2. Increase Quality SS3. Increase construction speed SS4. Easy adaptability SS5. Control on dangerous substance SS6. Increase production quantity SS7. Enhanced maintenance	**Weaknesses** SW1. Big components manoeuvre SW2. Lack of personalisation and customisation
External Analysis	**Opportunities** SO1. Reduction working onsite time SO2. Get high level of quality SO3. National economic growth driver	IBS are adequate for users and for building workers and society	IBS need: - improve assemblability - make smallest components - change design approach
	Threats ST1. Lack of market acceptance ST2. Lack of media attention	IBS need: - more public investments - more education (above all public)	IBS need: - new public regulation - public incentives

From a Social point of view, IBS is excellent for workers, users and society. It just needs to invest in assemblability systems, uses the right size of components depending on the dimension and organisation of site, works on design approach to the project, involving all the stakeholders from the starting phases of process. For maximising social acceptability, it needs more public investments and education, such as new public regulations.

Table 17[a,b]: SWOT analysis Social dimension, main factors and definitions

Table 17[a]. SWOT _ Social dimension, main factors and definitions		
factor	**definition**	**sources/insight**
SO1. Reduction working onsite time	Especially for city centre, a short duration of the building site is a great benefit for the entire neighbourhood.	(Elnaas, 2014)
SO2. Get high level of quality	IBS can assure high level of quality.	(Elnaas, 2014; Švajlenka, Kozlovská, Spišáková, 2017)
SO3. National economic growth driver	«[IBS] has been recognised as one of the key factors contributing to national economic growth and recently has been part of the knowledge-based economy».	(Ozorhon, 2013)

Table 17b. SWOT _ Social dimension, main factors and definitions		
factor	**definition**	**sources/insight**
ST1. Lack of market acceptance	«Against every evidence, people's perception is usually against IBS. Back to 80's, there were sporadic OSC building collapse accidents around the world. This has caused misconceptions about OSC buildings ever since, and many people hold the opinion that OSC buildings are more structurally vulnerable. However, earthquakes and laboratory testing have already proven that precast structures can be used very safely and reliably in earthquake-prone regions like Sichuan and Tibet, as long as careful attention is paid to workflow the design and construction».	(Jiang et al., 2018; Zhang et al., 2014)
ST2. Lack of media attention	Media are not interested in increasing the right perception on IBS.	(Elnaas, 2014)
SS1. Ensure work safety	Off-Site manufacturing techniques offers more safety to working condition, reducing accidents and ell health, because most of activities take place under the factory-controlled environment.	(Elnaas, 2014; Jaillon, Lara, Poon, 2008; Jiang et al., 2018)
SS2. Increase Quality	IBS can improve quality and so they can lead the reduction of maintenance and utilities costs.	(Goodier, Gibb, 2005; Jaillon, Lara, Poon, 2008; Jiang, 2018)
SS3. Increase construction speed	«Faster construction can also improve housing completion rates and satisfy higher levels of demand».	(Elnaas, 2014; Švajlenka et al., 2017)
SS4. Easy adaptability	The project-based design and the re-design approach allows IBS to offer easy adaptability for future changes and customer's needs.	(Elnaas, 2014)
SS5. Control on dangerous substance	Factory production takes great control on used components and reduces unknown substances.	(Elnaas, 2014)
SS6. Increase production quantity	If a society needs houses, IBS can be a mass-production response.	(Benros, Duarte, 2009; Noguchi, Hernàndez-Velasco, 2005)
SS7. Enhanced maintenance	IBS optimises maintenance and durability.	(Luther et al., 2007)
SW1. Big components manoeuvre	The transport and the positioning of big and heavy 3D components can cause inconveniences to site area.	(Elnaas, 2014)
SW2. Lack of personalisation and customisation	One of the problem perceived for IBS is the lack of customisation, above all during construction in site.	(Elnaas, 2014)

Constraints to industrialisation between heteronomy and design barriers

This chapter makes a synthesis that faces the 'question IBS' from the point of view of the design: it isolates the factors outside building market, the external ones of the design phase and the internal of design. This research aims to compare only with the factor strictly linked to this last category, which is maybe the small ones, but is the one the design can positively influence.

Factors on the tables refer for codes and number to the four dimensions swot analysis of previous paragraphs.

The structural external conditions

Structural external conditions are all the conditions not depending directly on building market or design process. These heteronomies, depending on Country system, infrastructures, economic-cultural-social context strongly influence building innovation (Scoccimarro, 2008), but cannot directly be influenced by the design of a building or a system. For this reason, this research does not focus on them.

Table 18: The structural external conditions

Table 18. The structural external conditions			
STRUCTURAL EXTERNAL CONDITIONS		Internal Analysis	
		Strengths	Weaknesses
External Analysis	Opportunities		CW1. Higher upfront cost CW4. Costs are distance-based NW2. CO_2 production increase in case of site long distance from factory NW3. Difficult long-distance transport for large, heavy loads IW3. Lack of understanding of local authorities IW4. Lack of understanding of national authorities IW5. Lack of regulations
	Threats	IT1. Incomplete policies and standards ST1. Lack of market acceptance ST2. Lack of media attention	

Design can face these external conditions choosing the right IBS system in the right place (not far from site), working with local authorities and controllers to facilitate the use of IBS and promoting them. The single design process cannot influence by itself these external conditions: the design process must consider them during decisional phases for understanding the most sustainable construction system on the market in that context.

The production and infrastructures conditions

The structure of production sector and the conditions of the infrastructures are the settings linked to the production of the components or systems. They depend on private production market and the public infrastructures systems (above all connections) and the public regulatory framework.

Table 19: The production and infrastructures conditions

Table 19. The production and infrastructures conditions

PRODUCTION AND INFRASTRUCTURES CONDITIONS		Internal Analysis	
		Strengths	Weaknesses
External Analysis	Opportunities		CW1. Higher upfront cost CW2. Use of heavy machinery CW3. Insufficient industry investment in R&D CW7. Necessity of a stock production system NW1. Lack of research and development practices NW3. Difficult long-distance transport for large, heavy loads IW2. Lack of research and development motive IW5. Lack of regulations
	Threats	CT3. IBS stock necessity and cyclic market CT4. Non cost-effectiveness for not specialised companies IT1. Incomplete policies and standards ST1. Lack of market acceptance ST2. Lack of media attention	

Design cannot directly influence the public regulatory framework or infrastructure systems, but, at right scale and conditions, design can be a driver for the production structure, especially when public-driven or public-promoted.

Large-scale production needs a constant demand for most of systems, especially for the serial ones: in most case, they are not competitive. Small-scale production cannot afford stock policies. The design must choose the appropriate scale for each project or must favour systems that are not influenced by scale or high upfront costs.

The building place of a project is an independent variable that has a strong influence on the decision of the choice of the construction system: IBS systems can be competitive only in a specific distance between production site and building site and for these reason there cannot be system universal effective.

Attention and acceptance are nowadays among the factors against IBS: if a project wants an innovative IBS system, it must invest a lot of time and resources in communication, in decision sharing and participation of all the stakeholders.

The design-driven conditions

The design-driven conditions are the factors strictly linked to decisional process. This book affirms that on-demand design process (OD.D of p. 101) is one of the possible answer to overcome or, at least, limit negative factors at this scale of influence.

Table 20: The design-driven conditions

Table 20. The design-driven conditions

DESIGN-DRIVEN CONDITIONS		Internal Analysis	
		Strengths	Weaknesses
External Analysis	Opportunities		CW5. Low tolerance interface even on site CW6. Lack of knowledge about durability CW7. Necessity of a stock production system NW4. Use of heavy machinery NW5. Ground ad hoc interface required IW1. Lack of OSC expertise and stakeholder coordination IW6. Lack of customisation IW7. Barrier to creativity SW1. Big components manoeuvre SW2. Lack of personalisation and customisation
	Threats	CT2. All the future use must be design-in-advance projected (early freeze design) CT3. IBS stock necessity and cyclic market CT4. Non cost-effectiveness for not specialised companies ST1. Lack of market acceptance	

All the pre-assembled systems need a long and precise design phase, with early freeze design (CT2): all the decisions must be anticipated before production phase. These conditions for closed systems and serial processes are certainly a limit to personalisation and customisation (IW6, IW7, SW2), but in an open process with no pre-constructed elements it just moves all the decisions to the first step of the process, with a lot of benefit for quality and velocity of construction. An open system with no stock necessity could overcome the necessity of expansive and unprofitable investments and could bypass the need of adapting the production to the cycles of buildings (CT3).

To be accepted (ST1, IW1) design must involve all the stakeholders (including final users) and choose the right builder with the right expertise. Most of time, however, especially for very big projects, the builder chooses the designers and the possibility to choose for a IBS system depends only on the will and previous experience of the builder, that usually does not have the expertise (IW1) or the cost effectiveness (CT4) to manage or use IBS. In this case, design has a very little influence on building process.

The low tolerance on site (CW5) can be overpassed by a IBS pre-assembled off-site, in which very few joints (already prepared on components and easy to be dry-clamped) must be realised on site and with light and simple tools.

The durability (CW6) is a requirement of every building: some IBS, especially the more innovative ones, need years to be validated. The standardisation of technical solutions and laboratory/prototypes tests can address these problems, together to few on-site operations (the most dangerous and flimsy elements of building).

The necessity of a stock production system (CW7) is a limit for most of IBS that needs a considerable use of capital and that has not an easy interchangeability of elements and pre-defined and pre-assembled elements. This weakness can be overcome thanks to systems that use standard or ready-made elements for making 'on-demand' off-site pre-assembled components, using technological and typological solutions designed in advance: in this case, the stock is a stock of knowledge and solutions, not components. This approach prevents also the lack of customisation (IW6) and creativity (IW7). This is the case, for example, of SCB (containers are ready-made and everywhere available) or wood systems, that make totally pre-assembled 2D or 3D components, starting from a catalogue of tested solutions.

Heavy machinery (NW4) is a weakness hardly surmountable with pre-assembled systems, especially 3D: the only strategy is programming the short time of use of heavy machinery making the connections between elements fast, easy and safe.

Ground interface (NW5) can be a problematical joint for IBS that typically stand upon a traditional on-site made foundations that have usually different conceptions, bigger tolerances, less flexibility. This can make the interface difficult, with the necessity to interpose other elements (pre-assembled o made ad-hoc on-site) between the IBS and the ground attachment to compensate the incompatibilities and non-matches. Innovative, industrialised, flexible and pre-assembled foundation (such as screw-poles20 or other dry techniques) can overcome this weakness.

[20] As an example: www.krinnerfoundations.com (visited on 07/06/2021).

The seven categories of design for building process

This paragraph proposes a classification of the building process that starts from the active role the design should have in building sector to create connections and give a clear direction to the project.

In the early Sixties in Italy[21] some pioneers (Cetica, Ciribini, Frateili, Petrignani, Zanuso …) theorised that the building sector was near to a big positive revolution that would have definitely introduced the building sector into industry (Cetica, 1963), in Italy as in many other Countries. This did not happen. As did not happen after every cyclical building market crisis: in an optimistic positivism, IBS is asked to be the solution to structural and innate problems of the market (Maldonado, 1970; Mandolesi, 1978; Spadolini, 1963), but this mantra is every time disregarded (Frateili, 1987).

Even today, construction and industry, even if strongly linked and interdependent, are far from having the same approaches, methods, quality, results. Frateili made a deep and unwelcome conclusion, true also today: «assistiamo a un duplice semi-fallimento dell'industrializzazione edilizia rispetto agli obiettivi architettonici: di quella aperta perché poco o niente praticata dalla produzione edilizia, per la mentalità cantieristica prevalente (senza contare la quasi assenza di un interessamento negli architetti); di quella per sistemi chiusi per la sua scarsa duttilità. Eccezioni per la prima tecnica quei sistemi studiati ad hoc dal progettista all'interno di un intervento una tantum; per la seconda tecnica, il caso di quegli studi di architettura qualificati dimostratisi capaci di ottenere risultati operando prevalentemente sui volumi»[22] (Frateili, 1987, p. 105).

Process and production are the starting combination of the Sixties' reflections on buildings market: this proposal highlights the differences inside building sector systems starting with the nature of the design, it does not focus on production method or materials. It starts from the place of the production and the time of the design, overcoming the 'double semi-failure of building industrialization' quoted by Frateili in the above sentence and it suggests a 'third way', between open and closed systems, mass production and customisation.

This proposal starts from a concept on design by Ceragioli: «… non è affrontato dal punto di vista della produzione o dei singoli elementi. Non si propone una tecnica, ma un modo di affrontare il progetto che possa utilizzare la tecnica più appropriate nelle diverse condizioni [...] non tanto un sistema, ma una vision sul progetto»[23] (Ceragioli, 1977, p. 32).

This classification does not aim to be an analysis of stream decision process, which often goes deep inside the process, splitting and breaking in dozens of different actions and decision sub-phase, but that probably do not investigate the effective macro-categories and that could not anticipate and sum up the complexity of construction of nowadays' world.

From those masters this research takes the methodological approach, some analysis categories and, with new personal elaborations, some key-concepts, some definitions and classifications.

First of all, from Petrignani (AA.VV., 1965) we assume that you can talk

[21] The research starts from Italian Sixties debate because the contemporary market of today is not so far from the one of that time and because in the cultural positivistic framework of those generations the "mantra" of Industrialisation (promptly disregarded) is similar the debate of today on this topic.

[22] «We are witnessing a double semi-failure of building industrialization with respect to architectural objectives: of the open one because little or nothing practiced by building production, due to the prevailing shipbuilding mentality (not to mention the almost absence of an interest in architects); of that for closed systems due to its poor ductility. Exceptions for the first technique are those systems studied ad hoc by the designer within a one-off intervention; for the second technique, the case of those qualified architectural firms that proved capable of obtaining results by operating mainly on volumes». For a complete synthesis of the theoretical work of Frateili, you can see Campioli, 2017 http://www.aisdesign.org/aisd/enzo-frateili-lindustrializzazione-delledilizia.

[23] «…it is not approached from the point of view of production or single elements. We do not propose a technique, but a way of approaching the design that can use the most appropriate technique in different conditions…. not so much a system, but a vision on design».

about 'industrialisation' of a sector only if there is a decision-making concentration so that the decision-making chain has a unified and integral conception.

This suggests that building sector can hardly be 'industrialised', because the decision-making chain is heavily fragmented: there are the designers[24], the owners of the land, the customers, the buyers, the public stakeholders, the builders, the companies that makes products, the production place (the site is always in a different place) … and they often have different purposes and not coordinated times. In an industrialised process (Nardi, 1976), the owner of the factory has all the decision-making power and can manage the designers, the engineers, the production, the marketing and the production place that is always the same with the same conditions.

The place in which the objects (elements, components, systems ... of the construction) are made is a central aspect of the 'industrialising' question. The principal actions of a building are transformation and assembly (Ciribini, 1984; Frateili, 1973).

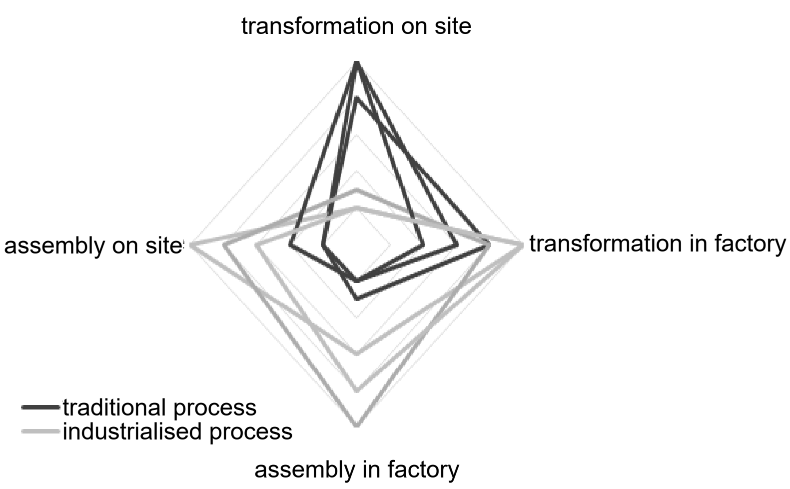
This work defines[25]:

transformation as 'a series of irreversible actions that, using resources (as water and energy) and performative machinery (that cuts, saws, …), modify raw material or secondary material into different elements, taking time for curing, adjustment, adaptation';

assembly as 'a series of reversible actions that, using few or no resources (as water and energy) and machinery only for transportation and joining, join together finished or pre-finished components, in a little amount of time'.

These actions can happen in factory or on site. As the graph 10 below shows, the traditional process and the industrialised one can be detached considering precisely where the actions happen. All the points in this radar graph are qualitative and represent a tendency, not a real point. This is the reason the graph shows not only one line but a sort of cloud of tendency, to indicate the wanted approximation of the image.

[24] The design process is fragmented itself.
[25] Original definitions.



Graph 10: The 'place' of components. The localisation of assembly and transformation, between factory and site (original elaboration as a qualitative graph for showing visually the concept)

A traditional building process is a process in which most of the transformation operations happen on site, using elements transformed in factory[26], and in which the assembly operations are very limited because on site most of actions needs transformation (no dry joint or clamping, massive use of water, demolition of elements,…). An industrialised process, instead, has very few transformations on site: most of the transformation happens in factory and the assemblies are in factory or on site (for the level of pre-assembly, see the below chapters). In confirmation of this, Frateili introduces the idea that building industrialisation corresponds to 'strategia dei componenti'[27] and that a «condizione di attuazione della industrializzazione è la produzione e il pre-assemblaggio spinto degli elementi che avvengono presso la fabbrica […] questo presuppone una certa continuità della domanda ed interventi distribuiti sul territorio»[28] (Frateili, 1982, p. 37).

The definition of industrialisation can also start from a question (Crespi, 1979; Frateili, 1982): *which is the difference between industrial design and building design?* This research assumes that the aim of the industrial design is the project of objects and the aim of the architectural design is the project of inhabitable spaces. These definitions[29] are the bases for the classification of next paragraph, in which the position of different kind of design, inside decision-making chain, and the position of transformation and assembly gives an interpretation of different aspects of building process.

Considering the role of the design inside the traditional and industrialised building process and thanks to some suggestions of Sixties Italian studies (AA. VV., 1965) this work proposes a design-centred classification of building production system process. Starting from the previous points definitions and considerations, it introduces seven categories that define seven different approaches the design can have to building system process. This classification starts from the role that the design has inside the building process and not from techniques or the structures of the components.

This is the major novelty compared to other classification proposals[30] that start from final objects rather than from the design and decision-making phase. This classification helps to identify the reason why some processes, more than others, have emerged and spread and which processes remained just some interesting but not mass-used idea, in order to identify which process could be effective and useful nowadays.

First of all the new classification considers 3 places of possible working phase, 3 actions and one target:

1. the 3 places are (in the below scheme are the 3 horizontal lines of each category): *factory*, as the primary place of production of elements and component, in a controlled environment and with a series production; *studio*, as the place in which the design of the building is developed; *site*, as the construction place in which the building is firmly arranged.
2. the 3 actions are (are the first 3 elements explained in the legend below): the *definitions of goals and requirements* is the phase in which the design team defines the targets, the outline and the frame of the project, both architectural and industrial, each one for its own specific path; *the architectural design* is the process that leads to the definition of the inhabited spaces, as the final result of

[26] Most of the time, even traditional building process uses industrialised elements (bricks, concrete,…) but they cannot be used without additional transformations.
[27] Components strategy.
[28] The condition for the implementation of industrialization is the production and pushed pre-assembly of the elements that take place at the factory [...] this presupposes a certain continuity of demand and interventions distributed throughout the territory.
[29] See (Frateili, 1973) for a complete dissertation on this issue (pp. 19-22).
[30] See for example (Modern Methods of Construction working group, 2019).

the building complex process; *the industrial design* is the process that leads to the definition of the objects that will be used in the building process.
3. The building is the final result of each building process.

After this introduction, below you can find the categories in which the building system has been divided according to the role of the design in the project process: this classification is the tool to investigate which categories are more suitable in today's market. In the description below each category, there is a telling example of architecture explaining the idea expressed by the scheme. A reasoned history of IBS uses this new classification with more examples follows in the next paragraph.

Elemennts of the process for the defition of the seven categories of the design-based process (original elaboration)

Where:
'GR Goals and Requirements' are the cornerstones of the design, such as goals, targets and demands of the entire project.
'Architectural Design' is the design phase that creates the connections for the realisation of the building and is usually specific for each project.
'Industrial Design' is the design phase that creates the connections for the realisation of the components of the building, without concerning a specific building or a definite construction site.
'Building' is the physical inhabitable output of the building process, as culmination of every construction process.

The seven categories of the design in construction process

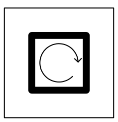
Considering the connections and the logical sequence of the project process that outcome from the previous analysis of building system, and cosidering the procees from the point of view of the design, highlighting the interaction between the elements, we can identify seven categories.

The first one is AI.D (All-Inclusive Design) that refers to prefabricated close systems. The second is Pa.D (Passive Design) that is the category of traditional buildings with its evolution in the third category PE.D (Passive Evolved Design). The fourth category is In.D (Installation Design) that refers to pre-fabricated, usually heavy, industrial buildings. The fifth category is Ad.D (Advanced Design) that is an open process virtually with no limits for technology and budget. The sixth category is Ex.D (Extended Design) and refers to transfer technology from non-building sectors. The seventh category is OD.D (On-Demand Design) that is the open process that includes active and industrialised components pre-assembled.

The following table is a summary of the seven design based categories, with short examples that specify them.

Table 21: Synthetic summary of the design-centred classification

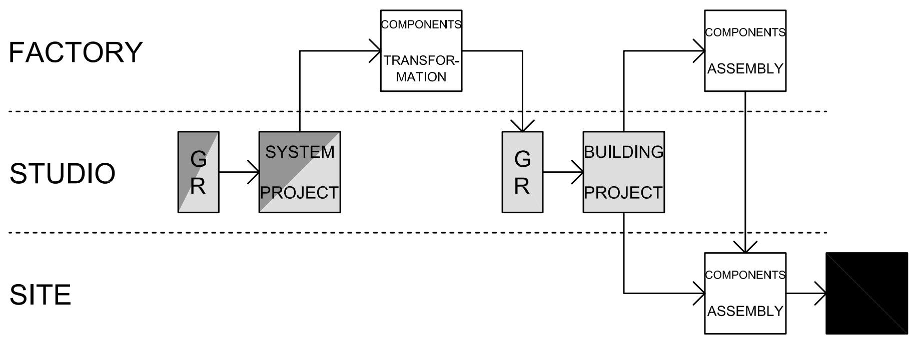
Table 21. Synthetic summary of the design-centred classification			
acronym	**name**	**reference system**	**example**
AI.D	All-Inclusive Design	Close system	Kurokawa's Nakagin Capsule Tower (Tokyo, Japan, 1972)
Pa.D	Passive Design	Traditional open system	Traditional buildings
PE.D	Passive Evolved Design	Evolved open system for open catalogues	Buildings using 'evolved' components, such as boards, panels, CLT (Cross Laminated Timber) or systems as ventilated façade,…
In.D	Installation Design	Componenting open system in close catalogue	Warehouse industrial pre-fab buildings
Ad.D	Advanced Design	Advanced open system for open components	Foster's Hong Kong and Shanghai City Bank (Hong Kong, 1985)
Ex.D	Extended Design	Extended open system for transfer components	Nouvel's Nemausus (Nimes, France, 1987)
OD.D	On-Demand Design	On demand open system for active components	Wood pre-fab system, cHOMgenius project,...



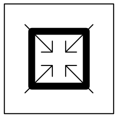
AI.D
ALL-INCLUSIVE DESIGN

for
CLOSE SYSTEM

All-Inclusive design



All-inclusive design is the design of Close Systems, in which the entire process is inside a unique decision-making chain. The design of the construction system corresponds to the design of the building and the design of the components. There is only one unique 'design' that includes all the aspects of the buildings and there are above all assembly operation on-site. We can anticipate what you can find in next chapters: the buildings using these systems are interesting but isolated experiments, not replicable and not sustainable in a large scale. A perfect example is Safdie's Habitat 67 (Montreal, Canada, 1967) or Kurokawa's Nakagin Capsule Tower (Tokyo, Japan, 1972).

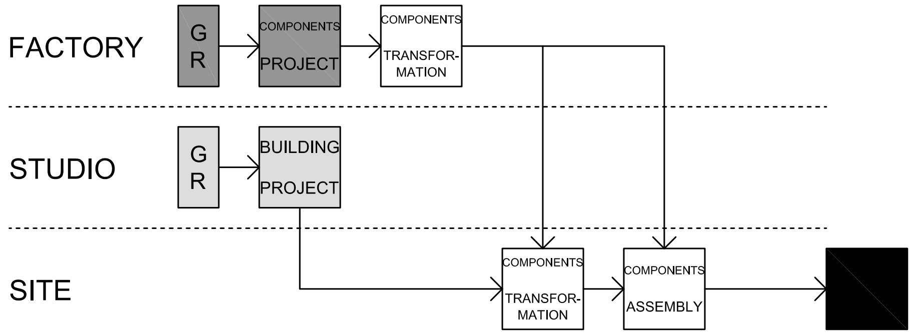


Pa.D

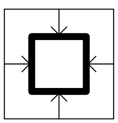
PASSIVE DESIGN

for
TRADITIONAL
OPEN SYSTEM

Passive Design



Passive design is the design of a Traditional Open System. It is the most common system for most of the buildings around the world. The design and the production of the components and systems are disjointed from the design and production of the building. All the basic elements are produced in factories in a large scale, without any customisation, expect for some dimensions (windows or similar). The designers of the building limit themselves to choose the products (usually small, standardised elements) on different catalogues, starting from their performances and costs. On-site most operations are transformation and the 'pure' assembly is limited. The construction site uses a lot of water, glues and other interface systems (often universal subframes) to compensate the high tolerance mandatory to join components not always compatible between themselves. Probably the 90% of building worldwide belongs to this category.

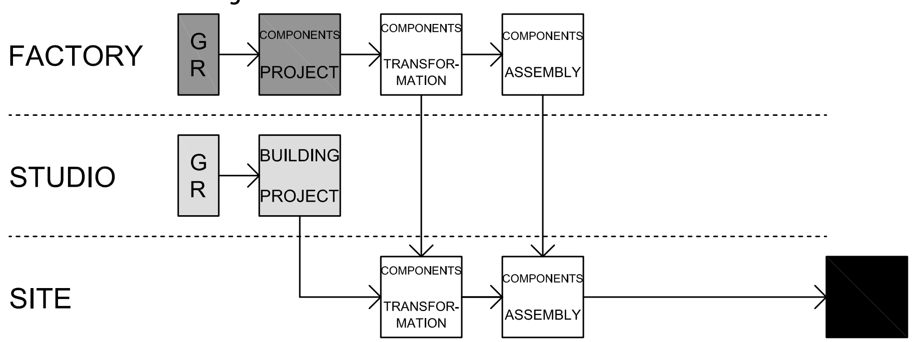


PE.D

PASSIVE EVOLVED
DESIGN

for
EVOLVED OPEN
SYSTEM
(open catalogue)

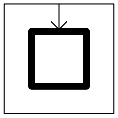
Passive-Evolved Design



Passive evolved design is the design of Evolved Open System. It represents an evolution of the Passive Design Pa.D, in which some components can be assembled in factory, there are more assembly operations on-site and the construction site is 'cleaner'. The demolitions are limited and building design can chose from traditional and 'evolved' components, such as boards, panels, ventilated façade, Cross-laminated timber (CLT, as XLAM).

The core conception of the process is firmly 'traditional' (with a passive role of the design compared to the products), using some 'evolved' components, such as 'semi-components'[31].

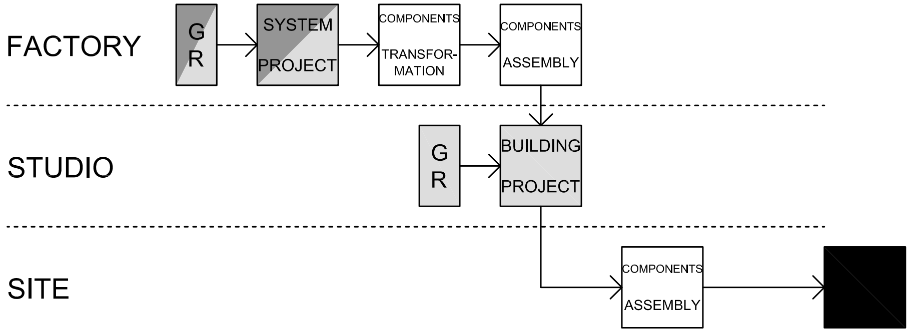
[31] Semi-components (semicomponenti): components with a low technological complexity, but with an high level of functional and performing value (Ginelli, 2002),



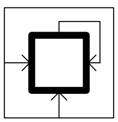
In.D
INSTALLATION
DESIGN

for
COMPONENTING
OPEN SYSTEM
(closed catalogue)

Installation Design



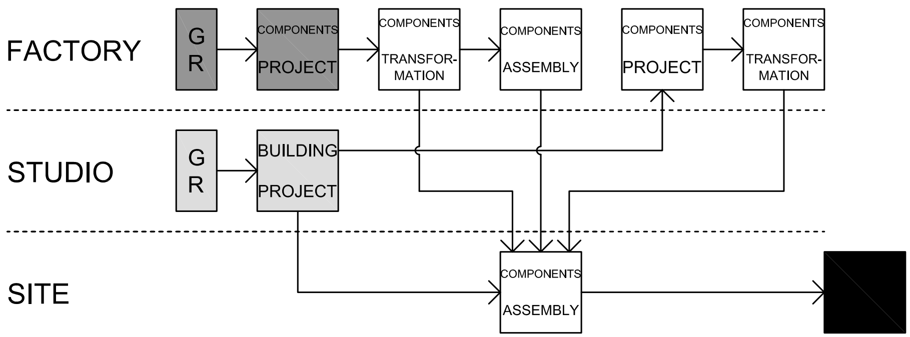
Installation design is a design of a Componenting Opens System. It is a system in which the architectural design has many limits for the project, because it can only choose from a closed catalogue of a single factory (or at least a catalogue for each sub-system). No custom change is possible and the architectural project must perfectly adhere to the catalogue(s). The system design usually prevents the possible configurations of the future buildings, but some degrees of freedom are possible. On-site most operations are assembly. These systems are nowadays no more actual for housing, except than for warehouse industrial pre-fab buildings.



Ad.D
ADVANCED DESIGN

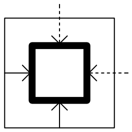
for
ADVANCED OPEN
SYSTEM
(open components)

Advanced Design



Advanced design is the design of Advanced Open System, in which there are no transformations on-site and in which, together with an open catalogue of passive-evolved design, the designers project ad hoc some elements that are transformed and assembled in factory, arriving on-site ready to be jointed, as a big Meccano. Examples of these systems are Foster's Hong Kong and Shanghai City Bank (Hong Kong, 1985) and Piano&Rogers's Centre Pompidou (Paris, France, 1977). This process is fascinating and makes landmarks, but it cannot be a model because cannot be replicated or transferred on a mass scale because «[Foster] rappresenta uno dei modelli più sofisticati e più raffinati di controllo del progetto sotto specie ideologica ed esibisce forme molto accattivanti, ma che non hanno nessuna trasferibilità reale per poter incidere sulla massa della produzione perché, in presenza di materiali speciali e tecnologie sofisticatissime, il costo è una variabile indipendente»[32] (Scoccimarro, 2008, p. 118).

[32] «[Foster] represents one of the most sophisticated and refined models of project control under an ideological species and exhibits very attractive forms, but which have no real transferability to be able to affect the mass of production because, in the absence of special materials and highly sophisticated technologies, the cost is an independent variable».

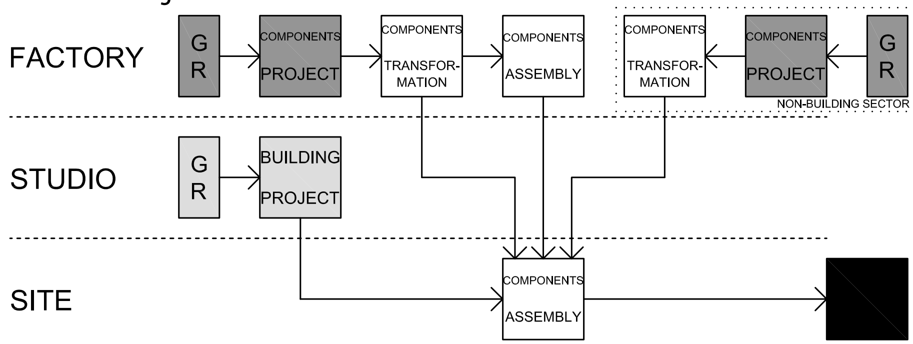


Ex.D

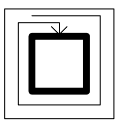
EXTENDED DESIGN

for EXTENDED OPEN SYSTEM
(transfer components)

Extended Design



Extended design belongs to an Extended Open System, in which the catalogue in which the designer of the building can chose the elements can be outside building sector. Components can be found in naval or mechanical sectors and, as transfer elements, they can be used with traditional and evolved elements. Interfaces must be specially-made developed. An example of this system is Nouvel's Nemausus (Nimes, France, 1987). The small number of this category nowadays suggests that it can be applied only for some elements of the construction and that is very difficult to extend this process on a large scale.

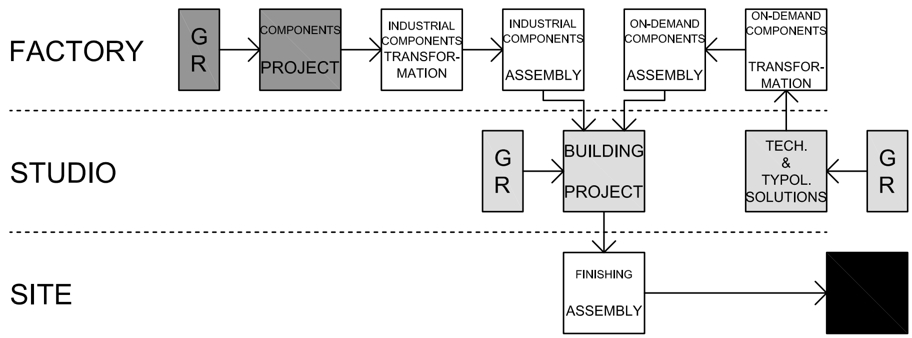


OD.D

ON-DEMAND DESIGN

for ON DEMAND OPEN SYSTEM
(active components)

On-Demand Design



In an On-demand for Open System, the building design phase has two different stages: one is the project of technological and typological solutions and the second one is the building project. They are related, but the first one is disjointed and a priori with respect to the future buildings. The first phase has only some general hypothesis about the final project and it does not design clear elements, but sets the standard, the practical tools for the flexible techniques that will realize the components and the joints between them. The building design phase uses the solutions to provide the new building project, together with components and tools from current production: the building design phase has not constraints about shapes or volumes, inside standard housing constructions, because there is not a catalogue of components from which gaining elements or planes. Examples could be wooden industrialised houses (as Rubner's[33]), 3D printing on site constructions[34], on-demand SCB such as cHOMgenius, re-fabrication systems (Kasperzyk et al., 2017).

[33] https://www.rubner.com/en/haus/your-rubner-house/. Unlike other systems (CLT for example) Rubner systems are tailor made using their know-how and sets of solutions and tools, specifically designed and produced for that specific building. CLT buildings, instead, use a wood component as a structural element and can be led back to passive-evolved design, more than an on-demand design.

[34] https://www.3dnatives.com/en/3d-printing-construction-310120184/#! for examples.

Timeline of innovation in buildings

- 1750s John Smeaton: cast iron components for wind and water mills.
- 1779 Abraham Darby: first wholly iron bridge from cast iron components
- 1790s Jacques Soufflot: wrought iron roof trusses used at the Louvre, Paris
- 1796 Charles Bage: mill at Shrewsbury, first iron-framed structure
- 1830s H. Manning: first prefabricated house, 'Colonial Cottage for Emigrants'
- 1851 Joseph Paxton: the Crystal Palace, pioneering iron and glass structure
- 1855 Henry Bessemer: patent for steel-making process
- 1866 William Barlow: St Pancras station roof using wrought iron components
- 1878 W.H. Lascelles: first use of precast concrete plates in walls and floors
- 1884 Steel sections for construction, then the first skyscrapers (in Chicago)
- 1889 Gustav Eiffel: Paris tower in wrought iron
- 1890s Sears Roebuck Co.: catalogue sales of building elements
- 1902 August Perret: multi-storey RC framed apartments, Paris
- 1910s Frank Lloyd-Wright: factory fabricated complete kit-of-parts homes
- 1914 Le Corbusier: Maison Dom-ino, design separates support from infill
- 1919 Le Corbusier: ground-breaking article 'Mass production houses'.
- 1922 Walter Gropius and Adolf Meyer: the Bauhaus Baukasten system
- 1926 Le Corbusier: Monol, Citrohan and Domino house showcased.
- 1927 Buckminster Fuller: Dymaxion, factory producible metal house.
- 1940 Buckminster Fuller: prefabricated modular bathroom
- 1942 Konrad Wachsmann and Walter Gropius: General Panel System housing
- 1947 Le Corbusier: Unitè d'Habitation, seminal modular apartment block
- 1961 Konrad Wachsmann: publication of The Turning Point of Building
- 1972 John Habraken: publication of his 'open systems' concept

Innovation milestones re-interpreted

This case history wants to collect the most significant examples of Industrialised system for building, above all residential, with some non-residential buildings, milestones of these approach to the project. For the collection of this case history were consulted, among other: (Banham, 1960; Benevolo, 1960; Ciribini, 1984; Fantoni, 1976; Gideon, 1941; Graf, Delemontey, 2020; Nardi, 1976; Sinopoli et al., 1976; Talanti, 1979; Tam, Tam, Zeng, Ng, 2007). The cases are directly taken from literature, reporting cases that mostly appear and were mostly cited.

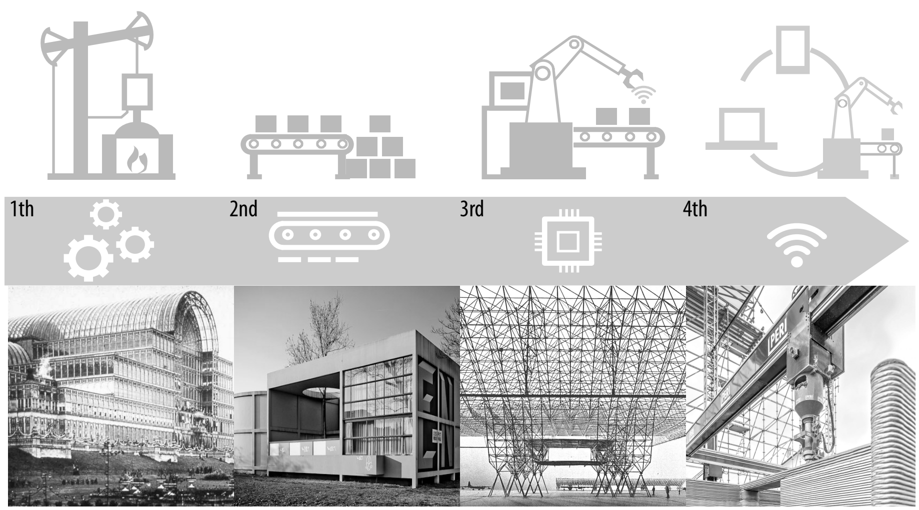
A first general synthesis of milestones in industrialisation can be suggested by the timeline on the left (Ågren, Wing, 2014).

After this first approximation, this book proposes an oriented and reasoned history of Industrialisation for housing, for better explaining the concepts of previous paragraphs, introducing parameters and classification. The cases have been delivered from scientific literature, comparing most cited and recurring buildings: the cases reported can be considered paradigmatic, so accepted by scientific community.

Every case is classified following the design-centred classification above proposed, with a double aim: to explain better the concept of the classification and to identify which category can be considered more 'useful' for the porpose of industrialisation of nowadays.

In the 'when' column, a letter identifies: B = the case is an entire building; C = the case is a component/technique; T = the case is a milestone theory.

In the 'where' column, a letter identifies the sub category of the diffusion of the case, such as: U = unicum, a single isolated case; S = series of realised buildings; W = widespread system.



Crystal Palace https://blog.inoxstyle.com/it/crystal-palace/

Pavillion de l'Esprit Nouveau http://architectuul.com/architecture/pavillion-de-l-esprit-nouveau

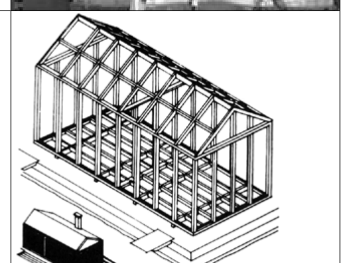
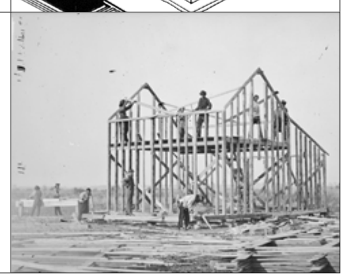
USAF Aircraft Hangar https://www.atlasofplaces.com/architecture/usaf-aircraft-hangar/

3D Printing https://www.thetimes.co.uk/article/germans-build-home-with-3d-printer-wd3r59vjv

The four industrial revolutions and the innovation in building (sources visited on 06/09/2021)

Table 22[a,b,...g]. Innovation milestone in architetcture industrialisation re-intrepeted with the seven catagories (all the images sources visited on 16/09/2020)

Table 22[a]. Innovation milestones re-interpreted

When	Where	What	Features and Design classification	Image
1624 B	Cape Ann, MA (USA) S	Some tens of houses were built in England and sent to American Colonies to build a new town[35]	Timber houses.	
1790 B	New South Wales (Australia) S	Simple timber-frame shelters built in England and sent to Australia' colonies[36]	Timber framed houses.	
early XIX cent. B	Sierra Leone and Eastern Cape (South Africa) S	Colonies houses[37]	Simple and shed-like structures, with timber frames.	
1830 B	England S	Manning Portable Colonial Cottage[38]	Prefabricated timber frame and infill components, designed to be mobile and easily shipped.	
1833 C	USA W	Light balloon frame[39]	The balloon frame of nowadays was established in this year.	

PE.D PASSIVE EVOLVED DESIGN for EVOLVED OPEN SYSTEM (open catalogue)

35 https://winthropmemorials.org/civic/pages/history-of-winthrop-clark.html#img2.

PE.D PASSIVE EVOLVED DESIGN for EVOLVED OPEN SYSTEM (open catalogue)

36 http://romseyaustralia.com/houses.html.

PE.D PASSIVE EVOLVED DESIGN for EVOLVED OPEN SYSTEM (open catalogue)

37 https://www.theguardian.com/world/gallery/2012/may/03/freetown-sierra-leone-architecture-pictures.

PE.D PASSIVE EVOLVED DESIGN for EVOLVED OPEN SYSTEM (open catalogue)

38 https://catalogimages.wiley.com/images/db/pdf/9780470275610.excerpt.pdf.

PE.D PASSIVE EVOLVED DESIGN for EVOLVED OPEN SYSTEM (open catalogue)

39 https://jeanhuets.com/whitman-house-framing-19th-century.

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[40] https://www.britannica.com/topic/Crystal-Palace-building-London.

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[41] http://s-media.nyc.gov/agencies/lpc/lp/1458.pdf

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[42] https://www.pinterest.it/pin/ 477592 735482814136/.

AI.D ALL-INCLUSIVE DESIGN for CLOSE SYSTEM

[43] http://www.fondationlecorbusier.fr/.

AI.D ALL-INCLUSIVE DESIGN for CLOSE SYSTEM

[44] https://catalogimages.wiley.com/images/db/pdf/9780470275610.excerpt.pdf.

Table 22[b]. Innovation milestones re-interpreted

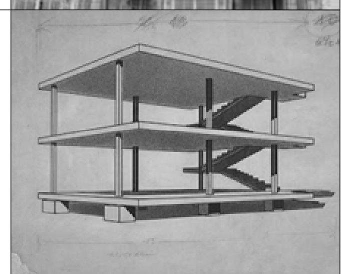
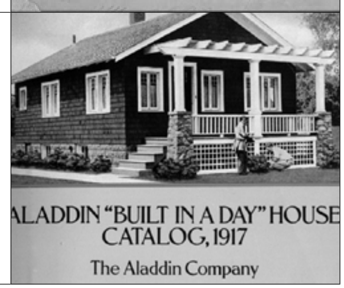
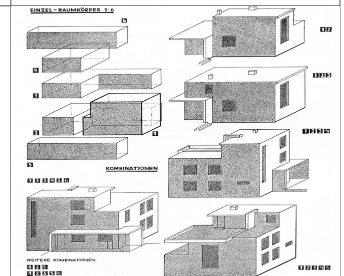
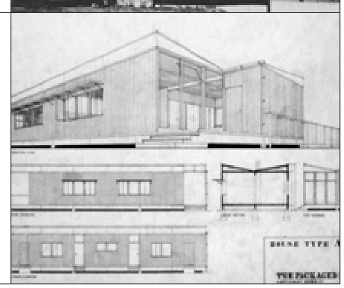
When	Where	What	Features and Design classification	Image
1851 B	London (UK) U	Paxton's Crystal Palace for the Great Exhibition[40]	The most extensive pre-fab building for many decades, made by iron, wood and glass.	
1856-1857 B	NYC USA U	J. Bogard's 254–260 Canal Street, also known as the Bruce Building[41]	Five-story building made by cast-iron prefabricated columns and 'all-window' façade.	
1902 B	Paris (France) U	A. Perret's Rue Franklin Apartments[42]	Multi-storey RC (reinforced concrete) framed apartments.	
1914 B / C	France S	Le Corbusier's Maison Dom-Ino[43]	Design separates support from infill.	
1917 B	USA S	Aladdin 'built in a day' house[44]	Low cost timber frame with standard length of components.	

Table 22[c]. Innovation milestones re-interpreted

When	Where	What	Features and Design classification	Image
1922 C	Germany S	Gropius's Bauhaus Baukasten system[45]	Construction kit system	
1927 B / T	Stuttgart (DE) U / S	Weissenhof neighbourhood for Deutscher Werkbund Die Wohnung international exposition[46]	Great use of prefabrication, especially for Gropius's, Le Corbusier's and Mies's houses.	
1927 B	USA U	Fuller's Dymaxion house[47]	A serial and industrialised metallic house.	
1932 C	USA W	New component[48]	Metal sandwich panel for buildings.	
1942 B / C	USA – Germany S	Gropius & Wachsmann's Packaged house system[49]	Industrialised system for housing.	

In.D
INSTALLATION DESIGN
for
COMPONENTING OPEN SYSTEM
(closed catalogue)

45 https://www.modulart.ch/baukasten-im-grossen.

Ad.D
ADVANCED DESIGN
for
ADVANCED OPEN SYSTEM
(open components)

46 https://medium.com/@MarkLorio/lesperienza-del-weissenhof-721b6df3037f.

AI.D
ALL-INCLUSIVE DESIGN
for
CLOSE SYSTEM

47 http://www.fontecedro.it/blog/dymaxion-house.

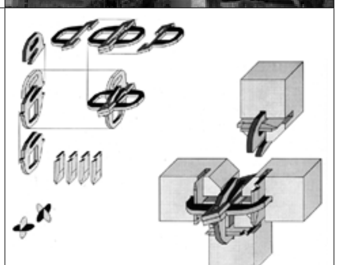
Ad.D
ADVANCED DESIGN
for
ADVANCED OPEN SYSTEM
(open components)

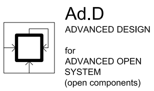
48 https://www.themodernhouse.com/journal/house-of-the-week-keck-and-atwoods-experimental-steel-houses/.

In.D
INSTALLATION DESIGN
for
COMPONENTING OPEN SYSTEM
(closed catalogue)

49 https://images.lib.ncsu.edu/luna/servlet/view/all/who/Wachsmann,%20Konrad/what/Architecture/?pgs=250.

Table 22[d]. Innovation milestones re-interpreted

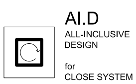
When	Where	What	Features and Design classification	Image
1940-1950 B	Nancy (today) France S	Prouvé's Maison Tropicale[50]	An interesting critical point of view can be found here[61].	
1948 B	USA U	Lustron House[51]	All-enamelled steel building system that used the automobile metal sandwich panel technology.	
1954-1968 B	USA W	Mobile Homes[52]	A pre-fab module placed on a chassis. These houses accounted for 25% of all single-family houses in USA.	
1967 B	Montreal (Canada) U	Safdie's Habitat 67[53]	A cell pre-fab system.	
1961 C / T	Book and most of Wachsmann's work	Book Wachsmann, K. (1961), The Turning Point of Building, Reinhold Publishing Corp., New York, USA[54]	See also (Sabatto, 2010).	



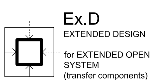
[50] https://failedarchitecture.com/la-maison-tropicale-from-failure-in-niamey-to-masterpiece-in-new-york.

[51] https://catalogimages.wiley.com/images/db/pdf/9780470275610.excerpt.pdf.

[52] https://catalogimages.wiley.com/images/db/pdf/9780470275610.excerpt.pdf.

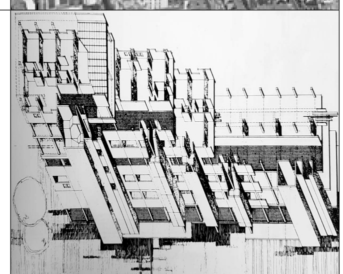


[53] http://www.habitat67.com/en/homage.



[54] The joint system as an example of Whachsmann's concept of innovation and industrialisation (Wachsmann, 1961, p. 142).

Table 22[e]. Innovation milestones re-interpreted

When	Where	What	Features and Design classification	Image
1968 B	San Antonio, TX (USA) U	Hilton Palacio del Rio Hotel[55]	Built for the World's Expo 1968. 20 stories made by 496 modules piled and fixed with welted steel joints in 46 days.	
1972 B	Nagakin (Japan) U	Kurokawa's Capsule Building[56]	A cell pre-fab system, fully furnished and pre-assembled.	
1977 B	Paris (France) U	Piano &Rogers's Centre Pompidou[57]	One of the first and most representative of 'technological exhibition' of the mechanical conception of building.	
1978 T	Lombardia Region (Italy) S (ideas)	Example project 'ANNA'[58]	Competition for the repertoire of projects like the Lombardia Region types IACP year 1978[59].	
1985 B	Shanghai (China) U	Foster's Hong Kong and Shanghai City Bank[60]	One of the first example of 'global building' assembled with components from all over the world.	

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[55] https://www.expressnews.com/sa300/article/Hilton-Palacio-del-Rio-helped-launch-San-12221972.php.

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[56] https://www.archdaily.com/110745/ad-classics-nakagin-capsule-tower-kisho-kurokawa.

Ad.D ADVANCED DESIGN for ADVANCED OPEN SYSTEM (open components)

[57] https://english.elpais.com/elpais/2017/02/02/inenglish/1486040831_170706.html.

Ad.D ADVANCED DESIGN for ADVANCED OPEN SYSTEM (open components)

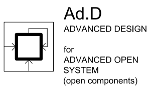
[58] Competition for the repertoire of Lombardy Region IACP type projects, 1978, aimed at identifying new building
[59] (AA.VV., 1978, p. 85).

Ad.D ADVANCED DESIGN for ADVANCED OPEN SYSTEM (open components)

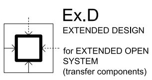
[60] https://divisare.com/projects/311759-foster-partners-hong-kong-and-shanghai-bank-headquarters-hong-kong.

Table 22[f]. Innovation milestones re-interpreted

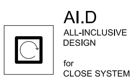
When	Where	What	Features and Design classification	Image
1986 B	London (UK) U	Foster's Lloyd's building[61]	Known as the 'Inside-Out Building' is another example of Foster's conception of design.	
1987 B	Nimes (France) U	Nuovel's Nemausus[62]	One of the few example of a project of 'industrial transfer', with interesting points but many problems, as highlighted by many critical essays.	
2015 B	Hunan (China) U	Broad Sustainable Building[63]	Mini Sky City 57 story, 800 apartment, built in 19 days, with 2736 modules pre-fab and assembled Installation: three floors per day.	
2019 B	London (UK) U	Doone Silver Kerr's Stow Away Hotel[64]	SCB of 26 HC containers assembled.	
XXI° cent. C	Europe W	RUBNER (as a possible example of the system)[65]	Costumed pre-assembled finished wall.	



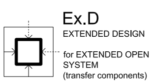
[61] https://www.ft.com/content/6033cb3a-ea5f-11e3-8dde-00144feabdc0.



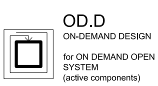
[62] http://www.jeannouvel.com/en/projects/nemausus.



[63] https://alchetron.com/Mini-Sky-City.

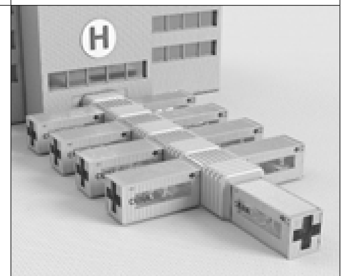


[64] https://www.stow-away.co.uk/gallery.



[65] https://www.rubner.com/en/holzbau/solutions/building-envelopes/wall-elements.

Table 22[9]. Innovation milestones re-interpreted

When	Where	What	Features and Design classification	Image
2020 B	Italy S	Carlo Ratti's containers hospital for Covid19[66]	Modular emergency building using SCB[80.]	
2021 B/C	The Netherland W (potentially widespread, but it is a very new system)	Saint Gobain's First printed inhabited house[67]	Building 3D printing.	

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[66] https://carloratti.com/project/cura.

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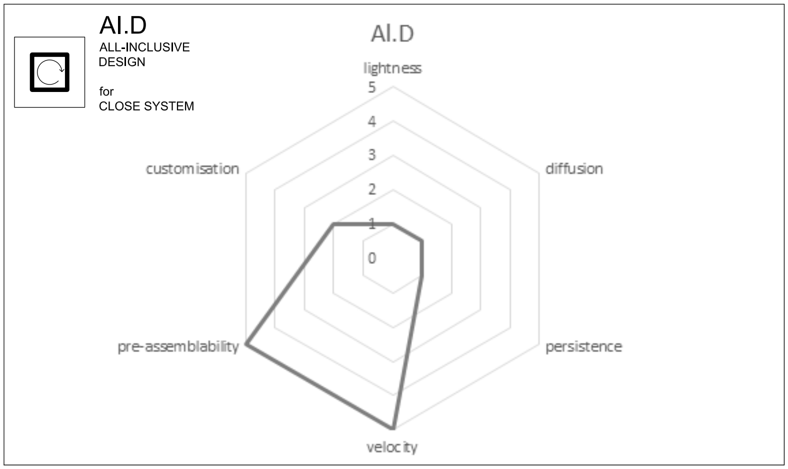
[67] https://www.batiactu.com/edito/premiere-maison-individuelle-realisee-beton-imprimee-61831.php.

Starting from case history, this paragraph starts answering some questions: why some systems spread and other did not? Can be found any common features for these systems? Which of these systems are still affordable today?

For answering, the seven categories are analysed using six characteristics:
lightness, related to physical dimension and weight of components. It helps to identify the transportability of the individual elements of the building and their manoeuvrability;
diffusion, as replicability and transferability of the solution/system (for housing), it indicates the easy spread of the system and, so, the possibility of the acceptance of the idea;
temporal persistence, as the length of life of the system (not only the buildings). This parameter helps to identify idea, that, unfortunately, had not acceptance and so cannot be example for new systems;
velocity of the building to be realised (construction phase). The duration of a construction site is an important environmental and quality marker: the shorter it is, the less impact the site has for the district;
pre-assemblability of the components. It is the degree of the level of industrialisation of a component, in part referred to the classification system to the second chapter;
customisation of the buildings and single modules. It represents the possibility to change some aspects of the components that seems one of the mandatory requirements of today's housing;

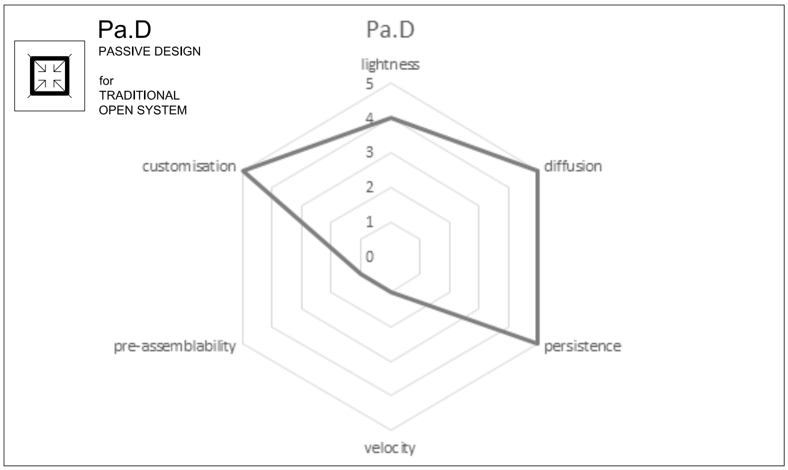
Beside each category, there is a qualitative radar chart, that from minimum value (1) to maximum (5) represents the score of that aspect for that category. These graphs just visually show the concept and the general quality of the categories, without claiming to be exhaustive or absolute.

1. lightness: 1, usually made by capsules or big (and heavy) pre-assembled elements
2. diffusion: 1, few iconic examples
3. temporal persistence: 1, the buildings have often maintenance problems
4. velocity: 5, the design phase takes a lot of time, but the realisation phase is very fast
5. pre-assemblability: 5, it is its best aspects
6. customisation: 2, few possibility of customisation, sometimes just inside furniture



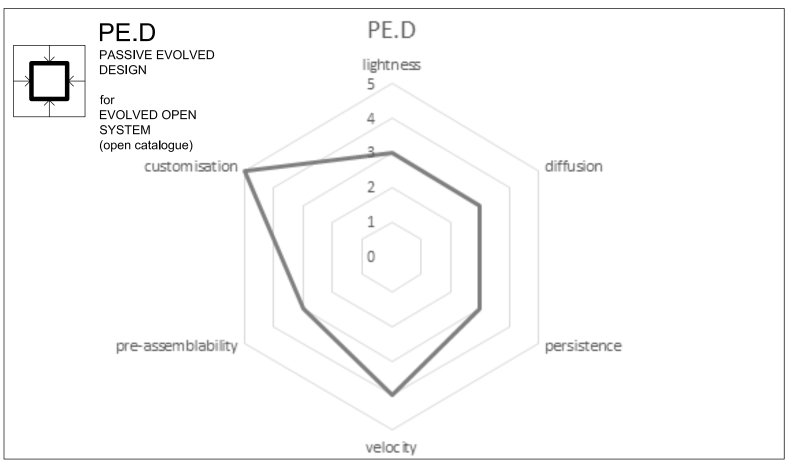
Radar chart for AI.D category (original elaboration)

1. lightness: 4, usually made by small and light components, easy handling
2. diffusion: 5, most of buildings around the world
3. temporal persistence: 5, millennial tradition
4. velocity: 1, each small component is assembled on site, often using hands
5. pre-assemblability: 1, most of components are assembled on site
6. customisation: 5, all the possibility of customisation



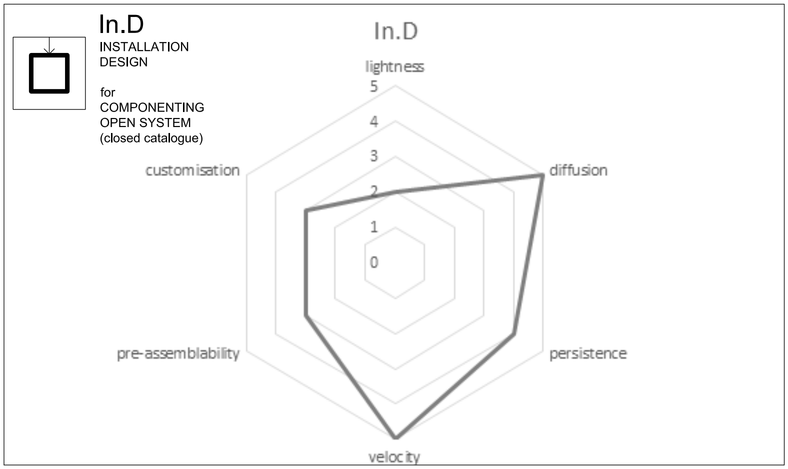
Radar chart for Pa.D category (original elaboration)

1. lightness: 3, medium and small components
2. diffusion: 3, large spread around the world
3. temporal persistence: 3, last decades tradition
4. velocity: 4, easily assembled on site
5. pre-assemblability: 3, more pre-assembled than Pa.D, but few functions per component
6. customisation: 5, potentially all the components on the market



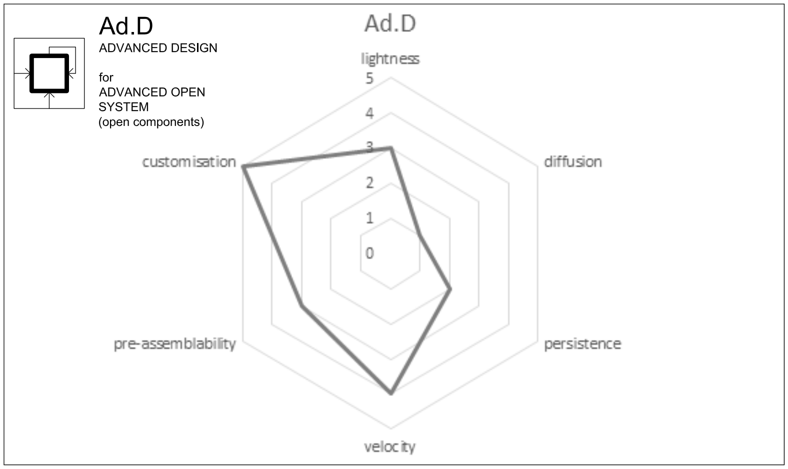
Radar chart for PE.D category (original elaboration)

1. lightness: 2, usually made by big components moved by heavy tools
2. diffusion: 5, most of industrial buildings around the world
3. temporal persistence: 4, decades tradition
4. velocity: 5, few weeks on site for big surfaces
5. pre-assemblability: 3, it uses pre-assembled components, but they have few functions
6. customisation: 2, inside the closed catalogue there are few possibilities for customisation



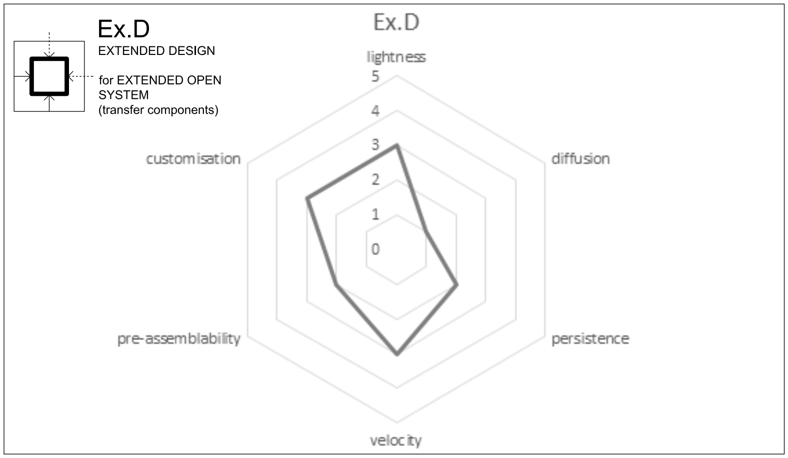
Radar chart for In.D category (original elaboration)

1. lightness: 3, often big and heavy components
2. diffusion: 1, only few iconic buildings
3. temporal persistence: 1, recent techniques with many maintenance problems
4. velocity: 4, the site operations are fast
5. pre-assemblability: 3, off site components need further assembling on site
6. customisation: 5, all the possibility of all the components on the market and new ad hoc ones



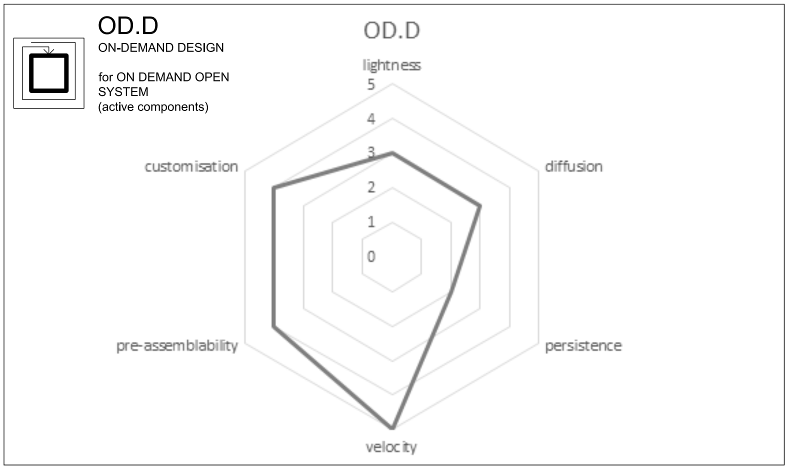
Radar chart for Ad.D category (original elaboration)

1. lightness: 3, usually made medium components
2. diffusion: 1, very few iconic buildings
3. temporal persistence: 2, few decades tradition with maintenance problems
4. velocity: 3, fast assembly on site
5. pre-assemblability: 2, they use industrial components, dry jointed on site
6. customisation: 3, the ‘transferred’ catalogue has limits to personalisation



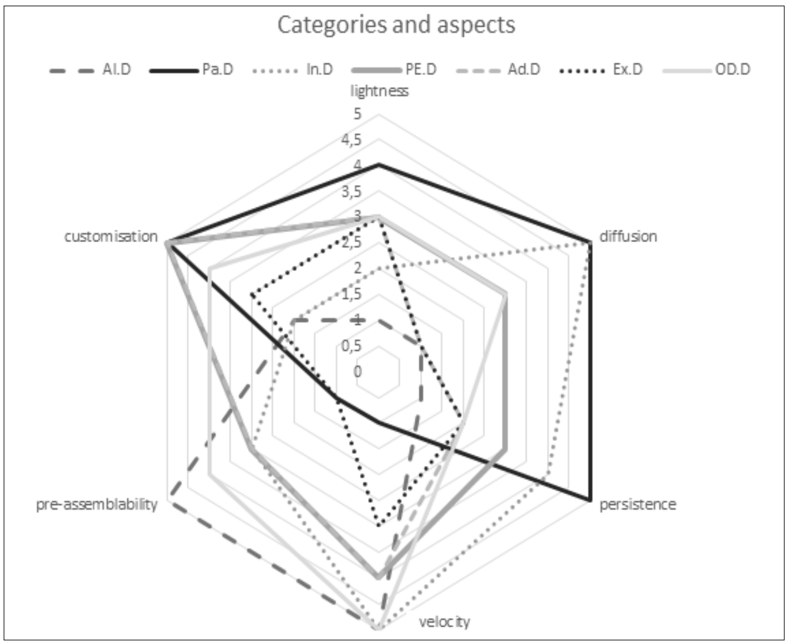
Radar chart for Ex.D category (original elaboration)

1. lightness: 2, usually made by medium and big components
2. diffusion: 3, fast spreading systems (especially using wood)
3. temporal persistence: 2, few decades tradition
4. velocity: 5, very fast on site
5. pre-assemblability: 4, most of components are assembled off site
6. customisation: 4, some limits imposed to the system itself



Radar chart for OD.D category (original elaboration)

After graphs that analyse the single process, the following one collect all the categories and gives a complex picture of the proposed classification.



General radar chart of the seven different categories of design and their aspects (original elaboration)

From these analyses, a synthesis is possible, in order to evaluate and to understand deeply these categories. Here some first deductions that will find in the next chapter adequate development in design guidelines:
- the most diffused and persistent categories are undoubtedly the traditional system for housing and warehouse (Pa.D and In.D), that has a long tradition
- PE.D, that is the evolution of Pa.D, is affirming its role and place, as many

reports highlight, but without diverging from the traditional approach
- pre-assembly does not seem an aspect involved in this diffusion: Ad.D is certainly fast and with higher level of quality (guaranteed by pre-assembling, as SWOT analysis highlighted), but there are very few examples of this category. As few examples can be found for Ex.D, that look just like some interesting experiments, but with no possibility to spread
- pre-assembling cannot be the starting aspect of a system to be competitive, especially if part of a close system as Ai.D (Nakagin tower, for example, has inspired very few other buildings)
- housing market asks for velocity on design process more than on site: it seems that starting the construction site is one the priority of every constructor
- customisation seems to be correlated to diffusion, except for In.D, that are nowadays used above all for factories, in which aspect is not considered important, except than for head quarter, in which, in fact, they do not use In.D
- Ad.D and Ex.D are often interesting examples of architecture, but always as unique moments: they cannot be considerate as a useful system for common buildings
- construction velocity does not seem an aspect influencing the diffusion, except for In.D (that is not usually related to housing).

After this first partial conclusions, next chapter collects all the suggestions from the analisys of previous considerations and proposes guidelines for possible organic approach to the project.

THE VALUE OF INNOVATION GUIDELINES FOR INNOVATIVE INDUSTRIALISED SYSTEMS FOR THE HOUSING OF TOMORROW

Secondo numerosi autori, l'innovazione tecnologica si colloca oggi all'interno di un complesso processo di sviluppo sociale, culturale ed economico, in cui si registra il superamento del suo convenzionale posizionamento, teso prevalentemente ad obiettivi di mercato con la diffusione di prodotti di R&S industriale. Secondo altri, ancora, l'innovazione è un processo culturale, è uno strumento al servizio dell'intelletto. In campo edilizio l'innovazione tecnologica si presenta come un rilevante fattore di sostegno alla ricerca sul progetto architettonico, con processi, prodotti e tecniche capaci di incidere significativamente sulla qualità della concezione e della realizzazione dei manufatti. In uno scenario in cui il progetto architettonico è elemento di proposizione e di controllo della qualità delle trasformazioni dell'ambiente costruito, l'innovazione non ne costituisce il solo versante tecnico-costruttivo, pur se evoluto, ma si offre come risorsa intellettuale[1].

(Losasso, 2010, p. 21)

This concluding chapter proposes guidelines that answer the main questions of this book 'What kind of IBS for housing today? Which are the preclusions and the barriers to IBS? How can these obstacles be overcome?'

The answers are design suggestions that start from the architectural technology cultural background for method, process and, above all, requirements for nowadays housing.

They take the boundary of investigation in scientific literature for IBS, working on a glossary of terms, introducing new visual categorisation of systems/products and proposing new process classification based on the role of the design and the possible trends of future building sector.

They also trace the history of industrialisation in the light of the new classification, pointing out the features of innovation, its possible future trends and emerging aspects.

They derive plus and minus of IBS from reports and market, confirming that IBS are mandatory today, highlighting the negative conditions that can be overcome by appropriate design decisions.

They draw a specific point of view on sustainability and resilience, setting the features a project should have to respond to these requirements of today.

The conclusion of this research path analyses the On-Demand process category from four innovation dimensions point of view introduced by (Epifani, et. al., 2006), elaborated and quoted by (Losasso, 2010) – product,

[1] According to many authors, technological innovation is now part of a complex process of social, cultural and economic development, in which its conventional positioning is surpassed, mainly aimed to market objectives with the diffusion of R&D products. In the building field, technological innovation is a significant factor supporting research on architectural design, with processes, products and techniques that can significantly affect the quality of the conception and construction of the artefacts. In a scenario in which the architectural project is an element of proposition and quality control of the transformations of the built environment, innovation is not the only technical-constructive side, albeit evolved, but offers itself as an intellectual resource (Ed.).

Opposite page: cHOMgenius project prototype, Busnago MB Italy. Further information available at https://www.dabc.polimi.it/en/ricerca/ricerca-competitiva/chomgenius-prototypesystemsharedproject/

process, marketing, organisation – inserting a fifth category – after sale services – to show its usefulness, its working method and its potentiality in the market of nowadays.

This division in five degrees of innovation allows facing the question on IBS from different points of view for better achieving the main goal of this book, thanks to the different aspects they can bring out.

As concluding output, this research introduces fifteen guidelines (five degrees of innovation divided in three categories). These guidelines aim to be universal recommendations and they are not related to a specific project, even if they were tested in a profitable way with cHOMgenius project. They can be referred to many technics and systems, but above all to pre-assembled timber houses, to some light building, to 3D printing buildings, to some SCB and many other types of innovative building, some of which have just some components or systems really innovative as intended here.

Some of these features are common to many building process: the challenge is to collect most of them in the same project because there are high chances they work in the contemporary scenario. This list deliberately avoids the words sustainability and resilience, but declines them in other more specific sub-requirements to be more effective and useful. Sustainability and resilience are defined in their specific sub-categories that the last synthetic table on p. 122 re-connect to the principals.

The following table summarises the categories and sub-categories, developed in the paragraphs below.

Table 1: Degrees of innovation for On-demand process, its categories and sub-categories

Table 1. Degrees, categories and sub-categories of innovation for On-demand

Degree of innovation	**Category**
Innovation of products	Durability Simplicity Stock out
Innovation of process	Off-site Reversibility Sharing
Innovation of marketing	Info-education Service not good Targeted advertising
Innovation of organisation	Guidance Standard workshop Transferability of solutions
Innovation in after sale services	Full service Guarantee Long-term rental

At the end of this paragraph, as a conclusion, there is a final graph summarising the path of this chapter and there is a visual synthesis of the guidelines and their genesis.

Innovation of products

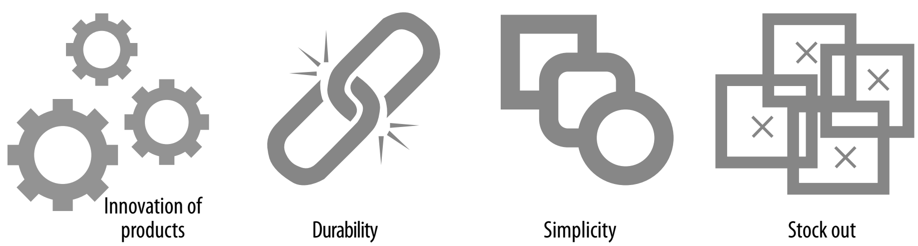
Innovation of products refers to single elements, components and plants. In an on-demand process, most of products are currently product from market, not made ad hoc for single project. They come from companies all over the world, chosen every time for their features relating to performances and requirement of every specific project.

Innovation must be simple. This is a mandatory feature for having a real widespread innovation. This simplicity, in term of components and production, needs a complex design phase and a proper supply chain. Only industrialised components specifically designed for re-use and recycle can guarantee many long lives to components and can guarantee an industrialised fast process of production without stock necessity. Investments on design, machinery and supply chain, more than in stock, guarantee customisable products. Durability, closely connected to simplicity, can overcome problems related to life cycle of certain IBS (especially the pre-fab cells of '70s) and the possibility of easily replacing damaged or obsolete elements.

Durability. Durability means the capacity to maintain its own characteristic and performances during time. In this case, this concept is extended introducing the concept from circular economy and flexibility: products must be detachable in their reusable sub-components or at least in their recyclable raw materials. Thanks to high maintainability, this can guarantee a longer life of elements. Another way to keep durability is multifunctionality: a product should fulfil many tasks by itself or thanks to other elements (in this case the role of assembly technique is fundamental).

Simplicity. In this context Simplicity is assumed as the necessity of a product to have a low technological complexity, but not necessary a low functional value. This feature is mandatory to guarantee the easy disassembly and recyclability of products (simple products can easily be detached and recycled), long life and operability and easy interface with other components so their assembly does not ask for expertise or specialised workers. Simplicity is also a declination of the 'soft approach' introduced in the definitions of resilience.

Stock out. Stock out in finance means the failure of the supply chain. In this case, because of the features of building markets, stock out is a way to express the necessity of no-stock policies for building but production on-demand. This can overcome the lack of customisation and the risk of over-production due to cycle-nature of building sector. The production on-demand allows adapting products to the conditions of each single project and site.



Innovation of process

The process is the phase that includes all the design and realisation aspects not related to elements and components found on market. It includes the interaction between the stakeholders, the assembly of the components and the design of interfaces, physical and immaterial, between elements.

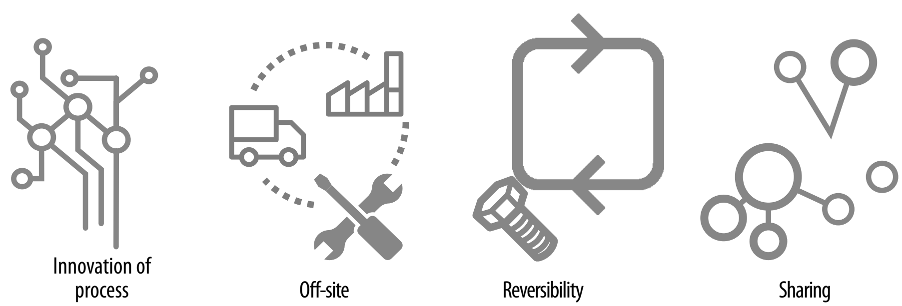
A flexible, shared, industrialised pre-assembling process can guarantee a flexible and customisable building, which is sustainable, resilient and safe for users and workers and with high quality. Off-site is the only condition to bypass on-site limits and dangers and only a customisable off-site based process can achieve the quality level required nowadays. On-demand process accepts complexity as an implicit condition of the project.

Off-site is the core of pre-assembly and thanks to it the building process takes place in the controlled environment of a warehouse: this can guarantee quality of assembly, production rate without outages due to external factors[2], safety for workers, easy manoeuvre of big components. Off-site operations can facilitate the redundancy of system because of more control and easier assembly.

Reversibility is the declination of flexibility for space, components and building parts. It responds to the main purpose of easy turning back of an action or intervention without damages[3]. It also includes the easy transformability of the building. Thanks to dry clamping joints, the components can be easily separated, from foundations[4] to rooftop[5], inserting the building in the circular economy virtuous end-of-life. Reversibility is also a feature of multifunctionality and creativity, because reversible interfaces can guarantee multi-use and multi-configuration of each elements.

Sharing is a key strategy for material components and immaterial aspects of the project. Redundancy, sharing and widespread storing can assure resilience and sustainability for forces, bad events, energies. Sharing should be also the attitude of the design: team design is the only strategy to manage the complexity of building today, assuring an effective and productive process. Sharing information and goals should involve also users and workers: this helps to qualify the interfaces between components and people, avoiding possible problems of compatibility.

[2] Building on-site can be subject to weather conditions, supply chain fragility, …
[3] See UNI EN 15898:2019 _ Conservation of cultural heritage - Main general terms and definitions.
[4] Using screw poles, for example.
[5] Using self-adhesive sheeting, easy to be unglued.



Innovation of marketing

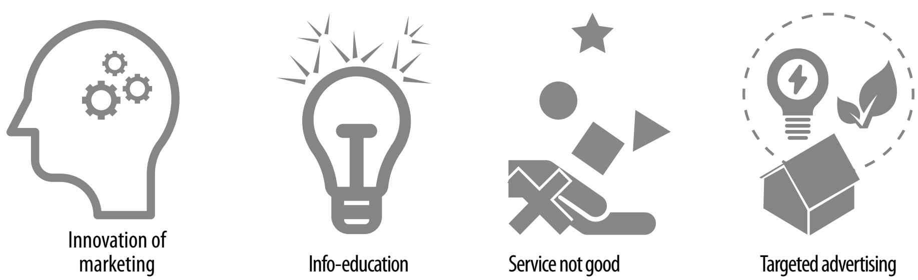
Innovation of marketing involves all the aspects before the decisional process. It includes actions and strategies that help stakeholders to choose IBS, from users to owners, from designers to companies, without forgetting public administration and controllers.

Marketing strategy are not strictly related to design process, but as all the other sector, even building needs nowadays to be explained and promoted, especially if you think about a house more as a service than as a good. Good examples can overcome mistrust of users and designers, demonstrating that advantages are more than disadvantages (and disadvantages are usually more perceived than real). Information and education could start from school (open them to innovative companies and techniques), or from public good example, or can benefit from public incentives or investments. On-demand project companies should work on training and make close contact with education system and vice-versa.

Info-education. Information and education are essential because the non-choice for IBS often depends on lack of knowledge, misunderstanding or prejudice. Stakeholder should have the right information: from university (education), to public administrator (lobbying), to designers and users (awareness of the benefits).

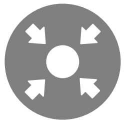
Service not good. A possible innovation in marketing is the idea to consider housing as a service more than a good: the distrust (sometimes fear) for IBS can be overcome if you consider to buy performances[6] instead of walls and floors, so that you are not more interested in the building technique. This is a trend more evident in Countries with big rental market and fast replacement of users. This new business model is increasing, as many reports[7] suggest.

Targeted advertising. Even though the house was the good that concentrate most of people's money, no advertise is invested to attract people to IBS. Countries invest a lot on incentives for requalification, but almost nothing for new high performances houses. Open houses or word-of-mouth can be an efficient way to increase market acceptance.



[6] This is what is happening with the introduction of energy classes.

[7] New Business Models: The construction industry is undergoing a significant criterion shift and is focusing on creating new business models that are technology and data-driven; they also foster better collaboration between stakeholders and increase productivity which has been a pain point in the history of the construction industry. https://www.researchandmarkets.com/reports/4847383/future-of-construction-global-2030 (visited on 20/05/2020).



Innovation of organisation

Innovation in organisation includes all the operations related to assembly off-site of the building. This kind of innovation expresses the features of the works before the building site and the possibility to make these works easy, transferable and replicable.

On-demand process has an intrinsic status of adaptability. On-demand was born for off-site, so expertise and organisation from different sector are usually incorporated in the building process. The transferability of the system should also be guaranteed by the simplicity of the solutions that the design should co-ordinate in a systemic complexity.

Guidance. A real innovation in building is something that can easily spread. A change of paradigm goes through an idea that, under the guidance of the inventor, can involve other people and companies, creating a sort of network (maybe in this case a franchising) that can adapt the system to local conditions and resources.

Standard workshop. An innovative organisation should provide for easy solutions that do not require complex machineries or high expertise. However, because IBS solutions usually require standard environment of a mechanical workshop, rather than renovating tradition building companies (hard work, always disregarded) it should be better using know-how, techniques and workers from industry working off-site. Doing this, you do not transfer industry to site, but site to industry, bypassing the historical stasis of building sector.

Transferability of solutions. Guidance and standard workshop solutions can easily make the IBS process transferable to different contexts, adapting to different requirements and adopting different components and techniques. All these make this kind of IBS replicable and adoptable to many different, and not only building specialised, companies.

Innovation in after sale services

After sale services is an innovation that is nowadays entering in building market. Something is happening with ESCO companies, by which you can buy a product and a full assistance on a plant, often linking the operation to the energy supply. The main idea of this degree of innovation is linking people to the company that provides their house, as for long-term rental for cars.

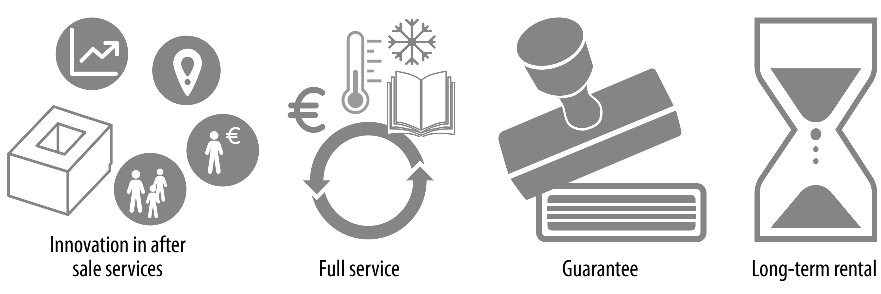
On-demand allows high standard of quality, reliability and maintainability, so companies are more open to long-term guarantee because it can drastically reduce their risks. People, for their part, are motivated to rely on a company to avoid any risk or difficulty, also achieving high degree of customisation and flexibility, without a big original investment.

Full service. An extension of guarantee can be applied with a full-service contract (as for cars): the users truly depend on company for housing, supplies, maintenance, relocation, housekeeping, … Companies know very well their products and know the risk of no-conformity is very low, thanks to a reliable and controlled process.

Guarantee. An IBS on-demand process guarantees high level of quality and certainty of results: for this reason the company can offer a guarantee of many decades on the building[8]. A housing completely assembled off-site in a workshop has standard as a machinery and can have long decades guarantee. This can overcome market distrust and lack of knowledge about durability.

Long-term rental. In parallel to buying with full service contract, another way of living can be proposed: exactly as cars[9] , users can conclude a full long-term rental contract, in which his house is a cluster of services and performances, rented for many years or for short times, with the possibility to change for bigger or smaller house, maybe in another town, with the same level of quality and services, completely customised for his own needs.

[8] Today, some IBS pre-assembled timber housing companies offer a guarantee of 30 or 35 years for their building.
[9] That from leasing converted to long-term rental policies.

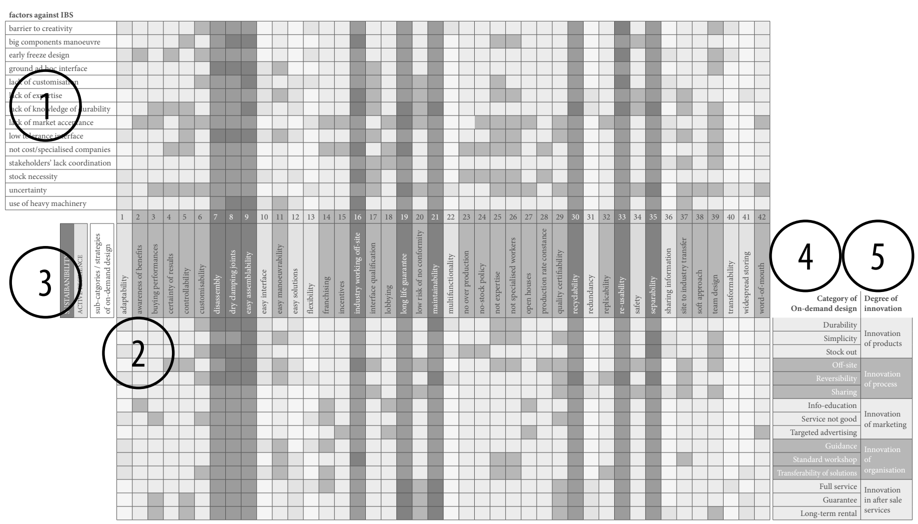


Matrix guidelines

The guidelines are condensed in a matrix that synthetises how the degrees in innovation can afford and overcome the barriers to IBS. The matrix joins the factors against IBS (1), crossed with strategies of on-demand design (2), some of which belong to active-resilience (light grey) or sustainability (grey) requirements (3), crossed with fifteen category of on-demand design degree of innovation (4), belonging to the five degrees of innovation (5).

Factor against IBS were derived from the analysis on IBS, and can be summarise in (alphabetical order): barrier to creativity, big components manoeuvre, early freeze design, ground ad hoc interface, lack of customisation, lack of expertise, lack of knowledge about durability, lack of market acceptance, low tolerance interface, non cost-effectiveness for not specialised companies, stakeholders' lack of coordination, stock necessity, uncertainty, use of heavy machinery.

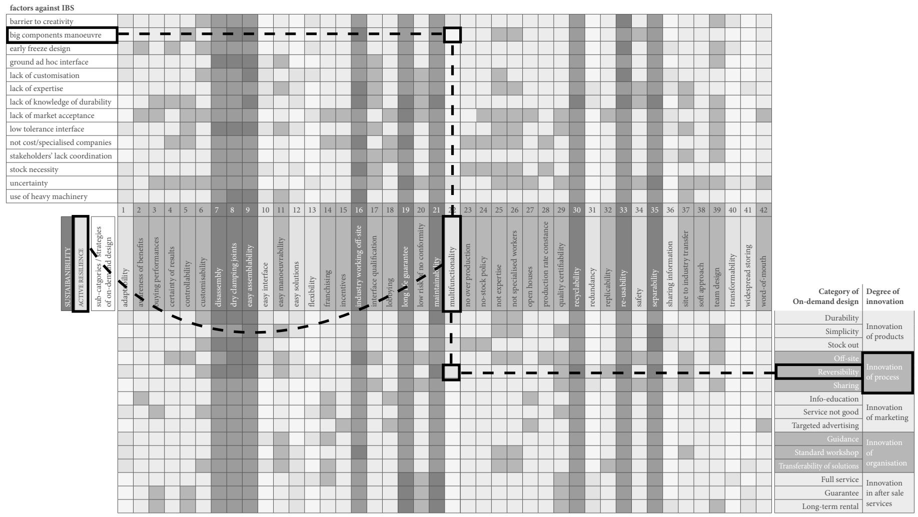
In the same way, possible strategies to overcome these barriers can be: adaptability, awareness of benefits, buying performances, certainty of results, controllability, customisability, disassembly, dry clamping joints, easy assemblability, easy interface, easy manoeuvrability, easy solutions, flexibility, franchising, incentives, industry working off-site, interface qualification, lobbying, long life guarantee, low risk of no conformity, maintainability, multifunctionality, no over production, no-stock policy, not expertise, not specialised workers, open houses, production rate constance, quality certifiability, recyclability, redundancy, replicability, re-usability, safety, separability, sharing information, site to industry transfer, soft approach, team design, transformability, widespread storing, word-of-mouth.



Construction of the comprehensive matrix scheme of on-demand guidelines (original elaboration)

The image below shows an example of how the guideline works:

Barrier to creativity is one of the factors against IBS development. *Multifunctionality* can be one of the possible strategies against this preclusion: it is not the only one, because even customisability, flexibility, re-usability ...,



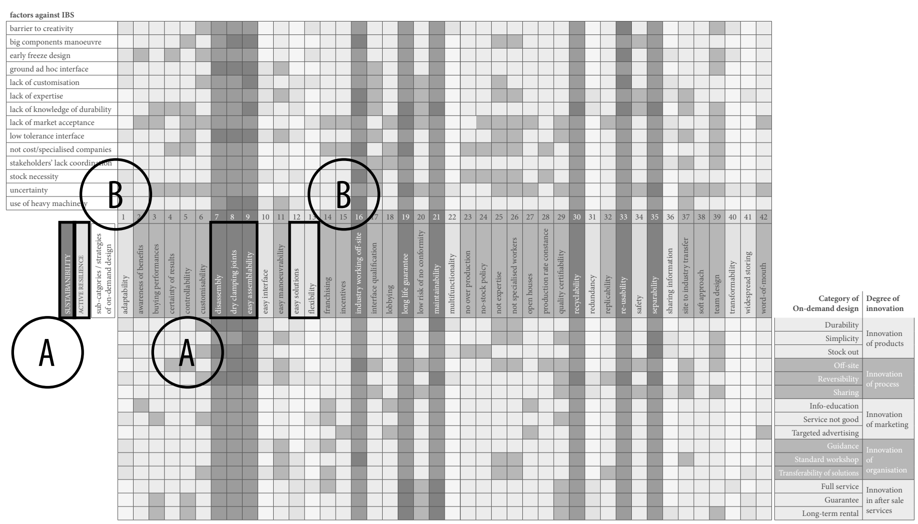
How to use the schematic guidelines (original elaboration)

are available strategies. Multifunctionality is one of the sub-category of Reversibility, belonging to the Innovation degree of process.

This matrix can be read both ways: in a passive way, from factors against IBS to degree of innovation, but also from a degree of innovation to the strategies, therefore becoming an active design strategy.

For example: if you are looking for innovation in organisation and in particular you aim to achieve transferability you need to develop easy interface and easy solutions that don't ask for expertise or specialised workers: these strategies help, among others, to bypass stock necessity, lack of customisation and the use of heavy machinery, together with the overcoming of the necessity of low tolerance interface or the lack of market acceptance.

The image below shows the belonging to sustainability (A) or active-resilience (B) to the sub-categories, also described by same grey tone.



Construction of the comprehensive matrix scheme of on-demand guidelines (original elaboration)

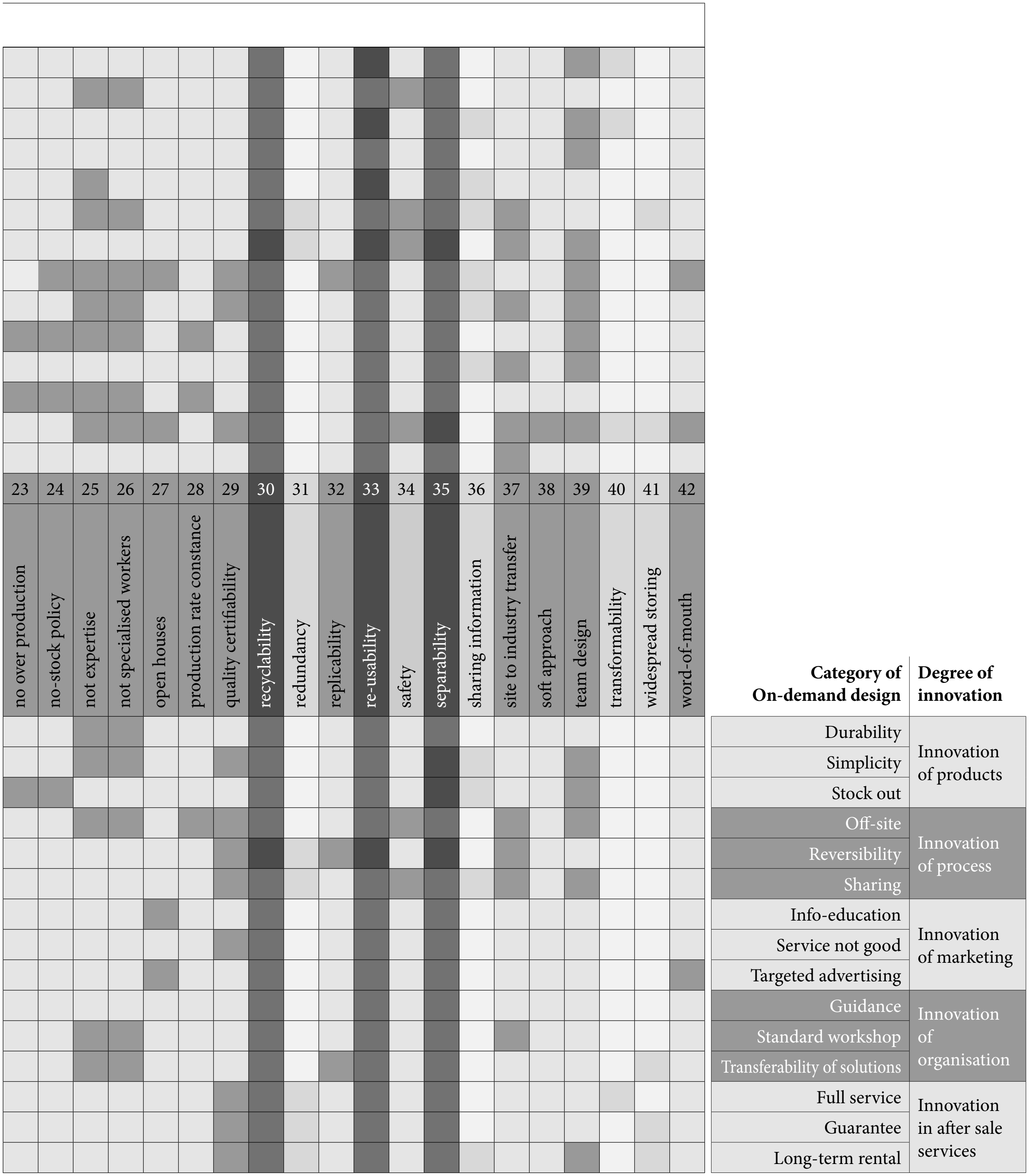
Table 1. Schematic Guidelines for On-Demand Design

factors against IBS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
barrier to creativity																						
big components manoeuvre																						
early freeze design																						
ground ad hoc interface																						
lack of customisation																						
lack of expertise																						
lack of knowledge of durability																						
lack of market acceptance																						
low tolerance interface																						
not cost/specialised companies																						
stakeholders' lack coordination																						
stock necessity																						
uncertainty																						
use of heavy machinery																						

SUSTAIBANIBILITY | ACTIVE RESILIENCE | sub-catgories / strategies of on-demand design

1	adaptability
2	awareness of benefits
3	buying performances
4	certainty of results
5	controllability
6	customisability
7	disassembly
8	dry clamping joints
9	easy assemblability
10	easy interface
11	easy manoeuvrability
12	easy solutions
13	flexibility
14	franchising
15	incentives
16	industry working off-site
17	interface qualification
18	lobbying
19	long life guarantee
20	low risk of no conformity
21	maintainability
22	multifunctionality

Table 1: Comprehensive matrix scheme of on-demand guidelines (original elaboration)


23
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39
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41
42
no over production
no-stock policy
not expertise
not specialised workers
open houses
production rate constance
quality certifiability
recyclability
redundancy
replicability
re-usability
safety
separability
sharing information
site to industry transfer
soft approach
team design
transformability
widespread storing
word-of-mouth
Category of On-demand design
Degree of innovation
Durability
Simplicity
Stock out
Innovation of products
Off-site
Reversibility
Sharing
Innovation of process
Info-education
Service not good
Targeted advertising
Innovation of marketing
Guidance
Standard workshop
Transferability of solutions
Innovation of organisation
Full service
Guarantee
Long-term rental
Innovation in after sale services

This work introduces new categories to read the building process and consider On-demand design a valid possibility for answering contemporary requirements of building, especially residential. Thanks to its features, it's possible to define guidelines that can overcome obstacles to innovation for housing and pursue mandatory requirements for nowadays buildings.

The guidelines suggested, profitably tested by cHOMgenius project, have a general purpose, related to the technological culture of design. They are universal, as they are not closely linked to specific techniques or products. For this reason, this book aims to propose a methodological approach and planning counterframes to IBS: the suggested strategies organise information and give recommendations divided in the highlighted five dimensions of innovation, but they are only one of the possible divisions.

They do not propose a protocol and deliberately do not introduce measurement for these strategies: factors and weighing are not necessary at this phase of the research, because the purpose is giving general and universal guidelines. In addition, the boundaries of each category are not impermeable and can intersect each other (as the previous graph well shows, with degrees of colour and not with a black/white – on-off – intersections), so that the strategies could be re-arranged for specific scope or particular contexts.

It is clear that factors and weighting are mandatory if the guidelines aim to become more 'standards': this research has assumed this as its limit of investigation.

Certainly, innovation of IBS is strongly emerging in these years, as pre-assembly timber housing market confirms: the real open question is 'if and how the features of this limited sector will spread and contaminate other sectors of housing'. In the next years the building market, also sustained and led by important investments such as Horizon Europe with the 5th cluster[10] or the Recovery and Resilience Facility and NextGenerationEU[11], will have a positive increasing transformation (Santilli, 2021) towards sustainability and resilience and IBS, as demonstrated, is the primary way also for housing market.

Open lines of investigation that could be explored in next years ca be: plus, end of life and pilot cases.

'*Plus*' belongs to regulatory instruments. It is a synthesis of the performances an innovative IBS has toward BAU[12] buildings that most of times do not emerge from traditional valuation systems: it could be useful, also to promote IBS, valorising performances and features that apparently make IBS more expansive but, that, analysing global cost of building, clearly emerge. This branch of the research has assumed the concept of hedonic price (Herath, Maier, 2011) as a possible way to bring out these important but not apparent features and to identify factors and weighing for strategies of previous chapter. In parallel, we are working with UNI-Ente Nazionale di Normazione to a Roadmap to disseminate this 'plus performances' for updating praxis or standards to the acceptance of these factors.

'*End of Life*' belongs to 'validation tools' of the project and it is in general the phase of building process less investigated and considered, despite it is emerging as one of the fundamental challenges for sustainability. A pre-assembled IBS with clamping dry-joint is certainly one of the best prerequisites for assuring an easy dis-assemblability of the building and, therefore, an easy and

[10] Climate, energy & mobility - https://op.europa.eu/en/web/eu-law-and-publications/publication-detail/-/publication/3c6ffd74-8ac3-11eb-b85c-01aa75ed71a1

[11] 2. Cohesion, resilience and values and 3. Natural resources and environment - https://ec.europa.eu/info/strategy/recovery-plan-europe_en

[12] Building As Usual, even if it is not always clear what 'usual' is.

low-cost disassemblability for re-using and recycling of components and elements. Together with 'Plus' research, 'end of life' assessment (not only from an LCA point of view) is a mandatory line of inquiry from a pro-active and design point of view, that has few literature and data, which we have been exploring with cHOMgenius and that needs deep analysis for obtaining operative tool and a related protocol for helping decisional phase of the design process.

'*Pilot cases*' belongs to the hard practical and experimental tools, mandatory in today scenario of construction: market and stakeholders need good examples and pilot case to reassure them and show how innovation is affordable and feasible. Good example of this approach could be the French 'Permis d'Expérimenter'[13] in which very innovative projects are sustained and promoted and can by-pass some rules and have a faster process, if the project uses innovative technical solutions.

In conclusion, a consideration about the 'schizophrenia' of contemporary building sector: on one hand we have companies that develop excellent innovative products, with all environmental and sustainability certifications of product and process. On the other hand, we have the building site, in which most of work is based on hands capability and that is exposed to the elements and uncertainty as in ancient times. In addition, few, excellent but non-wide-impacting on market innovative buildings cannot be real innovation for buildings: the real innovation must have impact on every people life and cannot be just a beautiful landmark or status symbol. Innovation should be simple and easy transferable and should have visible social dimension.

As liberal financial economy has demonstrated its auto-ruling incapacity, the same should be understood for building market economy: rules and public drivers are mandatory for a real 'revolution' that cannot be painless. Maybe this global economic and pandemic crisis, that has already decimated many construction companies, could be the occasion of setting a new innovative direction to building sector, able to combine social-economic requests with environmental demands for sustainability and resilience.

[13] https://www.cohesion-territoires.gouv.fr/permis-dexperimenter-faciliter-la-realisation-des-projets-de-construction-et-favoriser-0 (visited on 07/06/2021).

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CONTENT OF THE CHAPTERS
CONTENUTO DEI CAPITOLI

INDUSTRIALISING HOUSING. THE ROLE OF THE TECHNOLOGICAL CULTURE OF DESIGN

Innovation has been the file-rouge linking all the debates in Technological Culture of Design sector since it was born. Nowadays this subject has been disclosing, above all, in studies on sustainability, digitalization and resilience. Starting from possible remedies for the deflections in approaching the project, the new paradigm the project should adopt is the 'valorizing', thanks to, among others, flexibility and multifunctionality.

INDUSTRIALIZZAZIONE DELLA RESIDENZA. IL RUOLO DELLA CULTURA TECNOLOGICA DELLA PROGETTAZIONE

L'innovazione è da sempre il filo rosso che attraversa il dibattito all'interno della Cultura tecnologica della Progettazione, fin dalla nascita. Oggi questo tema si articola soprattutti nei temi della sostenibilità, della digitalizzazione e della resilienza. A partire da soluzioni che affrontino le possibili deviazioni nell'approccio processuale, il progetto deve adottare la 'valorizzazione' come nuovo paradigma, grazie anche, tra gli altri, alla flessibilità e alla multifunzionalità.

CONTEMPORARY HOUSING BETWEEN MARKETS, TRENDS, SCENARIOS AND CLASSIFICATIONS

Starting from the housing market needs and trends, it is clear that buildings are nowadays asking for industrialisation. Resilience and sustainability are two main drivers of this innovation asking. Both mandatory, they are analysed in their relations, in their sub-requirements and their implications for buildings construction. A new flexible classification for building components and techniques is proposed, starting from a terminological research on the semantics of industrialisation that can help to identify boundaries and limits of innovation and that can anticipate future scenario for buildings.

L'ABITAZIONE CONTEMPORANEA TRA MERCATO, TENDENZE, SCENARI E CLASSIFICAZIONI

I bisogni e le tendenze del mercato delle abitazioni contemporanee confermano un forte bisogno di industrializzazione, di cui i concetti di resilienza e di sostenibilità sono i motori principali. Entrambi ormai imprescindibili, queste due esigenze sono analizzate nelle relazioni reciproche, nei loro sotto-requisiti e nelle implicazioni per il settore delle costruzioni. In questo scenario, viene proposta uno nuova, flessibile, classificazione per i componenti edilizi e le tecniche costruttive, che parte da una disamina della semantica relativa alla industrializzazione, utile a identificare i confini e i limiti dell'innovazione e che può anche anticipare futuri scenari per le costruzioni.

BUILDING INDUSTRIALISATION BETWEEN CULTURAL BONDS SYSTEMIC OBSTACLES AND NEW PROCESS VIEWS

Building industrialisation perceptions, benefits, preclusions and obstacles are studied from many point of view in order to identify the reasons they have never become so popular. The identified factors are investigated by a four dimensions SWOT analysis that underlines elements influencing economic, environmental, institutional and social dimensions of sustainability. Within all the aspects highlighted in the SWOT analysis, the focus is on factors that can be traced back directly to design and can be oriented by it. A new point of view on design process is proposed, introducing seven categories that clarify the role industrialisation could have in building contemporary market.

L'INDUSTRIALIZZAZIONE EDILIZIA TRA CONFINI CULTURALI, OSTACOLI SISTEMICI E NUOVI PUNTI DI VISTA SUI PROCESSI EDILIZI

Le percezioni, i benefici, le preclusioni e gli ostacoli all'industrializzazione edilizia sono studiati da molteplici punti di vista, al fine di identificare le ragioni per cui essa non ha mai realmente preso piede. I fattori identificati sono analizzati da una analisi SWOT a quattro dimensioni, che evidenzia gli aspetti che influenzano la dimensione economica, ambientale, istituzionale e sociale della sostenibilità. All'interno di tutti gli aspetti emersi dall'analisi SWOT, viene posto l'accento su quei fattori che possono direttamente essere ricondotti al progetto e possono da esso essere orientati. Viene proposto un nuovo punto di vista sul ruolo del processo edilizio, introducendo sette categorie che chiarificano il ruolo che la industrializzazione può avere nel mercato dell'edilizia contemporanea.

THE VALUE OF INNOVATION. A PROPOSAL OF GUIDELINES FOR INNOVATIVE INDUSTRIALISED SYSTEMS FOR THE HOUSING OF TOMORROW

The proposed guidelines start as answers to design driven obstacles to industrialisation, proposing possible, feasible and tested strategies. Some of them are technical solutions, some others are approaches to the process or to the housing market in general. The innovation degree is analysed from five dimensions, as five possible strategies to disseminate and to grow industrialisation for housing building market.

IL VALORE DELL'INNOVAZIONE. UNA PROPOSTA DI LINEE GUIDA PER I SISTEMI INDUSTRIALIZZATI INNOVATIVI PER LA CASA DI DOMANI

Le linee guida proposte partono come risposta agli ostacoli di natura progettuale all'industrializzazione, proponendo strategie possibili, fattibili e testate. Alcune sono soluzioni tecniche, altre sono approcci al processo o al mercato dell'abitazione in generale. Il grado di innovazione è analizzato da cinque punti di vista, ciascuno come possibile strategia per diffondere e promuovere l'industrializzazione all'interno del mercato dell'abitazione.

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