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Review

A Review on the Factors Affecting the Use of Offsite Construction in Multifamily Housing in the United States

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Abstract: The increasing demand for multifamily housing in the United States requires alternatives for building more affordable and sustainable housing to improve the quality of life for millions of families. Offsite construction (OSC) strategies may be a viable alternative for tackling this problem. Although the use of OSC is significant in the multifamily housing market in the world and it is also very promising in the US, a scarce amount of literature has focused on this topic. The purpose of this study is to identify specific factors that affect decisions on the use of OSC in multifamily housing in the US. Focusing on the sustainability dimensions of construction—social, environmental, and economic—the authors reviewed literature that was published between 2000 and 2019 and identified factors that are related to OSC adoption in general construction, in housing construction, and, more specifically, in multifamily housing construction in the US. Subsequently, a discussion on some important factors affecting decisions on the use of OSC in the American multifamily market is provided. The discussion focused on factors that, although important, have been under explored in the literature that addresses the use of OSC in multifamily projects, especially in the US, which are: customer's attitude, building performance, and building comfort and indoor environmental quality (IEQ). In addition, a brief discussion regarding the importance of design to the uptake of OSC in multifamily projects is provided. This is one of the first studies dedicated to exploring the social, environmental, and economic factors that affect the use of OSC in multifamily housing in the US. The study also identifies research gaps, which serve as a roadmap for future research.

Keywords: multifamily housing; offsite construction; sustainability; decision-making factors

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1. Introduction

Housing is one of the most basic human needs; hence, the importance of ensuring universal access to adequate and affordable housing. However, even developed countries face problems in providing affordable housing for families of the different income groups. In 2017, a report from the United Nations indicated 1.6 billion people that were living in inadequate housing, while the stock of vacant houses was increasing [1]. It is vital to find alternatives that guarantee better households' quality of life by reducing the price of housing without compromising its quality. There are different approaches for tackling this problem, from housing policies, urban planning, and zoning, to construction techniques that increase the efficiency of the construction process to create a higher value-added product at a lower cost, such as those that involve offsite construction (OSC).

Although affordability is extremely relevant in the housing market and research supports the use of OSC as a way to increase housing affordability and sustainability [2,3], to date, little research has focused on a broad analysis of the factors that affect the adoption of OSC in multifamily housing in the US. The purpose of this study is: (1) to identify and provide an up-to-date analysis of factors that affect the use of OSC in the context of multifamily housing construction in the US through the lens of sustainability, (2) define the important criteria to be considered in multifamily housing projects and how they relate to the factors identified in item 1, and (3) identify and discuss the specific factors

that need to be addressed in future research focused on the use of OSC in the American multifamily housing market. The holistic approach that is based on the triple bottom line of sustainability ensures that all aspects of sustainability, which is, the social, economic, and environmental aspects are considered in decisions involving the use of OSC.

1.1. Offsite Construction

This study uses the acronym OSC in order to refer to prefabrication, modular construction, and modern methods of construction, in which either components or modules of a project are produced in a factory and then transported and assembled on the construction site [4]. The adoption of offsite strategies is acknowledged as a way to boost productivity, while increasing the quality and sustainability in the Architecture, Engineering, and Construction (AEC) industry [5,6]. In some countries OSC is quite consolidated within the AEC industry, especially in the housing sector, but, in many industrialized countries, the uptake of OSC has been lagging [7].

Historically, the combination of strong demand for housing and labor shortages in the construction sector has proven to be a driver for the adoption of OSC, especially in countries, such as the US [2]. Despite the benefits of OSC for productivity, quality, and sustainability, countries like the US and the UK have not experienced a consistent use of OSC over the years, due to factors such as poor quality, safety, and aesthetics, which have negatively impacted the reputation of this type of construction method [2]. After some dormant years, OSC is again experiencing a momentum in the AEC industry of the US. This is partly due to an increasing housing demand and workforce shortage [2], and partly due to the rise of digital tools, such as building information modeling (BIM), which are revolutionizing the design and construction of buildings [8,9].

1.2. OSC and Sustainability in Construction

The AEC sector has been facing increasing pressure to not only improve quality, productivity, and efficiency, but also the sustainability of its products and processes [2]. In this sense, new construction technologies play an important role, but they must comply with the triple bottom line of sustainability, which include the social, economic, and environmental dimensions [10].

In terms of environmental sustainability, studies revealed that the use of OSC provides improved environmental performance, including lower ecosystem damage and lower resource depletion, when compared to conventional construction methods [11]. As for social sustainability, among other benefits, the use of OSC is much safer and healthier for the construction workers than conventional construction [12]. Finally, the economic sustainability of using OSC is mostly associated with time savings [13] and reduced life cycle costs of the buildings, as the higher quality of OSC components results in reduced operation and maintenance costs [12,14].

1.3. Multifamily Housing in the United States

In recent years, the multifamily housing market in the US has experienced increasing demand, particularly for multifamily rental housing, since it stands for a much larger market than homeowner housing (Table 1). According to studies, by 2030, it will be necessary to build approximately 4.6 million new rental units in the US for different income levels [15,16].

The production of new units (starts and completions) and vacancy rates of multifamily units are important indicators for understanding the trends in the American multifamily market [17]. Although numbers for the past decade (2009–2019) have revealed a sharp increase in the number of units produced, there has also been a significant decrease of the vacancy rates of both rental and owned properties (Table 1). Vacancy rates vary widely between states or metropolitan regions, and recent study by Freddie Mac [18] based on vacancy rates over time revealed a shortage of 2.5 million homes in the US, with 29 states

presenting a housing deficit, which suggests a larger problem than what the national rates suggest in Table 1.

Table 1. Multifamily housing indicators 2009–2019.

Index	2009	2011	2013	2015	2017	2019
Starts	97,300	167,300	293,700	385,800	342,700	388,900
Completions	259,800	129,900	186,200	310,300	346,900	342,900
Total rental units	18,786,537	19,352,228	19,696,731	20,378,207	20,692,117	21,858,442
Rental Occupied	16,614,043	17,356,162	17,899,088	18,681,706	18,837,547	19,997,161
Rented, Not Occupied	293,788	330,193	322,330	342,299	336,357	339,309
For Rent	1,878,706	1,665,873	1,475,313	1,354,202	1,518,213	1,521,972
Vacancy rates—rental units (%)	10.00%	8.61%	7.49%	6.65%	7.34%	6.96%
Total homeowner units	2,720,261	2,612,132	2,505,441	2,566,658	2,650,842	2,782,032
Owner Occupied	2,474,084	2,371,061	2,344,494	2,425,255	2,509,713	2,647,796
Sold, Not Occupied	59,439	64,037	54,989	53,414	55,020	51,161
For Sale	186,738	177,034	105,958	87,989	86,109	83,075
Vacancy rates—homeowner units (%)	6.86%	6.78%	4.23%	3.43%	3.25%	2.99%

Notes: Multifamily housing with 5 or more units. Starts and completions data from U.S. Department of Housing and Urban Development [17], other data from U.S. Census Bureau [19].

Regarding the market perceptions on housing affordability and the use of innovative constructive techniques in multifamily housing to tackle this problem, a study focused on home builders' perception of housing affordability and construction innovation revealed that housing affordability is a serious concern to multifamily builders nationwide [20]. Regarding innovation and new technologies, over the next 2–5 years, 57% of multifamily home builders that participated in the study reported that they intend to adopt more innovative construction techniques, such as factory-built/modular, pre-cut, open wall panels, and closed wall panels. Furthermore, multifamily home builders are focusing more on factory technology and they are more likely to increase the use of innovative construction methods than single-family builders [20].

1.4. Factors Affecting Decisions on the Use of OSC in Construction

Research suggests that AEC professionals many times do not make informed decisions regarding the use of OSC on projects [21,22]. Such decisions are often based on cost rather than value, while research shows that the main benefits of using OSC may not be related to cost and profitability [21,23].

Identifying the factors that are to be considered in decisions on the use of OSC is crucial to understanding how limiting factors affect modular buildings throughout their life cycles [24] and to making sure that such decisions meet the current needs of the construction practitioners [25]. The most significant studies on factors affecting decisions regarding the use of OSC began to emerge in the 1990s [26,27], and, until today, the industry and academia have been dedicated to exploring factors that affect decisions on the use of OSC in different types of projects for different markets [2,23]. Regarding housing construction, research has assessed how the context of the housing industry from different countries affects the adoption of prefabricated housing construction [28].

These factors can be evaluated as benefits [21], barriers [29], advantages or hindrances [30], drivers and constraints [31], or risks [32]. Still, there is a lack of understanding of the applicability of the factors that are found in previous research on multifamily buildings and, more specifically, in the context of the American housing market. This is relevant, because previous research has identified a rising interest of home builders to use innovative construction methods and an increasing demand for multifamily housing in the American market [20].

2. Materials and Methods

This research consists of a two-phase literature review, followed by a discussion of the results. Phase 1 is based on a systematic review of literature that was published between 2000 and 2019. The literature investigated focused on the advantages and disadvantages, drivers and constraints, and factors that influence the use of OSC in diverse construction sectors from different countries and, more specifically, in multifamily housing, while considering the social, economic, and environmental aspects involved. In order to perform the systematic literature review, the authors defined terms that are associated with offsite construction, multifamily housing, sustainability, and factors affecting decisions, which were used as keywords in data selection and data analysis (Figure 1). Searches were conducted in Engineering Village and Scopus literature databases and complemented by the Google Scholar search engine. In the first round of searches (round 1), only peer-reviewed journal articles in English and addressing all of the three principles of sustainability (environmental, social, and economic) were collected. Articles focusing on heavy civil construction were excluded.

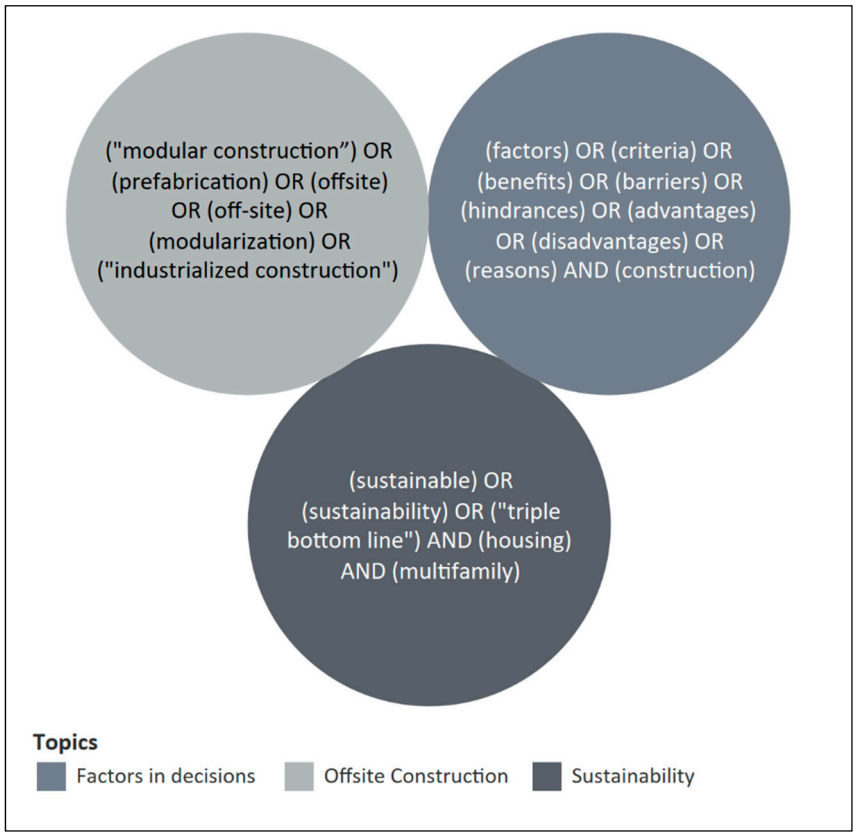

Figure 1. Keywords by topic.

Succeeding the literature search and the elimination of duplicated articles, one of the authors screened the articles by title, abstract, and keywords, according to the exclusion criteria that were previously established. This procedure allowed for the efficient exclusion of articles outside the scope of the research and the evaluation of the validity of the literature source. A total of 45 articles from 25 peer-reviewed journals resulted from this manual selection, with none of those focused on the use of OSC specifically in multifamily projects in the US. Therefore, the authors carried out another round of literature search (round 2) on the same databases and used the same keywords, but the word "United States" was included. Only the Google Scholar search engine found literature that was relevant to the study. This time, they collected all types of literature published between 2000 and 2020, namely: theses, dissertations, reports, conference papers, etc. The searches and subsequent document

screening resulted in a total of eight documents, basically grey literature, including two industry reports, four academic reports, and two master theses, which directly or indirectly addressed the use of OSC in the American multifamily housing market.

In both rounds, each document was analyzed, and a thematic analysis was performed, which allowed for categorizing the factors that were identified in the literature by themes according to the three widely accepted dimensions of sustainability: economic, environmental, and social [33], akin to the methodology that was adopted in recent studies on the adoption of OSC in construction [14,34–36]. The study also computed the frequency of each factor, which was identified as "a reference", i.e., each document that addressed a specific factor was counted as one reference. For the round 1 literature, each factor could have a maximum of 45 references, as for the round 2 literature, each factor could have a maximum of eight references.

In phase 2, the authors performed a review of the literature addressing specific criteria that should be considered in multifamily projects, but not necessarily related to the use of OSC. Searches for this type of literature were carried out broadly, on several platforms, while using terms that are related to multifamily housing and social, economic, and environmental sustainability. The authors collected journal articles, conference articles, and reports. Subsequently, based on the literature gathered, the authors mapped the key criteria to be considered in multifamily projects, while considering the needs of the owners, developers, and users.

By cross-referencing factors identified in rounds 1 and 2 of the systematic literature review with information found in phase 2, the authors selected and discussed some of the most relevant factors that are to be considered when adopting OSC in the American multifamily housing market. The factors discussed were selected according to the following rationale: (1) factors more significant in multifamily projects than in projects in general, (2) factors that relate to important development criteria in multifamily housing, and (3) factors that are under-researched in the context of interest of this study.

3. Results

Round 1 literature provided an overview of the factors affecting decisions on the use of OSC in different countries and markets (Figure 2). Almost 50% of the articles focused on the use of OSC in China and United Kingdom. Regarding the number of articles by applicable market and country, only 15 articles (33%) focused on housing construction—none of which specifically focused on the US market. The number of articles published annually has been erratic between 2000 and 2017 (Figure 3). However, approximately 29% of the articles (13 articles) were published between 2018 (seven articles) and 2019 (six articles), with a high number of articles focused on the construction market of Australia (six articles). Appendix A provides more information on the factors identified in each of the 45 articles investigated.

As for round 2 literature, focused on the American multifamily market, three documents discussed the American market as a whole, two documents focused on the Bay Area in California, and one article addressed the multifamily market in Maine. Appendix B provides more information on the factors that were identified in each of the eight documents investigated.

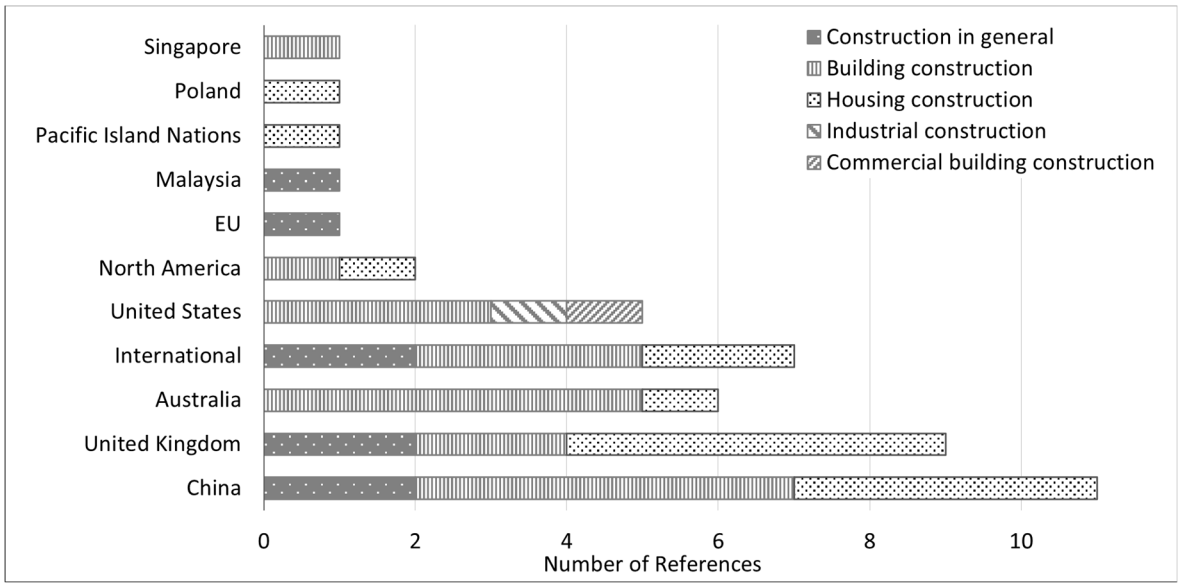

Figure 2. Round 1 literature—number of articles by applicable market and country (n = 45).

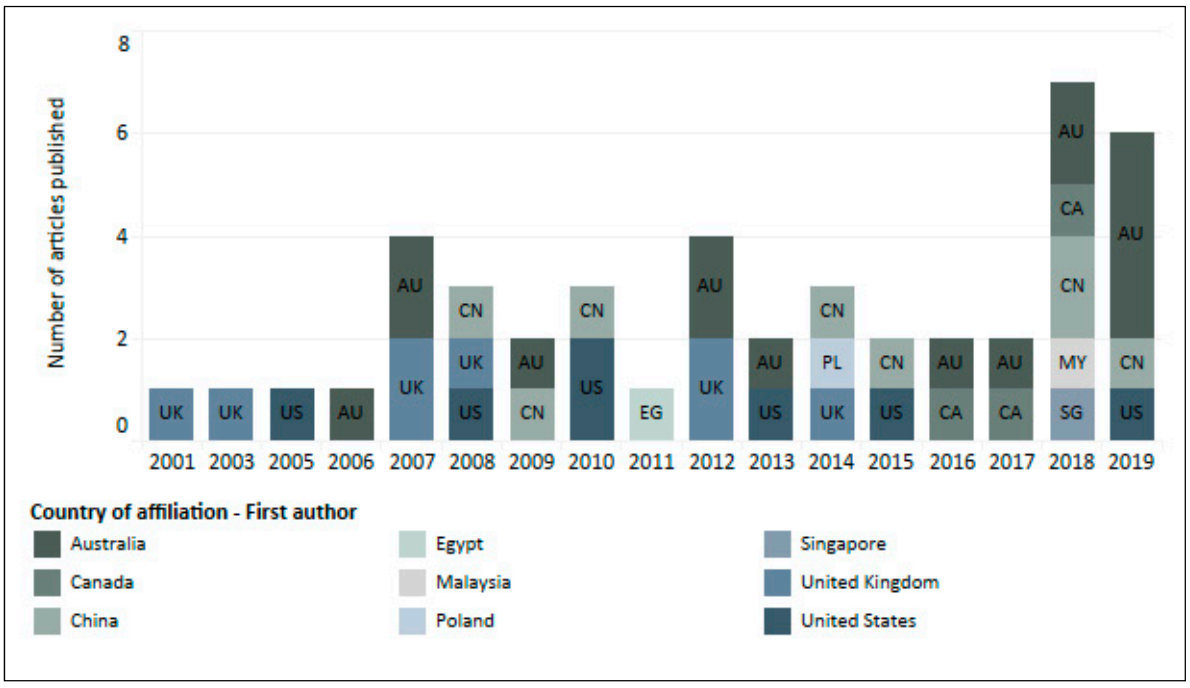

Figure 3. Round 1 literature—number of articles published by year (n = 45).

3.1. Literature Collected in Round 1—An Overview of the Factors Affecting the Use of OSC in Building Construction

The authors identified a total of 28 factors affecting the use of OSC in construction, which were grouped into three categories: social (n = 10), environmental (n = 7), and economic (n = 11). Individually, the most frequent factors, which were present in over 75% of papers, were costs, time, quality and product value, transportation and logistics, and labor.

3.1.1. Social Factors

The factors under this category are related to the impact of decisions on the use of OSC on product quality, labor relations, and society. The most frequent social factors were related to quality and product value, revealing an increasing concern regarding providing value-added products to customers. Labor related factors that involve a shortage of workers are historical drivers of the adoption of OSC, which currently represent an increasing concern for the AEC industry. Table 2 presents a summary of the social factors and subfactors and their frequencies, which sum up a total of 231 references (36%).

Table 2. Social factors and subfactors.

Factors	Subfactors	References (n = 45)	
		Frequency	%
Quality and product value	Improved quality and consistency; reduced call backs; durability; integrity of the building; testing in a production environment; performance predictability; reduction of defects and damages; inspection and supervision requirements; strict requirement for project quality control; customer-driven values; customization of projects; willingness to pay more for a better product	38	84%
Labor	Labor and skills demanded level; workers shortage; training and preparing workforce; availability and accessibility of skilled labor force; union agreements	34	76%
Safety and health in construction	Safety and health in the production environment; specific safety issues associated with use of equipment to manage large loads; need for improved construction safety	33	73%
Regulations and incentives	Level of knowledge and expertise of the professionals involved in construction (developers; designers; contractors; suppliers; workers); availability and accessibility of experienced professionals and workers	28	62%
Experience of professionals and suppliers	Legal and regulatory framework; building standards and codes; local codes and regulation requirements; permitting and inspections; government incentives; government policies and programs; government sustainability requirements, requests and incentives; modules import restrictions	27	60%
Social attitude and market culture	Market sensitivities; principles and cultural perceptions; acceptance/resistance to change and innovation; image of OSC; AEC industry's fragmented structure; culture of late design changes and modifications	21	47%
Aesthetics	Aesthetic solutions; lack of exciting design; monotony and repetitiveness in the aesthetics of buildings	16	36%
Customer's attitude	Clients requirements; customer perceptions; reaction to innovative suggestions; difficulty ascertaining the value of construction; owner's understanding; receptivity and acceptance; consumer-focused	14	31%
Stakeholders alignment	Effective collaboration and communication; contractual relationships; partnerships; contract type; detailed and defined project scope, and budget parameters; relationship between project members; industry and stakeholders acceptation of the changes and benefits	10	22%
Influence on society and local communities	Employment opportunities on-site and offsite; influence on culture and social development of local communities; effects of building construction on human health; urban regeneration	10	22%

3.1.2. Environmental Factors

The findings reveal that the frequency of environmental factors in the investigated literature was much lower than that of social and economic factors. In addition, in most cases (63%), the literature only referred to generic environmental factors, which were identified by the authors as "Environmental sustainability", which is understandable, given the shortage of in-depth studies on environmental sustainability that are associated with the use of OSC. However, the results do suggest increasing concerns regarding waste

and pollution factors. Table 3 presents a summary of the environmental factors and subfactors and their frequencies, which sum up a total of 135 references (21%).

Table 3. Environmental factors and subfactors.

Factors	Subfactors	References (n = 45)	
		Frequency	%
Environmental sustainability	General concepts such as environmental performance; environmental sustainability; sustainability requirements; environmental impact; environmental awareness; ecological construction; ecology preservation	28	62%
Waste and pollution	Waste management including recycling and reuse strategies; waste and pollution reduction; waste disposal; on-site noise and air pollution	25	56%
Materials and practices	Materials consumption and savings; recycled, reusable and renewable materials; material waste in construction; environmentally preferable materials; embodied energy-intensive materials (reduction of greenhouse gases emissions); carbon footprint; use of regional materials (reduction of negative impacts of transportation); material durability	22	49%
Building performance	Energy efficiency (energy consumption during the building life cycle); energy savings; energy harvesting systems; incentives to zero-carbon housing; energy consumption associated to thermal performance; carbon and greenhouse gases emissions; renewable energy; water and wastewater efficiency; water reuse and recycling systems; water harvesting systems; environmental certifications	21	47%
Site disruption	Project site and surrounding local communities' disturbance; impacts on environmentally sensitive sites; traffic congestion; noise during construction; imposition of specific hours to on-site work; planning for stormwater management; post construction environmental recovery	17	38%
Climate, weather and resilience	Severe local area condition, harsh weather and climate; wind speed; humidity and other weather conditions that degrade labor performance; climate independence; climate responsive housing; housing for resilience; building safety and security	13	29%
Building comfort and IEQ	Indoor air quality; indoor comfort; thermal and acoustic quality; health of occupants	9	20%

3.1.3. Economic Factors

This category includes strategies for reducing costs, increasing productivity, and reducing the risks that are involved in the construction business [37–40]. The findings confirm that decisions on the use of OSC are strongly monetary-driven [21,41]. When comparing the frequency of factors that are related to costs and time with the frequency of factors related to productivity and management, it is noteworthy that the literature focused on OSC has not focused on the potential of management tools to increase productivity and reduce the costs and project schedules. Table 4 presents a summary of the economic factors and subfactors and their frequencies, which sum up a total of 273 references (42%).

Table 4. Economic factors and subfactors.

Factors	Subfactors	References (n = 45)	
		Frequency	%
Costs	Initial costs; capital costs; operational costs; rework costs; overall life cycle costs; design costs; construction costs; price of the product; economies of scale (repetitive layout); profit; cost certainty; maintenance costs; end of life costs; cost control requirements; labor costs; affordability	41	91%
Time	Schedule and time constraints/restrictions; lead time; speed of construction; overall project duration; completion time certainty	38	84%

Table 4. *Cont.*

Factors	Subfactors	References (n = 45)	
		Frequency	%
Transportation and logistics	Transport of large dimension components (size restrictions); transport infrastructure; transportation restraints and regulations; delivery; site location, conditions, access, and limitations; site layout (storage and equipment location); on-site and off-site storage; equipment requirements and availability	37	82%
Design	Flexibility to accommodate design changes; suitability of design for OSC; standardization; passive solar and/or other innovative sustainable design strategies; standardized or cost-effective design solutions; module types and sizes; complexity of project design; interfaces, junctions, connections and constructions tolerances; design and construction coordination	32	71%
Risks and financing	Investment; ROI; financing; contractual risks; insurance; profit; uncertainty in lead time; increased planning and engineering requirements; capacity and reliability of delivery; safety and health risks; project risk profile	26	58%
Planning and processes	Simplified construction processes; process integration; intensive pre-project planning and engineering; early required key decisions; early design freeze; planning and scheduling logistics and on-site activities; company's structure and culture; company's strategies and involvement with new technologies; business models; organizational readiness and familiarity with OSC; project scope; project characteristics	25	56%
Supply chain and procurement	Production capacity; suppliers and manufacturers in the project area; availability of manufacturing facility within economical transport distance; procurement process and coordination; manufacture and supply integration; supply chain value creation and flexibility; easy supply and delivery	23	51%
Productivity	Offsite and on-site productivity; production efficiency	15	33%
Technology and innovation	Promotion of green building technologies; investment in research and development; testing new materials; impact of adoption of new technologies; availability and use of relevant information and communication technology	13	29%
Market and demand	Market demand; market trends; market maturity; targeted markets; market conditions; market size and cyclical changes; market forces; market analysis; demand gap; demand-oriented	12	27%
Management	Involvement of top management in decisions (upfront support); management as a structural facto affecting decisions; integrated management; constructability; site management; production monitoring	11	24%

3.2. Factors Affecting the Adoption of OSC in Multifamily Housing Internationally and in the United States

Still focusing on the round 1 literature, a total of 15 out of the 45 investigated articles (33%) focused on the use of OSC in housing construction, but only eight of them addressed the multifamily housing market. Figure 4 presents a summary of the factors that were found in those 15 articles, grouping the articles by market and also considering the country of applicability. Here, again, economic factors were the most frequent, but there is a relative balance between economic (81 references—40%) and social factors (73 references—36%). Regarding environmental factors, they are underrepresented (49 references—24%).

As for the literature focused on the use of OSC in multifamily housing in the US, five of the eight documents were published between 2019 and 2020, and it is noteworthy that economic factors were much more frequent (68 references—51%) than social (39 references—29%) and environmental factors (26 references—20%)—see Figure 5.

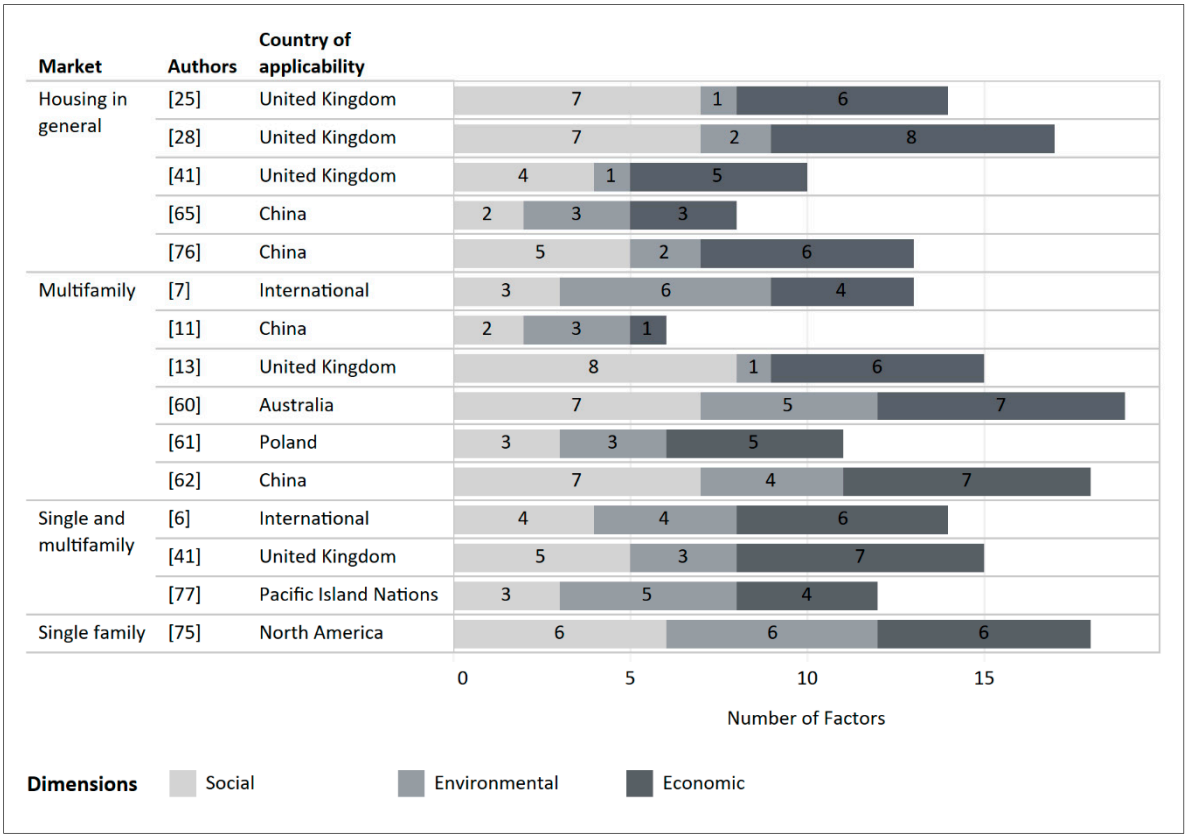

Figure 4. Factors affecting the adoption of offsite construction (OSC) in housing construction in different countries—the numbers refer to the number of economic, environmental, and social factors that are addressed in each article—round 1 literature (n = 45).

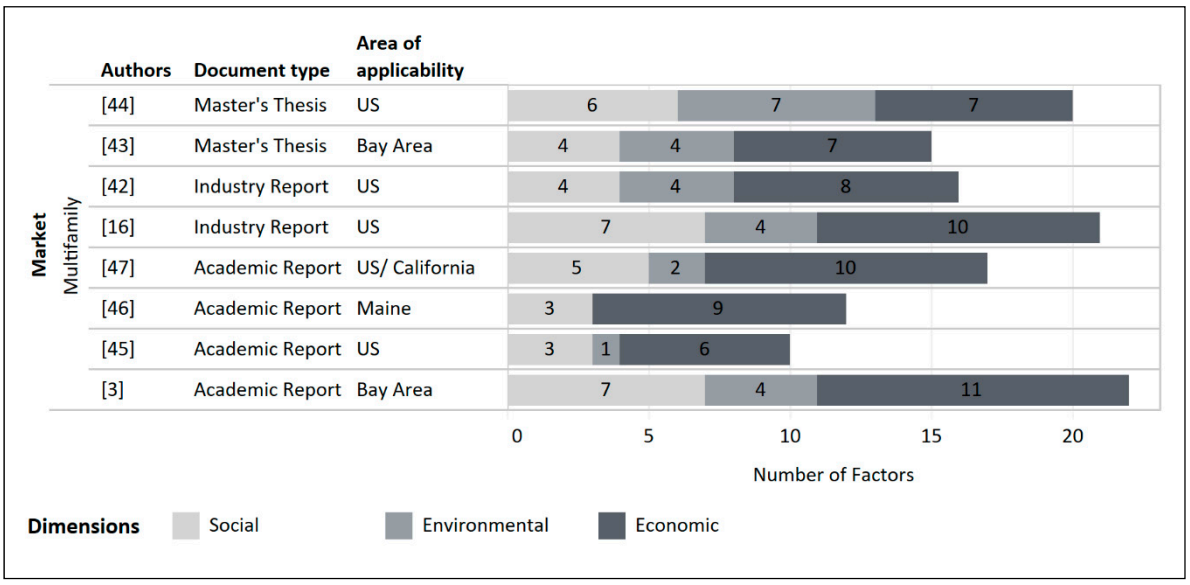

Figure 5. Factors affecting the adoption of OSC in multifamily housing construction in the US—numbers refer to the number of economic, environmental, and social factors addressed in each article—round 2 literature (n = 8).

From those eight documents, the two industry reports focused on the American multifamily market as a whole. The Fannie Mae report [16] is a very up-to-date document and it presented a type of "toolkit" with the potential benefits and challenges that housing

practitioners and stakeholders need to understand in order to take advantage of OSC in the US multifamily market. The document that was prepared by the industry organization Stewards of Affordable Housing for the Future [42] also presented an overview of OSC, but mainly focused on technologies and strategies that were potentially impactful in cost reduction, which have been adopted by the main providers of OSC in the US.

Stein's master's thesis [43] focused on the use of OSC in multifamily developments in the Bay area by analyzing the benefits and challenges of OSC according to the stakeholder's perspectives. As for Velamati's thesis [44], it addressed the use of OSC in high-rise buildings, focusing on multifamily and hospitality projects, while exploring the impact of design, legal aspects, building code, scheduling, and financing in this type of construction.

Feutz's academic report [45] addressed financing issues, especially for housing construction, and how to make institutional lenders more comfortable with investing in offsite construction projects in the US. Regarding the other three academic reports, they were focused on the multifamily market of specific areas in the US. Galante et al. [3] based their study on Stein's master's thesis [43], but with a stronger focus on the use of OSC to achieve more affordable housing developments in the Bay Area. Thompson [46] also focused on using OSC as a strategy in order to ensure the affordability of multifamily housing in Maine, while discussing the role of financial and governmental regulatory structures, the market demand for more affordable housing, the qualitative and quantitative benefits of using OSC, and the market's perceptions of OSC. Pullen et al. [47] analyzed the growth and trends for OSC in US, with a stronger focus on the California market, by exploring some factors that promote or hinder its uptake, which is especially important for multifamily developments, since, according to this study, most of the new industrialized construction companies were targeting multifamily housing projects.

3.3. Comparisons of the Investigated Literature

Some differences were noticed when comparing the frequencies of the factors that were identified in round 2 literature (eight documents), round 1 housing papers (15 articles), and all the articles collected in round 1 (45 articles). This suggests that decisions on the use of OSC in building construction involve factors that vary, depending on the specific characteristics of the market (project location) and the type of product (residential, commercial, etc.). However, more research on these differences is needed due to the lower number of articles found that specifically focused on housing (n = 15), and on the American multifamily housing market (n = 8). Following, some of the most noteworthy differences are discussed, according to each sustainability dimension.

3.3.1. Social Dimension

Figure 6 allows for a clear visualization of the differences between the various factors of the social dimension. The most significant differences were:

1. Regulations and incentives—these factors were much more frequent in the literature that was focused on American multifamily housing (88%) than in both general building construction (62%) and housing construction literature (50%).
2. Quality and product value—these factors were much less frequent in the literature focused on American multifamily housing (50%) than in both general building construction (84%) and housing construction literature (93%).
3. Aesthetics—these factors were not identified in the literature that was focused on American multifamily housing, but were relevant in the papers focused on housing construction (50%).

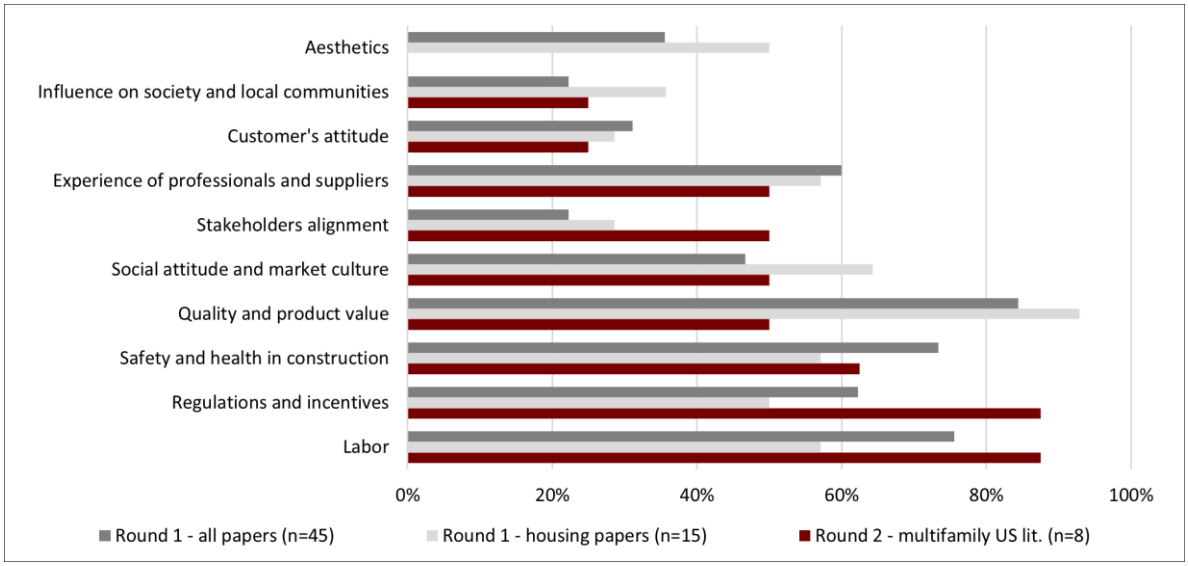

Figure 6. Social dimension—comparison of factors from round 1—all papers (n = 45), round 1—housing papers (n = 15), and round 2—multifamily in US literature (n = 8).

3.3.2. Environmental Dimension

Figure 7 shows the differences between the various factors within the environmental dimension. The most significant differences were:

1. Environmental sustainability—the frequency of these factors was low in both the literatures that were focused on American multifamily housing (38%) and housing construction (43%), but significant in general building construction literature (62%).
2. Building performance—these factors were much more frequent in the literature focused on housing construction (79%) than in both American multifamily housing (50%) and general building construction literature (47%).

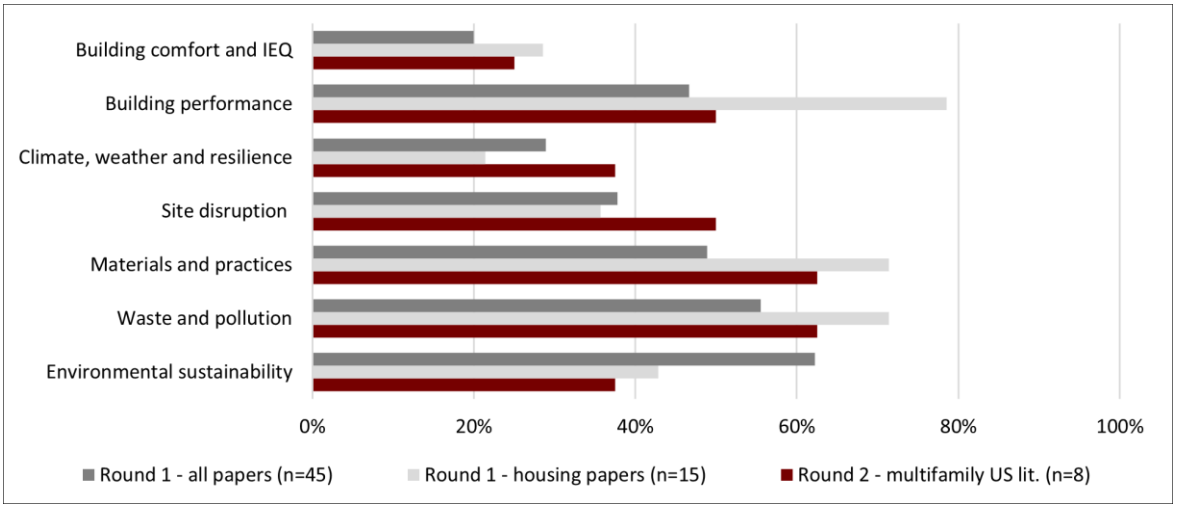

Figure 7. Environmental dimension—comparison of factors from round 1—all papers (n = 45), round 1—housing papers (n = 15), and round 2—multifamily in US literature (n = 8).

3.3.3. Economic Dimension

Figure 8 shows the differences between the various factors within the economic dimension. The most significant differences identified were:

1. Risks and financing—much more frequent in the literature that was focused on American multifamily housing (100%) than in both general building construction (58%) and housing construction literature (64%).
2. Market and demand—much more frequent in the literature that was focused on American multifamily housing (88%) than in both general building construction (27%) and housing construction literature (36%).
3. Productivity—much more frequent in the literature focused on American multifamily housing (88%) than in both general building construction (33%) and housing construction literature (7%).
4. Technology and innovation—much more frequent in the literature focused on American multifamily housing (75%) than in both the general building construction (29%) and housing construction literature (36%).

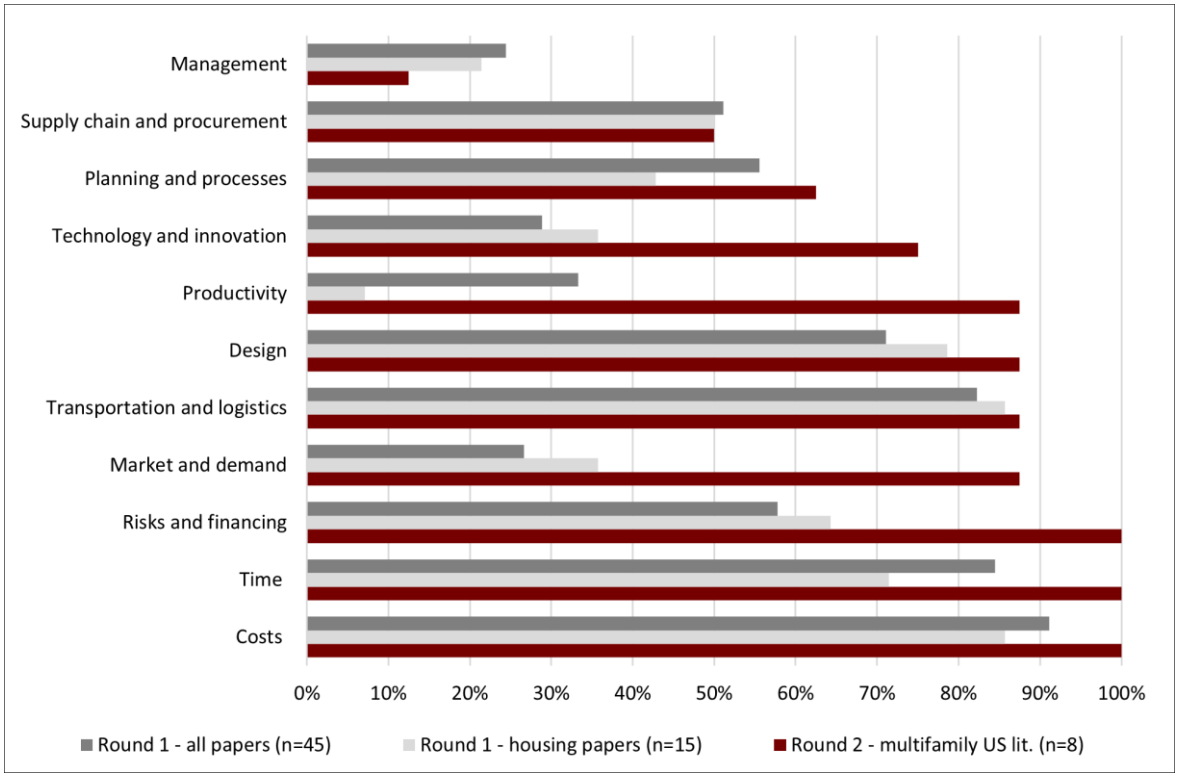

Figure 8. Economic dimension—comparison of factors from round 1—all papers (n = 45), round 1—housing papers (n = 15), and round 2—multifamily in US literature (n = 8).

3.4. Criteria to Be Considered in Multifamily Housing Projects

Different market segments may consider different decision-making criteria for the use of OSC; therefore, in order to better understand the specific needs of multifamily housing projects, the authors identified in the literature the key criteria to be considered in such projects, when considering the needs of owners, developers, and users of multifamily projects. Additionally, the authors associated each criterion with the respective factor that affect the use of OSC (Table 5).

All of the criteria listed above are important, but not all are equally relevant when discussing the prospect of using OSC in multifamily projects, particularly in the US. Following, a discussion on the relevance of some of these criteria for OSC adoption in multifamily projects is presented.

Table 5. Key criteria to develop multifamily housing projects.

Criteria	Respective OSC Factor	References
Affordability, profit, costs	Cost	[10,48–51]
Building quality, value of the product, quality control	Quality	[48,49,52–54]
Duration, delivery speed	Time	[48,49,51]
Design efficiency, flexibility, functionality, dimensions, configuration, efficient layout, standard units, custom vs. standard, design targets, robustness of design	Design	[10,48,49,52,53,55–57]
Risk management, financing strategies, construction loans, interests, capital markets, return for equity	Risks and financing	[10,48,49,51,54,56]
Building codes, regulations, incentives, standards	Regulations and incentives	[10,48–51]
Building performance, energy and resource efficiency	Building performance	[10,48,51,53,56,57]
Customer's satisfaction, users' experience, post-occupancy evaluation, households' needs	Customer's attitude	[49,52,53,55,56]
Comfort, indoor environment quality, healthier materials, sustainable materials, low emitting products and materials	Building comfort and IEQ	[10,48,51–53,55–58]
	Materials and practices	
Market conditions, market mechanisms	Social attitude and market culture	[48,49,51,54]
	Market and demand	
Location, services, infrastructure, surroundings, resilience, communities	Logistics	[10,48,51–53,59]
	Influence on society and local communities	
	Site disruption	
Appearance, aesthetics, cultural aspects	Aesthetics	[52,53]
Business model, delivery methods	Planning and processes	[53]
Climate adaptation, resilience, building safety	Climate, weather and resilience	[10,53]

4. Discussion

When considering the findings discussed in this study so far, the authors noted that:

- Many factors need to be considered in decisions about the use of OSC, but such factors are under-researched in the context of the use of OSC in multifamily housing projects in the US.
- The type of construction project affects the above factors.
- Many criteria need to be considered in multifamily housing projects.
- The particulars of the US multifamily housing market affect the above criteria and factors.

By cross-referencing this information, the authors identified opportunities for future research on some of the key factors that are to be addressed in American multifamily housing projects when considering the adoption of OSC. The gaps identified stood out due to a combination of the following reasons: (1) they are more significant factors in multifamily projects than in projects in general, (2) they relate to development criteria in multifamily housing previously identified, and (3) they are factors under-researched in the context of interest of this study. The relevant factors that emerged from this analysis are presented in Table 6, namely customer's attitude, building performance, and building comfort and IEQ, which are identified in red and can be considered as soft factors in decisions that are related to OSC adoption. As for design, identified in green, the authors discussed its important role in the context of this study.

Table 6. Relevant factors to be discussed within the American multifamily market.

Factors	More Significant in Multifamily Projects	Relate to Development Criteria in Multifamily Housing—Table 5 [1]	Under-Researched in the Context of OSC Adoption [2]
Social Factors			
Quality and product value		X	
Labor			
Safety and health in construction			
Regulations and incentives	X	X	
Experience of professionals and suppliers			
Social attitude and market culture		X	X
Aesthetics		X	X
Customer's attitude	X	X	X
Stakeholders alignment			X
Influence on society and local communities		X	X
Environmental Factors			
Environmental sustainability			
Waste and pollution			
Materials and practices		X	X
Building performance	X	X	X
Site disruption		X	X
Climate, weather and resilience		X	X
Building comfort and IEQ comfort	X	X	X
Economic Factors			
Costs	X	X	
Time	X	X	
Transportation and logistics		X	
Design	X	X	
Risks and financing	X	X	
Planning and processes		X	
Supply chain and procurement			
Productivity			X
Technology and innovation			X
Market and demand		X	X
Management			X

Notes: [1] Based on the connections identified in Table 5. [2] Under-researched factors are the ones with a frequency lower than 50% in all the articles collected in round 1 (n = 45).

Discussions on time, quality, and cost factors (triple constraints), as well as some other economic, social, and environmental factors have been already widely explored in the literature of OSC and multifamily housing [13,41,60]; therefore, they were not included in the following discussion, but they are still considered to be key factors and criteria for the development and use of OSC in multifamily housing in both the US and other countries. It is important to emphasize that, for owners and developers, technical aspects, access to financing and incentives, and flexibility of regulations are extremely important factors, because they directly affect the cost and duration of multifamily projects. In contrast, for users and households, comfort, efficiency, and the adequacy of the design to theirs needs are crucial factors.

4.1. Customer's Attitude

The customer's attitude, influences, perceptions, and satisfaction are connected to the quality of the built environment and services provided, which make these factors paramount in the context of multifamily housing projects [52]. These factors relate to the satisfaction of not only users, but of all stakeholders that are involved in the project—owners, developers, architects and construction companies [3]. For this reason, post-occupancy evaluation is a great tool for assessing the level of satisfaction of customers aiming to improve user experience, ensuring that new developments are better suited to

user's needs, reduce risks, and guarantee better financial returns for owners, developers, and investors [52,56].

Focusing on end users, the importance of customer's satisfaction is magnified in multifamily projects, due to the need to meet the demands of different households, requiring the adoption of strategies and clever design in order to allow flexibility, efficiency, and comfort [10,48,61]. Flexibility is important to allow for adaptable housing for present and future needs of households [10], but it can be compromised with the use of OSC. Strategies of mass customization help to meet the customers' needs and minimize the lack of flexibility in OSC [37].

In the context of OSC, customers' perceptions are an under researched topic. However, research has found that owners' and customers' perceptions are among the main drivers or barriers to OSC adoption [23]. This is because customers can react to innovative suggestions with different attitudes, which range from supporting to hampering [62]. In fact, the owner's willingness to accept modular construction is one of the most critical decision-making factors for OSC projects [38]. Therefore, it is critical to adopt strategies to attract and keep customers—owners, developers, and general contractors that are interested in innovation in construction [3,47].

4.2. Building Performance

Building performance factors comprise topics that are related to energy and resources use throughout the building life cycle [10,57]. This is extremely important in the occupancy phase of multifamily projects, as many families in the US are struggling with rising housing costs, which include utilities, and very often compromise more than 30% of families' income and prevent them from having a better quality of life [63].

Focusing on energy consumption, this category includes the energy that is used to manufacture, transport, and assemble the building components during the construction phase [34,60], noting that research suggests that energy consumption during the construction phase is considerably reduced when OSC is employed [11,35]. During the occupancy of the building, thermal performance is an important issue to be considered [6,22,35,56,57], which can be highly improved with OSC, because it ensures increased levels of insulation and a tighter building envelope [16,44,60].

Other important topics requiring attention in multifamily projects while using OSC relate to renewable energy use, including energy harvesting systems that are intended for reducing the carbon footprint of buildings [41], and incentives to zero-carbon housing [41,56,64]. Research related to water and wastewater efficiency in the context of OSC addresses strategies for reducing potable water consumption through monitoring, reuse, and recycling systems [14], and water harvesting systems [6]. Once again, research on water consumption during the construction phase suggests a better performance with the adoption of OSC [11,65].

4.3. Building Comfort and IEQ

IEQ refers to the environmental quality of a building as for the health and well-being of its occupants, for it involves lighting, air quality, indoor temperatures, relative humidity, noise, and ventilation levels [10,52]; hence, its great significance in multifamily projects. The need for improved energy performance has made buildings increasingly airtight and less ventilated, which contributes to the deterioration of the IEQ [58]. This fact stress the need to balance energy efficiency and environmental comfort in an affordable manner, through strategies such as passive design and the use of more sustainable and healthy materials [10,48].

IEQ starts in the design stage, when building materials and systems are defined [48], but it is an important factor during the construction stage as well, since the construction methods and the quality of the work play an important role in the IEQ of a building [56]. Building IEQ is a topic under-researched in the context of OSC, but research suggests that components prefabricated in a factory-controlled environment allow for better thermal and

acoustic comfort [66], and improved indoor air quality, for the use of dry materials and moisture control are required [22,44]. Despite the relevance of IEQ factors, they may be overlooked in decisions that are related to the adoption of OSC [14].

4.4. Design

Building design must be human-centered; hence, the importance of design in residential projects [56]. Importance that is magnified in multifamily projects, for there is a need to meet the needs of different families, requiring the adoption of clever design to allow for flexibility, efficiency, and comfort [48,61]. In addition, multifamily housing design should foster the creation of healthy, sustainable, and resilient environments and communities [10,59]. Design factors affect the social, environmental, and economic sustainability of housing projects, because decisions that are made in design phase impact the entire life cycle of the buildings, also affecting the buildings' dwellers [67]. However, factors that are related to the design of multifamily housing using OSC are still poorly addressed in the specialized literature.

The adoption of OSC makes design decisions even more crucial, and early design decisions allow for better defining the strategy and level of adoption of OSC in a project [16,44], as OSC reduces the flexibility to accommodate late design changes, which is one of the most significant issues reported by AEC industry professionals [4,28,68]. Hence, the importance of correctly planning the design phase duration and timely freeze the design [39,69]. Standardization in design is another important aspect of OSC, as it allows for repeatability and cost-effectiveness [6,32]. However, some companies in the US allow for fully customizable design [42].

As for the environmental aspect of buildings design, it is important to highlight that passive design and other sustainable design strategies are being successfully incorporated into OSC, highly benefitting multifamily projects [6]. Finally, focusing on the technical aspects of design, OSC involves issues that are related to module dimensions [38], interfaces, junctions, connections [25,37], and construction tolerances [24], which impact on the logistics, assembly, and ultimately affect the quality of the buildings. Consequently, it is paramount to associate the adoption of OSC with tools that facilitate design, project coordination, and information flow, such as BIM and project management platforms [38,70]. In this sense, some manufacturing and vertically integrated firms in the US have engaged in partnerships with Autodesk software corporation [47].

5. Conclusions

Based on research that was published between 2000 and 2019, this study identified 45 peer-reviewed journal articles addressing factors that affect the adoption of OSC considering the three sustainability dimensions: economic, environmental, and social. Of those 45 articles, only 15 focused on housing construction, and, of those, eight addressed multifamily housing. Because none of the investigated articles contemplated the American multifamily housing market, a second round of literature investigation focused on multifamily housing in the US, but not restricted to just peer-reviewed journal articles, found eight documents published between 2000 and 2020. The analysis of the literature resulted in a compilation of 28 factors affecting decisions on the adoption of OSC in building projects. The comparison of the factors identified in literature: (1) focused on building construction in general, (2) housing construction, and (3) multifamily housing construction in the US suggests that, in the housing market, and particularly in the multifamily market, the factors affecting the use of OSC are different from other segments.

In order to better understand the specific needs of multifamily housing projects, the authors identified in the literature the key criteria to be considered in such projects. In addition, the authors identified and discussed three important factors that need to be addressed in future research on the use of OSC specifically in the American multifamily market, namely customer's attitude, building performance, and building comfort and IEQ, and risks and financing. The discussion also included a brief overview of the importance of

design, while addressing the benefits and challenges that OSC poses to owners, developers, and users. Therefore, the content of this study contributes to the body of knowledge that makes up the domain of offsite construction.

Limitations are inherent to research and, in this study, the results were limited to the search strategies that were used to collect the literature. The thematic analysis that was performed in order to identify and categorize the factors was susceptible to subjectivity and potential bias, which is also a limitation. Further studies to support the conclusion of the paper may include: (1) interviews or surveys with experts from the AEC industry to validate the specific factors that affect the use of OSC in the American multifamily market and rate their relative importance, (2) more comprehensive studies on the differences between the factors to be considered when adopting OSC in housing projects and in other buildings' types, (3) the assessment of successful strategies to use OSC in multifamily projects in the US, and (4) examination of up-to-date technology or policy that promote the uptake of OSC in multifamily housing construction.

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Appendix A

Table A1. Factors Affecting Decisions on the Use of OSC Identified in Round 1 Literature (n = 45).

	Economic											Environmental									Social										
References \ Factors	Costs	Time	Transportation and Logistics	Design	Risks and Financing	Planning and Processes	Supply chain and Procurement	Productivity	Technology and Innovation	Market and Demand	Management	Environmental Sustainability	Waste and Pollution	Materials and Practices	Building Performance	Site Disruption	Climate, Weather & Resilience	Building Comfort and IEQ	Quality and Product Value	Labor	Safety & Health in Construction	Regulations and Incentives	Experience of Professionals and Suppliers	Social attitude & Market Culture	Aesthetics	Customer's Attitude	Stakeholders Alignment	Influence on Society and Local Communities			
[38]	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X			X	X			
[31]	X	X	X			X	X	X				X							X	X	X	X	X	X							
[21]	X	X	X				X					X							X	X	X	X									
[71]	X	X	X	X		X	X					X							X	X	X		X	X							
[60]	X	X	X	X	X		X				X		X	X	X	X	X		X	X	X			X		X	X	X			
[11]	X												X	X	X				X									X			
[22]	X	X	X	X	X	X							X	X	X	X		X	X	X	X					X		X			
[72]	X	X	X	X	X								X	X	X	X	X	X	X	X	X	X	X					X			
[29]	X	X	X	X	X	X		X				X	X			X	X		X	X	X	X	X	X	X						
[6]	X	X		X	X		X		X				X	X	X			X	X				X	X	X						

Table A1. *Cont.*

References	Economic												Environmental										Social								
Factors	Costs	Time	Transportation and Logistics	Design	Risks and Financing	Planning and Processes	Supply chain and Procurement	Productivity	Technology and Innovation	Market and Demand	Management	Environmental Sustainability	Waste and Pollution	Materials and Practices	Building Performance	Site Disruption	Climate, Weather & Resilience	Building Comfort and IEQ	Quality and Product Value	Labor	Safety & Health in Construction	Regulations and Incentives	Experience of Professionals and Suppliers	Social attitude & Market Culture	Aesthetics	Customer's Attitude	Stakeholders Alignment	Influence on Society and Local Communities			
[25]	X	X	X	X			X			X		X							X	X	X	X	X	X				X			
[37]	X	X		X	X	X		X				X	X						X		X			X							
[23]	X	X	X				X				X	X							X		X										
[4]	X	X		X	X				X	X		X							X	X	X	X	X	X	X						
[35]	X	X				X		X					X	X	X					X	X					X					
[39]	X	X			X	X	X	X	X			X							X	X	X	X	X	X							
[73]		X	X	X					X	X		X				X			X	X	X		X								
[12]	X	X	X	X	X	X	X	X			X	X	X	X	X	X			X	X	X	X	X				X	X			
[74]	X		X	X	X	X	X				X		X						X	X		X			X	X					
[67]	X	X	X	X	X	X		X			X		X	X					X	X	X		X			X					
[65]	X		X		X								X	X	X				X		X										
[34]	X	X	X	X				X				X	X	X	X	X			X	X	X		X	X							
[14]	X	X	X	X	X			X			X		X	X	X	X	X	X	X	X	X			X	X	X		X			
[75]	X	X	X	X	X						X		X	X	X	X	X	X	X		X			X	X	X		X			
[76]			X	X		X	X		X		X	X			X				X	X		X	X				X				
[69]	X	X	X	X	X		X	X				X					X		X	X	X	X	X		X	X					
[68]	X	X	X	X	X		X		X	X		X		X	X		X	X	X	X	X	X	X	X			X				
[66]	X	X	X	X			X						X	X		X				X	X	X	X								
[41]			X		X	X	X		X						X					X		X		X			X				
[28]	X	X	X	X	X	X	X			X		X				X			X	X	X	X	X	X	X						
[13]	X	X	X	X		X	X					X							X	X	X	X	X	X	X		X				
[41]	X	X	X	X	X	X				X			X	X	X				X		X	X	X		X						
[61]	X	X	X	X						X		X	X	X									X	X	X						
[77]	X	X	X	X									X	X	X		X	X	X	X								X			
[78]	X	X	X			X	X			X		X							X	X		X	X	X	X						
[24]	X	X	X	X		X	X	X					X	X	X	X	X		X	X	X	X									
[70]	X	X	X	X	X	X		X				X					X			X	X	X						X			
[7]					X			X	X	X		X	X	X	X	X		X	X			X				X					
[30]	X	X	X	X	X							X							X				X			X					
[79]	X	X	X	X		X				X		X									X	X	X		X	X	X				
[32]	X					X	X		X	X		X								X		X		X	X						
[80]	X	X	X	X	X	X	X		X		X	X				X	X		X	X	X	X	X			X	X				
[36]	X	X	X			X						X	X	X	X	X		X	X	X	X	X	X								
[40]	X	X	X		X	X	X	X	X	X	X	X	X				X		X	X		X	X	X	X		X				
[62]	X	X	X	X	X	X			X				X	X	X	X			X	X	X	X		X	X	X					

Appendix B

Table A2. Factors Affecting Decisions on the Use of OSC Identified in Round 2 Literature (n = 8).

References \ Factors	Economic											Environmental									Social								
	Costs	Time	Transportation and Logistics	Design	Risks and Financing	Planning and Processes	Supply chain and Procurement	Productivity	Technology and Innovation	Market and Demand	Management	Environmental Sustainability	Waste and Pollution	Materials and Practices	Building Performance	Site Disruption	Climate, Weather & Resilience	Building Comfort and IEQ	Quality and Product Value	Labor	Safety & Health in Construction	Regulations and Incentives	Experience of Professionals and Suppliers	Social attitude & Market Culture	Aesthetics	Customer's Attitude	Stakeholders Alignment	Influence on Society and Local Communities
[16]	X	X	X	X	X	X	X	X	X	X			X	X	X	X			X	X	X	X	X	X			X	
[45]	X	X			X			X	X	X			X							X		X					X	
[3]	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X		X	X	X	X	X			X	X	
[42]	X	X	X	X	X	X		X	X				X	X	X			X		X		X		X	X				X
[47]	X	X	X	X	X	X	X	X	X	X		X			X					X			X	X		X	X	
[43]	X	X	X	X	X		X			X		X		X		X	X		X	X	X		X					
[46]	X	X	X	X	X	X		X	X	X											X		X	X				
[44]	X	X	X	X	X			X		X		X	X	X	X	X	X	X	X	X	X		X	X				X

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