

Article

COVID-19 and Green Housing: A Review of Relevant Literature

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Abstract: This review presents an analysis of three hypotheses. The articles provide a specific perspective on green housing before, during, and post COVID-19. The validations of these hypotheses were performed by analyzing the scientific literature worldwide and by adding a statistical analysis of appropriate articles from the Scopus database. The purpose of this review is to overview the research written on housing developments during the upsurge of COVID-19 along with the responses from the green building sector, because this field appears to be rapidly emerging by the sheer volume of research studies currently undertaken. Foremost peer-reviewed journals covering construction, urban studies, real estate, energy, civil engineering, buildings, indoor air, management, economics, business, environmental studies, and environmental sciences that were published last year were selected for review. The review was conducted by applying a combination of various keywords and the criteria for paper selection, including sustainable building, green construction, green building, resource-efficient, a building's lifecycle, COVID-19, energy, water, consumption, health effects, comfort, occupant behaviors, policy, economy, Industry 5.0, energy-efficient retrofitting, and profit. Two, innovative elements in this study stand out when comparing it with the most advanced research on green housing before, during, and after COVID-19. The first innovation relates to the integrated analyses of COVID-19 pandemic, housing policies of countries and cities pertinent to COVID-19 that impact green housing and the wellbeing of their residents as well as the impact made by residents and a housing policy on the dispersion of COVID-19. This research additionally establishes that a green building analysis is markedly more effective when the analysis comprehensively covers the life process of a green building, the participating interest groups that have their own goals they wish to implement, the COVID-19 situation, and the external micro- and macro-level environments as a singular entity.

Keywords: green housing; sustainability; COVID-19 and pandemic; real estate market; household preference; technologies; trends; a review

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1. Introduction

The current health emergency has proven to be a crisis like none other recalled in modern times. There seemed to be no other manner to overcome it, but for countries to instigate lockdowns that brought their economies to a standstill. Thereby the result has been the worst recession since the Great Depression. Lives were overturned in numerous ways to deal with this crisis. The ensuing collapse of economies occurred at unimaginably rapid rates and magnitudes. Changes to people's lives everywhere have been profound: slowdowns of economies, loss of jobs, upheavals of climates, upsurge of technology, and automation resulting in job losses, upswing of digital currencies, depressed returns on savings, greater inequalities, and rising debts. Nonetheless, along with the usual global

forces, this unexpected crisis holds promise of a new challenge and opportunity at building a brighter tomorrow for everyone. Good faith and shared goals constitute the means for solutions even when the problems are unusually pressing. The expected recovery then can mean a global economy that serves all [1].

The housing sector has suffered numerous difficulties from the pandemic, including in the field of green buildings. The sector's problems are not limited to the present but will continue for some time. Problems include renting during the COVID-19 surge. Responses to pandemic policies require attention, and these need to be understood in terms of their impacts. Other topics involve coordinating policies in light of housing outcomes during the COVID-19 outbreak. Then, following the pandemic, consideration must be made of relationships between landlords and renters and of the entire concept of green buildings. Lock-downs have already lasted over 10 months. Thus people were forced to sleep, eat, work, work-out, and socialize, all at home. This leads to one conclusion—larger living spaces that overlook green areas need to constitute the focus of green housing design strategies.

The COVID-19 pandemic has added a great deal of uncertainty to many areas of human life—at work, at home, in leisure time. For many people, their homes are now the only place where they work and spend free time. A look at various aspects of housing through the lens of the pandemic is, therefore, very important. The question is whether the drive to protect human health will become the key point in the analysis of housing priorities, with a focus on the quality of indoor environment, the choice of building materials, and expected changes in sustainable design requirements for residential buildings. Finally, a rethinking of sustainability requirements for residential buildings is one challenge of this pandemic. Future building assessment will likely focus more on its occupants than the building itself. More waves of the COVID-19 outbreak are possible and to mitigate its influence, its impacts must be analyzed.

Currently many countries face many challenges and needs for housing improvements requiring solutions. Micro-, mezzo-, and macro-environments in housing pertinent to COVID-19 involve numerous aspects. Working from home is on an upswing; thus, suitable environments must be enabled. COVID-19 is bound to cause new requirements for future homes. These will involve resource efficiency throughout a building's lifecycle, larger lots as well as smart bathrooms and bidets. There will be new aspects to multi-generational homes, which will now require unique spaces, such as, e.g., more rooms and more bathrooms. Future homes cannot be simply smart homes—they must be healthy and energy-efficient homes. Floor plans will require more open spaces. Creative locales within the home can be designed for office use. Management teams will be designated for infra-structural facilities and different, smaller teams for technical facilities. Daily hygienic needs must be on-site in simplified designs. Checklists must be generated for daily health and safety needs. Building Information Modelling (BIM) and other digital means need to fight with COVID 19, e.g., by digital risk monitoring on construction sites and in work sites. Relevant systems would include data analysis, alerting, video surveillance, Internet of things (IoT), and non-invasive temperature monitoring. Plans should include reporting on health on a daily basis and the ability to diagnose remotely. Proptech would change facilities management on a step-by-step basis by employing workplace wellbeing, efficient energy consumption, optimal use of available space, and data management.

The literature under review originated only in part of the countries the pandemic has affected. Therefore the studies reviewed do not include all the areas around the world that have been infected by this virus. Hence, the affected countries with extremely vulnerable populations still call for adequate coverage. Nonetheless, there is a considerable overview of proposed policies aimed at the pandemic, so the green housing research community and its overall sector has been considered in light of the main, pertinent guidelines.

Aspects of green housing in the era during and post COVID-19, green housing trends and its interrelations are presented in the Figure 1. These factors are briefly analyzed below.

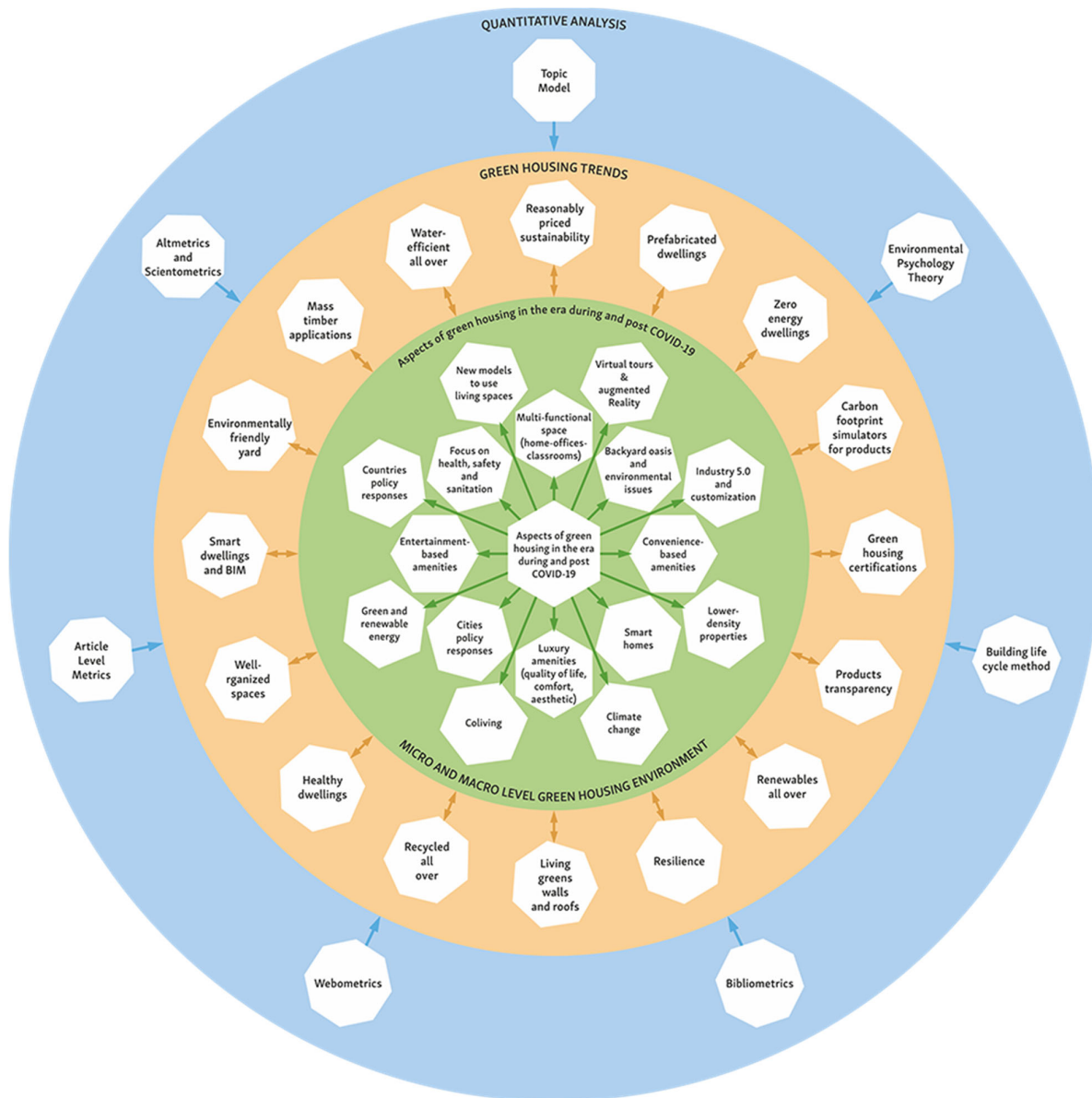


Figure 1. Green housing quantitative and qualitative aspects during and after the COVID-19 pandemic.

A quantitative analysis on green housing is possible by applying the Topic Model, Environmental Psychology Theory, building life cycle method and certain elements of Bibliometrics, Webometrics, Article Level Metrics, Altmetrics, and Scientometrics. These methods are briefly described next.

“How can the development of ideas in a scientific field be studied over time?” This was the question that Hall et al. [2] attempted to answer by studying the history of ideas using topic models. An analysis of the historical developments in Computational Linguistics field from 1978 to 2006 was also undertaken by Hall et al. [2] by applying unsupervised topic modelling to the Anthology of Computational Linguistics (ACL). Their study involved inducing topic clusters by applying Latent Dirichlet Allocation for investigating the strength of every topic over time. The methods employed by Hall et al. [2] discover developments in this field. These included the rise of probabilistic methods from their beginning in 1988, a stable growth of pertinent applications and a pronounced drop of

research in semantics and understanding between 1978 and 2001, which showed some growth only after 2001.

Rosen-Zvi et al. [3] provide the author–topic model for modelling topics pertinent to document authors, meant to upgrade topic detection in documents with authorship information. Topic modelling on abstracts from the Proceedings of the National Academy of Science (PNAS) was applied by Griffiths and Steyvers [4] to identify topics with growing or falling popularity from 1991 to 2001. A topic model for geographically distributed documents was developed by Yin et al., 2011 [5]. Here latent regions detected by inference, which explain document positions. Newman and Block [6] determined the temporal dynamics of topics from 1728 to 1800 in the Pennsylvania Gazette, which constituted an approach for temporal information. Network information between linked documents in the relational topic model were included by Chang et al. [7] for the purpose of modelling such links between websites. Meanwhile Lamba and Madhusushan (2019) [8] were applying topic modelling on full-text research articles that they took from the DESIDOC Journal of Library and Information Technology (DJLIT) from 1981 to 2018.

Webometrics is the term Almind and Ingwersen [9] applied to reference quantitative studies of the web. A definition of webometrics was provided by Björneborn and Ingwersen [10]. They claimed it is the study of bibliometric and informetric approaches, which serve as a source for the quantitative aspects of the construction and use of information resources, structures, and technologies on the Web.

Bibliometrics refers to the analysis of scientific publications by applying a set of quantitative methods. A bibliometric study involves quantifiable forms of a publication or any aspect of that publication, such as its number of words, the time delayed after its submission until its publication and other similar aspects. Bibliometric measures that appear most often are the following [11]:

- The productivity of some certain researcher or research group measured by the number of respective publications issued.
- The number of citations from a publication appearing in later publications written by other scholars to indicate the interest generated by that respective publication.
- The number of downloads of an electronically available publication by readers to indicate its importance.
- The number of times on average that articles published in certain journals are cited within a certain time period following publication to indicate of the scientific importance of that journal or how comprehensive its peer review is.

How the scientific community handles a particular piece of research constitutes its scientific impact. Thus the interest the scientific community pays to some certain article in a professional journal after publication is a matter undertaken by Article Level Metrics (ALMs) by a wide range of metrics. Such metrics can include citations, usage statistics, discussions regarding online comments and social media and social bookmarking as well as different recommendations [12]. Lin and Fenner [12] covers why Article Level Metrics constitute an important extension of traditional citation-based journal metrics as well as presents several examples. A variety of metrics, e.g., have been accumulated and displayed by Public Library of Science (PLOS) since 2009 for every one of its articles. Furthermore PLOS also collects metrics about how many times an article has been saved in online reference managers like Mendeley in addition to its statistics on the frequency a certain article has been viewed and downloaded, meaning the statistics on its citations and usage. Other metrics included by PLOS regard the frequency of discussions about an article in its online comments, in science blogs and/or in the social media. In addition to these metrics, PLOS also notes the frequency of recommendations of a certain article by other scholars. A consideration of citations alone would exclude all the other valuable information, which these added metrics provide [12].

The “impact” or “reach” of some, one article is referenced as Article Level Metrics (ALMs), referencing an entire range of measures offering such insights. Citations at the

journal level are measured by the well-known Impact Factor. Meanwhile the research impact of an article is measured by ALMs aiming for transparency and thoroughness. ALMs view citations and their usage and, additionally, present the coverage of an article along with discussions that appear on the social web [13]. The discussions regarding an individual article along with its sharing and use comprise a picture that Article Level Metrics (ALMs) present. The effort of ALMs involves measuring impact at the level of a single article. To accomplish such a measure, some traditional data sources like times cited are used by ALMs as well as certain new sources like tweets. The definition of altmetrics specifically references such an effort to include new data sources for measuring impact brought about by either an article, a journal or even by some certain scholar. Data sources are the heart of altmetrics, not some level of aggregation. ALMs specifically define the impact of some, certain article by merging altmetrics with traditional data points [14].

A different group of metrics has appeared recently, over the past few years. This group, which has evolved to becoming a topic of interest and research in scientometrics, is now known as alternative metrics or altmetrics. It obviously differs from classical bibliometrics, as its name indicates, since it offers an alternative to citation analysis [15]. In Lin and Fenner [12] opinion, altmetrics used a very wide-ranging collection of metrics, such as citation of papers, papers views and downloads, recommended, science blogs, journal comments, discussed in Twitter, Wikipedia, or Facebook. Altmetrics is especially well defined by Priem et al. [16], who describe what it involves and how it can be used in addition to pinpointing the subjects of its focus. That different alternative metrics could be correlated with numerous traditional metrics, including, e.g., citations, was proposed by Priem et al. [16], or, alternatively, expert opinions might undertake an analysis of such a correlation.

The scientific measurement of work of scholars involving the means of analysis of their publications along with the citations within those articles is known as scientometrics (Wiktionary). The measure and analysis of science is a science called Scientometrics. Its practice frequently involves the use of bibliometrics or measuring the impact of publications (Freebase). Scientometrics is an instrument of the Sociology of Science, which is a sub-discipline dealing with quantitative evaluations of scientific activity that documents the sectoral economy of the scientific optical discipline, as per Vega-Muñoz and Arjona-Fuentes [17]. Furthermore these scholars proclaim that its application can also extend to the sub-discipline covering the sector of economics research and development.

In order to design and implement an effective green building life cycle process, it is necessary to analyze comprehensively its constituent parts, the participating in it interested groups as well as to consider external micro- and macro environment impact. In green building life cycle process stages, alternative variants are formed by changing a construction site, by rating possible green building volumetric-planned and other solutions, construction, and maintenance processes, etc. Variability of solutions helps to consider more rationally the present COVID-19 situation, external micro- and macro environment level factors, to make the project cheaper; to satisfy better architectural, aesthetic, comfort and other requirements of the client as well as aims of all participating in the project interested groups (see Figure 1).

The effectiveness of a green building life cycle process highly depends on external micro- and macro level environment. The factors of the external macro level environment, such as the implemented by the government and cities politics, influences the effectiveness of the green building life cycle process. Real estate policy in countries and cities (responses and challenges) as well as other macro level factors are described in more detail in Section 5.1. Micro level factors (a nice place, good infrastructure of the place, sources of funding, etc.) also largely condition the effectiveness of the project. The influence of micro level environment to green housing is described in more detail in Section 5.2—COVID-19 and Its Possible Effects on Future Homes.

How can effective green building life cycle process be determined, if different interested groups participate in it, there can be hundreds of thousands of alternative projects variants, when, with the change of constituent parts of green building life cycle process,

COVID-19 situation, external environment, the effectiveness of the entire project also changes? In addition, the implementation of some aims can be more rational economically than others; however, they are differently significant from other aspects. Thus, it is considered that the effectiveness of green building life cycle process depends on the rationality of its constituent parts, the level of interested groups goals achievement and the rationality of the external environment. This analysis formally describes how with the change of constituent parts of the project, COVID-19 situation, external environment, the level of different goals achievement, and the level and price of green building life cycle process effectiveness change.

The research's object consists of green building life cycle process, the participating in it, and willingness to implement its interested group's goals, COVID-19 situation, and external micro- and macro level environment as a whole. Green Housing Topic Model was developed in order to perform a detailed analysis of this analysis object.

The objective of research is the increase of green building life cycle process effectiveness by applying a newly developed Green Housing Topic Model.

It has not been analyzed in detail till now how COVID-19, housing COVID-19 policies of countries and cities impact green housing and the wellbeing of residents, and also the residents and a housing policy impact the dispersion of COVID-19. A green building analysis is also much more effective in a comprehensive analysis of green building life cycle process, the participating in it interested groups, willing to implement their goals, COVID-19 situation, external micro-, and macro level environment as a whole. Due to these two reasons, the research was undertaken in order to fulfil the gap in the knowledge of the green housing before, during, and post COVID-19. The analysis given in Sections 3–5, shows that the analyzed question is important and actual while seeking for the increase of green building science spread.

2. Methodology

An integrated quantitative analysis on green housing before, during, and after COVID-19 is possible by applying the Topic Model, Environmental Psychology Theory, building life cycle method, and certain elements of Bibliometrics, Webometrics, Article Level Metrics, Altmetrics, and Scientometrics. These methods were described in brief in the Introduction.

Development of the Green Housing Topic Model took place during the course of the research when the worldwide scientific literature was under analysis and the statistical analysis was taking place of appropriate articles from different bibliographic databases. The development of the Green Housing Topic Model occurred in seven stages:

1. Search
2. Compilation of a two-dimensional green building map
3. Comparison of articles published in 2019 and 2020 on green buildings by specific key search words
4. Raising a hypothesis (Hypothesis 1) on the correlation and distribution of topic words
5. Compilation of a colored document-frequency matrix
6. Raising and validating the two hypotheses (Hypotheses 2 and 3) and the interlink between them
7. Establishment of green housing trends on a micro and macro scope

Brief descriptions of these stages follow.

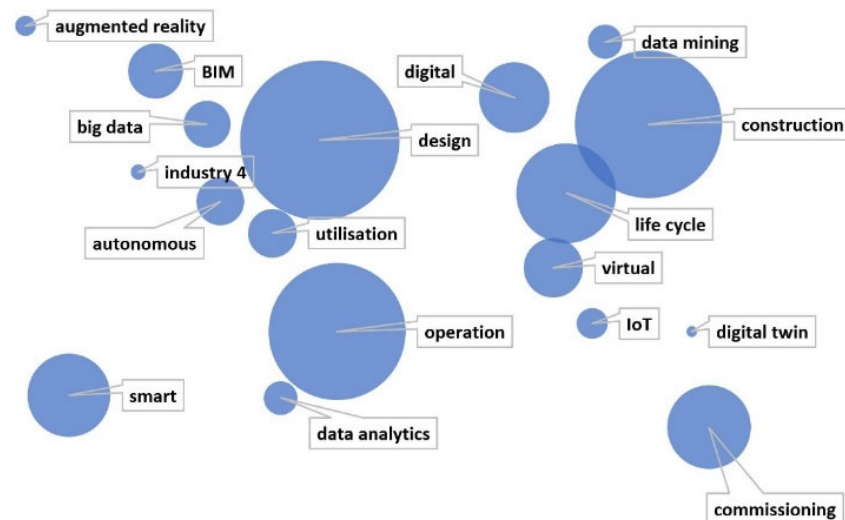
In the first stage of the Model, we performed a scientific literature search SCOPUS and Web of Science databases. We also analyzed the publications of American Planning Association and American Society of Civil Engineers peer-reviewed journals and the announced publications of Organization for Economic Co-operation and Development. Databases were searched by using a combination of various keywords and the criteria for

paper selection including green building, sustainable building, green construction, resource-efficient, a building's lifecycle, COVID-19, energy, water, consumption, health effects, comfort, occupant behaviors, policy, economy, Industry 5.0, energy-efficient retrofitting, and profit. Searches were limited to research published from 1974 up to the date of the search (5 March 2021).

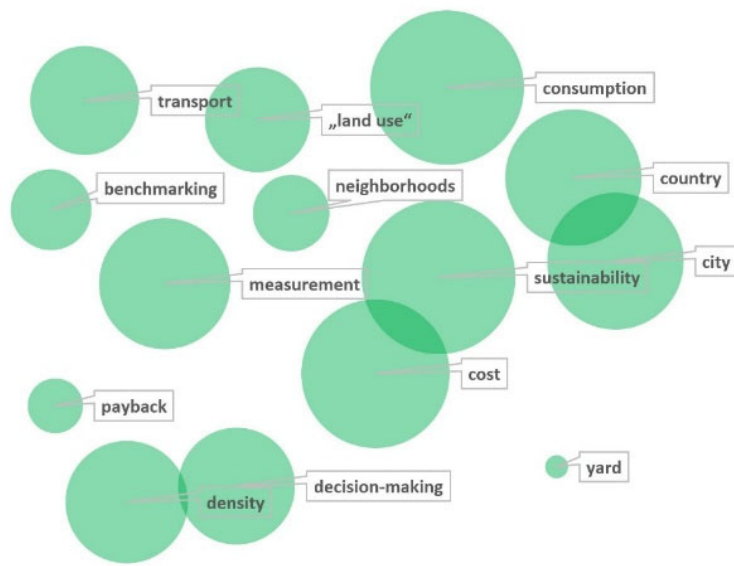
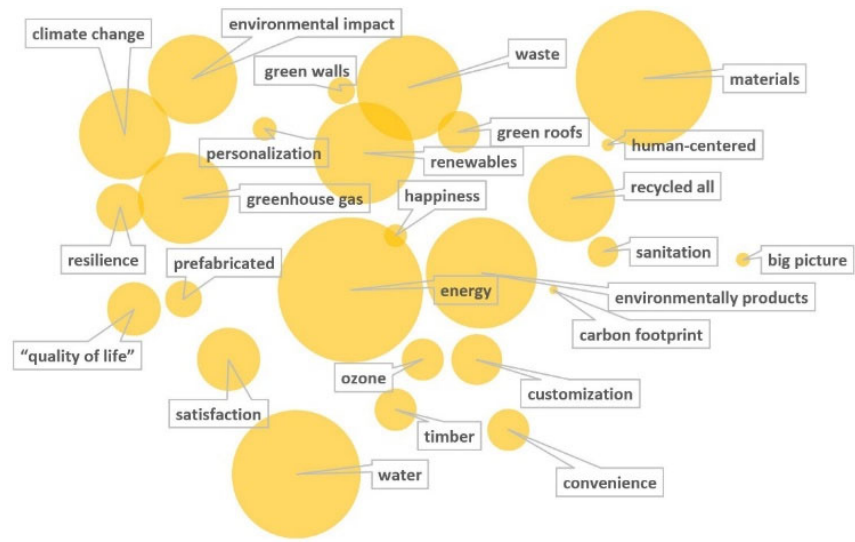
For example, 3477 green building articles were publicized in a Web of Science Core Collection database from 1999 to 2021. The following papers were announced in Web of Science Categories: construction building technology (952), engineering civil (776), environmental sciences (607), architecture (311), environmental studies (298), urban studies (167), regional urban planning (111), public environmental occupational health (63), business (57), computer science artificial intelligence (57), etc. Web of Science Core Collection database green building $H_i = 81$, average citations per item is 10.33, the sum of times cited is 35,906 (without self-citations—27,692), citing articles are 21,089 (without self-citations—19,600). In the analyzed period, in total 1877 articles, 1384 proceedings papers, 162 reviews, 41 editorial material, etc., were printed on green building topic.

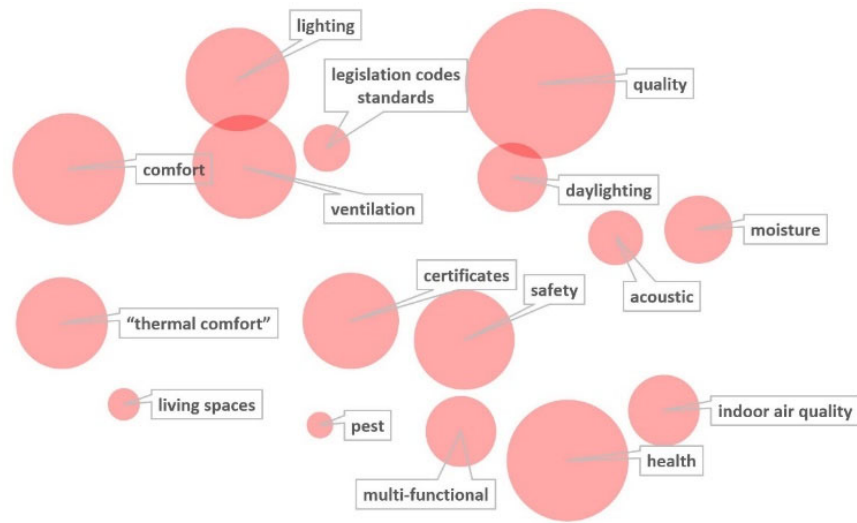
Figure 2 displays a two-dimensional green building map. Its basis constitutes the data from the search SCOPUS database from the second stage of the model. This figure indicates topic similarities as per the manner of their distribution over keywords. The topic label additionally indicates how to best capture the semantics of the top keywords. Figure 2 presents the keywords taken from the search on green buildings in 2019 in a circle. These reflect the following on a green building:

- a life cycle along with the latest information, artificial intelligence and other technologies applied to it (a)
- level of user satisfaction with green buildings and resources and aspects of green matters, environmental protectors, and renewables (b)
- national, city wide, residential area and decision-making dimensions (c)
- green building aspects (d).



(a)



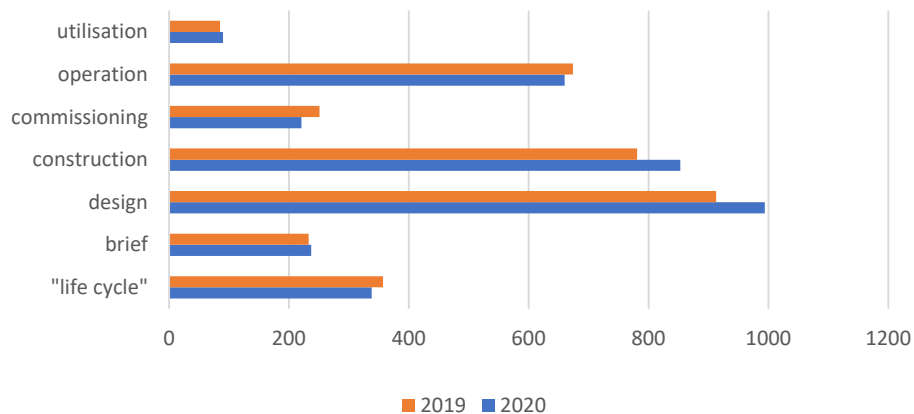


(d)

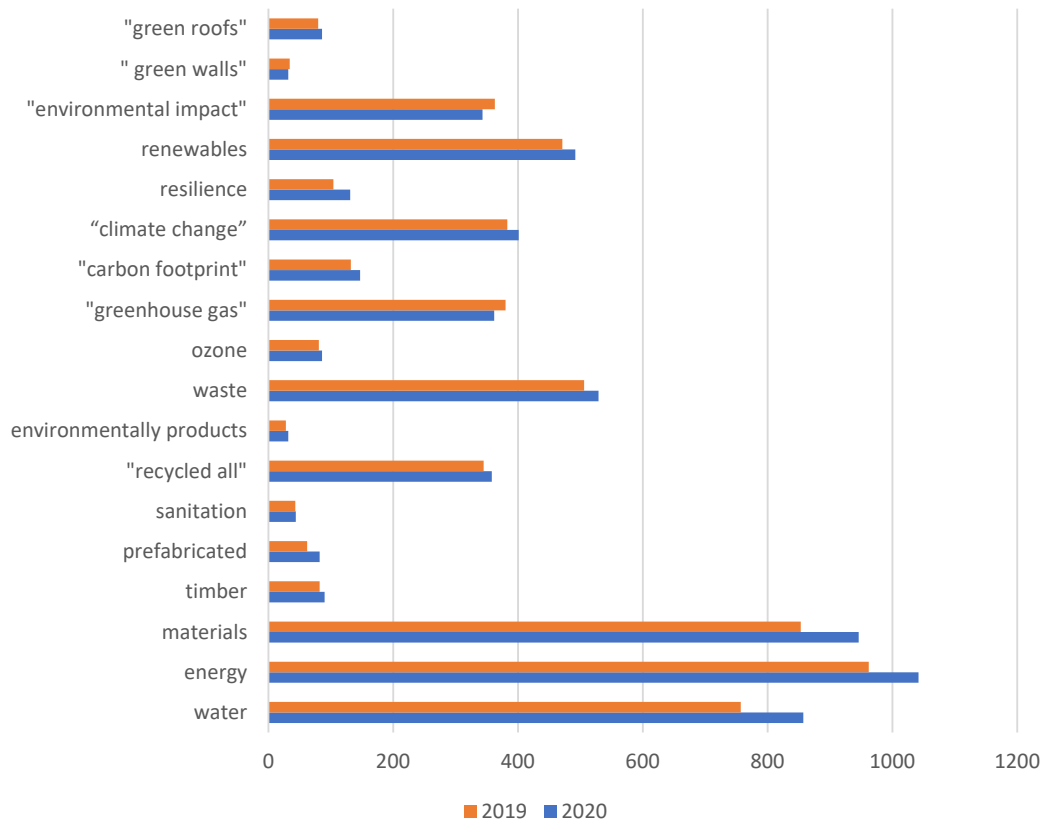
Figure 2. Two-dimensional green building map with circles in sizes indicative of the number of articles published in the Scopus journal database in 2019 according to specific key search words on green buildings. A life cycle along with the latest information, artificial intelligence and other technologies applied to green building (a); level of user satisfaction with green buildings (b); national, city wide, residential area and decision-making dimensions (c); green building aspects (d).

Figure 2 submits circles in sizes indicative of the number of articles issued in ScienceDirect journals in 2019 according to the key search words for specific green buildings.

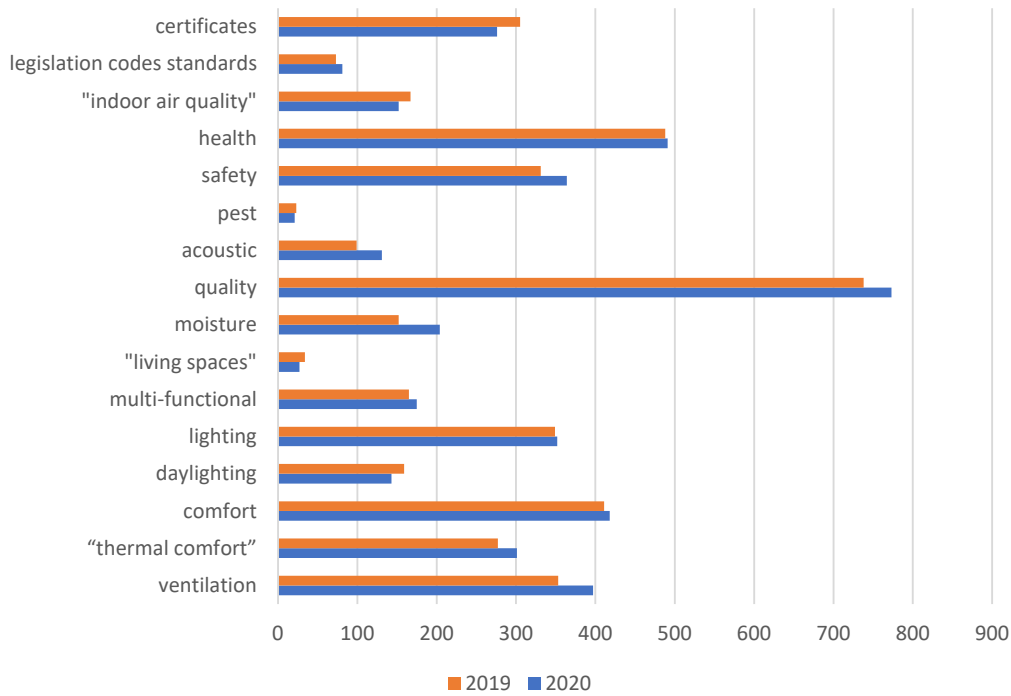
Comparisons of articles published in 2019 and 2020 in the Scopus journal database according to specific key search words for green building during the Third stage of the model. Figure 3 shows the y axis containing the numbers of articles found in the Scopus journal database by year according to specific key words. For example, in 2020, there were 853 articles in the Scopus journal database published according to the key words “green building” and “construction”, whereas, in 2019, there were 781 such articles. The overall number of articles in the 2020 database under analysis increased by 8.5 percent when compared with the 2019 database. Meanwhile, during this same period, the number of articles on green housing increased by 10.5 percent.



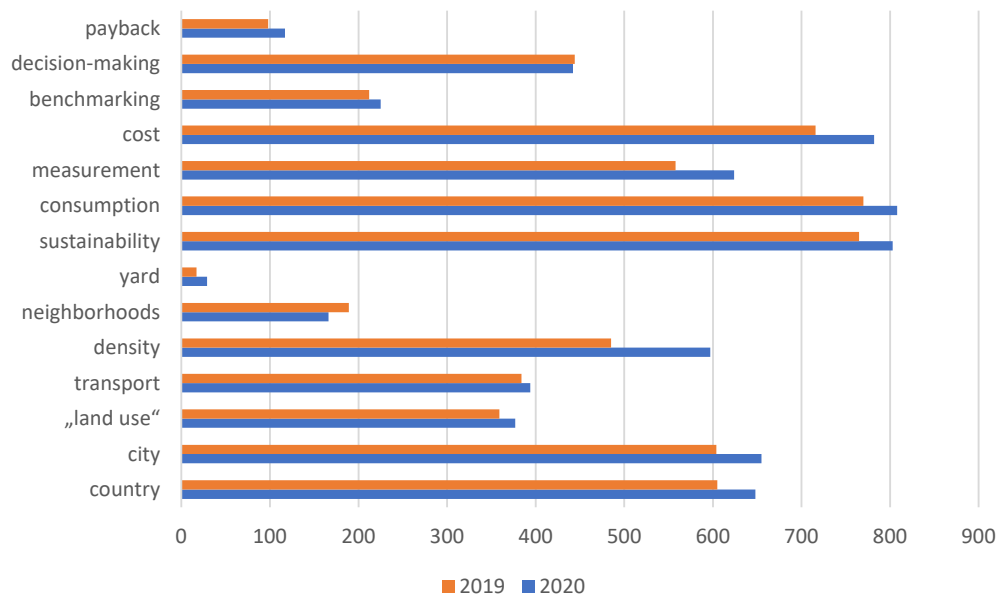
(a)



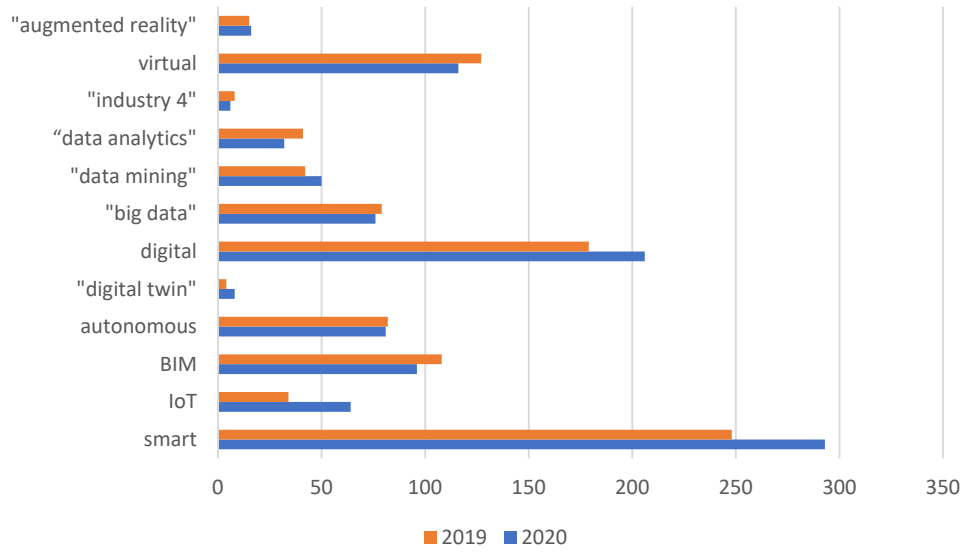
(b)



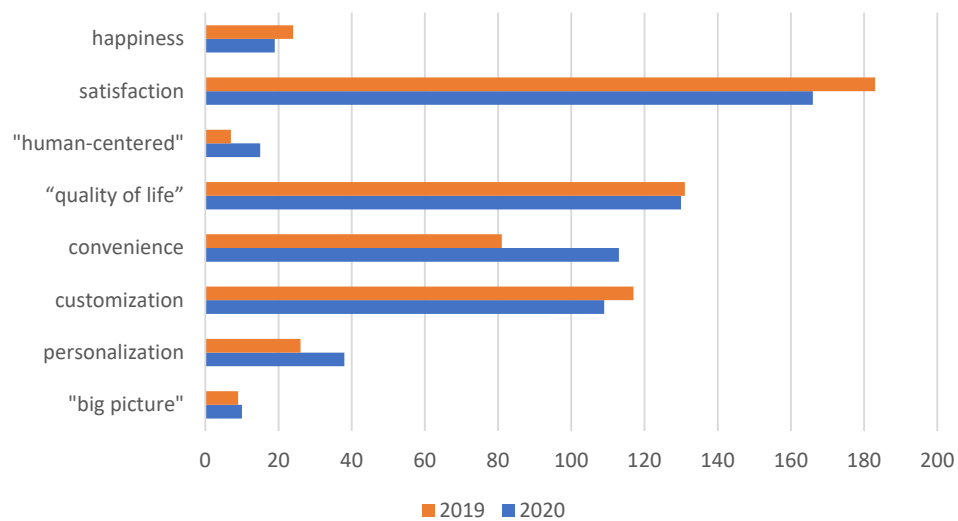
(c)



(d)



(e)



(f)

Figure 3. Comparison of articles published in the 2019 and 2020 Scopus journal databases by key words reflecting (a) Green building life cycle, (b) Resources, green matters, environmental protectors, renewables, and climate change aspects, (c) Green building aspects, (d) National, city-wide, residential area and decision-making dimensions, (e) Applications of latest information, artificial intelligence, and other technologies and (f) Level of user satisfaction with green buildings.

The correlation and distributional hypothesis of topic words was raised and substantiated during the Fourth stage. A qualitative approach to automatically uncover the coherence of a topic are, as proposed by researchers in the field, topic coherence measures [18,19]. Meanwhile the root of the underlying idea lies in the distributional hypothesis of linguistics [20]. Additionally words with similar meanings tend to occur in similar contexts. Whenever all or most words relate with one another, e.g., the leading N words of a topic, then the topics are considered coherent [7]. The distributional hypothesis was also raised during the course of this research that the key words relevant to the green building topic strongly correlate with one another (see Table 1).

Table 1. Strong correlation coefficients obtained between user satisfaction with green buildings, the life cycle of a green building and the national, city-wide, residential area, and decision-making dimensions.

	country	city	"land use"	sustainability	"quality of life"	"human-centered"	satisfaction	happiness	"life cycle"	brief	design	transport	density	neighborhoods	yard
country	1	0.995	0.995	0.996	0.992	0.776	0.991	0.853	0.989	0.994	0.997	0.997	0.991	0.987	0.899
city	-	-1	0.995	0.995	0.989	0.774	0.984	0.856	0.980	0.988	0.996	0.997	0.994	0.986	0.880
"land use"	-	-	1	0.996	0.991	0.777	0.983	0.833	0.986	0.987	0.994	0.996	0.984	0.988	0.902
sustainability	-	-	-	1	0.985	0.726	0.986	0.827	0.993	0.987	0.998	0.995	0.986	0.984	0.900
"quality of life"	-	-	-	-	1	0.781	0.979	0.871	0.972	0.988	0.984	0.989	0.980	0.986	0.888
"human-centered"	-	-	-	-	-	1	0.759	0.710	0.694	0.790	0.751	0.778	0.823	0.749	0.618
satisfaction	-	-	-	-	-	-	1	0.866	0.990	0.993	0.990	0.992	0.984	0.991	0.859
happiness	-	-	-	-	-	-	-	1	0.804	0.875	0.829	0.854	0.862	0.872	0.676
"life cycle"	-	-	-	-	-	-	-	-	1	0.985	0.993	0.988	0.974	0.980	0.891
brief	-	-	-	-	-	-	-	-	-	1	0.991	0.994	0.986	0.990	0.877
design	-	-	-	-	-	-	-	-	-	-	1	0.997	0.991	0.985	0.893
transport	-	-	-	-	-	-	-	-	-	-	-	1	0.991	0.991	0.885
density	-	-	-	-	-	-	-	-	-	-	-	-	1	0.977	0.873
neighborhoods	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.861
yard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Table 1 shows a matrix in which the obtained correlation coefficients were strong between user satisfaction with green buildings, the life cycle of a green building and the national, city-wide, residential area and decision-making dimensions (see Table 1). Analogically strong correlations were also obtained between other key search words. These strong correlations indicate that the key search words were appropriately selected for performing the analysis on green housing before, during, and after the COVID-19 Big Picture analysis. The distributional hypothesis was also confirmed during the progression of this study that the key words pertinent to the green building topic strongly correlate with one another.

The Fifth stage involves compiling a colored, document-frequency matrix. The columns of the colored, document-frequency matrix presented in Table 2 contain key words reflecting user satisfaction with green buildings and the life cycle of a green building. The rows of Table 2 contain the number of articles found in the Scopus journal database by year according to specific key words. For example, in 2020, there were 130 articles published in the Scopus journal database containing the key words "green building" and "quality of life", whereas, in 2009, there were 24 such articles. These numbers appear within the colored cells of the matrix by which the darkness of the color demonstrates the number of published articles, the darker the color, the greater the number of published articles.

Table 2. Key words reflecting user satisfaction with green buildings and the life cycle of a green building as well as colored cells in which the darkness of the color demonstrates the number of published articles (the darker the color, the greater the number of published articles).

Year	" Big Picture"	Personalization	Customization	Convenience	" Quality of Life"	" Human-Centered"	Satisfaction	Happiness	" Life Cycle"	Brief	Design	Construction	Commissioning	Operation	Utilization
2020	10	38	109	113	130	15	166	19	338	237	994	853	221	660	90
2019	9	26	117	81	131	7	183	24	357	233	913	781	251	674	85
2018	5	33	99	60	108	14	162	15	353	211	847	716	257	567	78
2017	13	21	94	66	102	4	148	7	365	191	909	783	253	612	71
2016	5	18	74	54	97	5	119	14	295	180	718	651	205	481	49
2015	2	14	53	50	70	3	103	9	257	128	614	523	178	394	49
2014	3	9	49	38	65	3	74	8	197	108	467	385	147	327	44
2013	6	12	32	30	48	2	52	7	115	86	302	267	118	218	37
2012	5	2	36	30	64	-	59	3	128	92	330	278	122	211	32
2011	4	8	21	21	57	3	38	8	102	65	341	309	94	199	21
2010	4	3	31	24	35	2	44	9	97	63	211	184	99	159	10
2009	1	-	10	15	24	1	14	1	47	28	108	95	41	77	11
2008	1	3	16	5	18	-	24	3	56	51	132	109	57	84	15
2007	-	3	9	5	10	-	6	3	26	28	80	57	33	48	8
2006	1	1	6	5	9	-	18	2	55	25	113	87	45	70	1
2005	1	-	2	6	6	-	6	-	24	11	46	32	13	21	2
2004	1	-	1	1	4	-	3	-	7	6	26	22	11	11	1
2003	-	1	1	1	2	-	2	-	3	9	22	17	10	12	1
2002	-	1	1	1	4	-	1	-	6	3	23	22	7	10	5
2001	-	-	1	1	2	-	3	-	6	2	14	11	3	6	-
2000	-	-	1	-	1	-	-	-	6	4	12	12	3	7	3
1999	-	-	2	1	2	-	1	-	3	1	7	7	2	5	1
1998	-	-	1	-	-	-	1	-	1	-	5	4	1	2	-

The interlink between green housing and COVID-19 was methodically studied during the Sixth stage of the model to test the hypothesis regarding the interactions between COVID-19, the housing COVID-19 policies of relevant countries and cities and the behaviors of their residents along with their demands for green housing. Two hypotheses were raised during the Sixth stage:

Hypothesis 2: *COVID-19, housing policies of countries and cities during COVID-19 impact green housing, and the wellbeing of their residents; additionally the residents and a housing policy impact the dispersion of COVID-19.*

Hypothesis 3: *A green building analysis is markedly more effective, when the life process of a green building along with the interest groups participating in it with goals they wish to implement of their own, the COVID-19 situation and the external micro- and macro-level environments are comprehensively analyzed as a single entity.*

The validations of these hypotheses were performed by analyzing the scientific literature worldwide and a statistical analysis of appropriate articles in the Elsevier ScienceDirect bibliographic database. The scholars of this research integrated research design enrichments to derive greater reliability of the hypothetical relationship between COVID-19, the housing policies of pertinent countries and cities, and how their residents behave pertinent to their

green housing demands. The validations of these two hypotheses were performed by applying scientific literature (see Sections 3–5) and statistical (see Section 2) analyses.

The establishment of green housing trends both on the micro- and macro-scope was performed by applying an analysis of scientific literature (see Sections 3–5) during the Seventh stage of the model.

The numeric data obtained pertinent to the presented conclusions were made based on the Green Housing Topic Model.

3. Sustainable Housing

3.1. *Changes in the Way of People and Communities Live, Interact, and Work, and the COVID-19 Pandemic*

The number of publications about COVID-19 on Web of Science (WoS) has been growing this year and more than 6000 references are now available, as it has on ScienceDirect where more than 8000 references can be found, but, in both cases, less than 1% of them deal with buildings or the built environment. A more focused research, however, shows that various journals published articles dedicated to the built environment in the context of the COVID-19 pandemic, analyzing potential preventive measures or discussing this issue through the lens of sustainable development [21]. However, from another viewpoint, every service unit has needed greater consumption of energy, water, and cleaning products due to the reduced capacities of outside services, e.g., the schools, shops, and restaurants that have ceased being users [21].

Lockdowns have changed the way people and communities live, interact, and work, and the COVID-19 pandemic reminds us the necessity to make the built environment resilient, including outdoor spaces, but especially homes, offices, entertainment facilities, public buildings, and other indoor spaces. How can the concept of public health and wellbeing be adjusted to the context of a future with evolving and transformed living places? Learning from this period of physical distancing, this research integrates wellbeing and hygiene in buildings, highlighting possible responses both for new and existing buildings. The following key categories of public health and wellbeing recommendations for sustainable, safe, and healthy housing have been selected: water consumption and wastewater management; solid waste management in cities; sharing, adaptability, and flexibility of living spaces, ensuring enough space per person, and adding compliant functions to buildings; reclamation of the basic archetypes and principles related to indoor air quality, thermal comfort, and sustainable architecture; visible and accessible green spaces and elements; electromagnetic fields and housing automation; building and décor materials and products for interior design. The recommendations from the aforementioned categories can serve as a basis for local health agencies, public health experts, policy makers (tax incentives tied to building refurbishment), and designers in speaking up for policies and actions aimed at promoting and maintaining physical and mental wellbeing in healthier living places [22].

The spread of SARS-CoV-2 with its extended lockdowns, school and university lectures moving online, and millions of people forced to turn to teleworking and spend most of their time at home has changed the way of life in home spaces. The pandemic has also made an impact on real estate values, with some characteristics becoming more desirable, while others falling out of favor. A group of university researchers present their ideas in this brief study. They are experts in public health and architecture-related health issues and have been addressing the health problems related to modern urban life and homes for many years. This aim could promote closer and broader scientific links between medicine and architecture to improve the wellbeing of people in any environment, with emphasis on urban settings [23].

When, on 11 March 2020, the World Health Organization (WHO) declared the COVID-19 outbreak a pandemic, the Italian Government imposed severe lockdowns with

extremely restricted movement. As people were forced to stay indoors, all their life happened at home where they ate, slept, exercised, worked, socialized, and engaged in other activities. Evidence shows that housing is a significant determinant of health. The lockdown measures related to COVID-19 response and their impact on mental health and wellbeing are, therefore, an interesting area to explore. In Europe, Northern Italy has been one of the most affected regions by the pandemic, and the authors of this study carried out a large online survey of 8177 students from a university institute in Milan. Our analysis shows a link between poor housing and higher risk of lockdown-related depressive symptoms. Among surveyed people, those reporting a drop in performance when they work from home were more than four times more likely to report depression as well. Housing design strategies should focus on larger and more livable living spaces facing green areas. Authors argue that a stronger multi-interdisciplinary approach is needed to investigate the ways the built environment can affect mental health. Such approach, where sociology, epidemiology, public mental health, environmental health, and urban planning intertwine, would benefit decision making and inform housing and welfare policies aimed at ensuring the wellbeing of people [24].

The COVID-19 pandemic has changed many aspects of our life and is offering an opportunity to change the way we design our living spaces. A comfortable and healthy home is an important contributor to mental and physical wellbeing. Based on the latest documents, including peer-reviewed papers, news, media articles, blog posts, and expert opinions, this study presents a critical review of COVID-19-related lessons and looks at changes in the sustainability requirements for residential buildings that can be expected. Lockdowns tested the three main aspects of residential buildings, i.e., comfort, environment, and health and safety. A major overhaul of these aspects towards sustainability is expected. Proper sanitation to diminish the probability of getting infected, new touchless technologies, and greener and more intimate spaces for better mental health are just a few solutions that can improve health and safety protection in our homes. The lockdowns have resulted in much greater consumption of household energy globally due to the increased time people spend at home. One example is the 30% increase in energy consumption during the daytime, as per U.K. statistics. These sorts of spikes in use had occurred during mornings previously, when people would be getting ready to go to work. U.S. statistics show an overall increase in household electricity use of up to 8% during lockdowns. Another key topic during the pandemic is waste management because waste must be kept apart to prevent virus transmissions, since viruses can survive for 3–4 days on different surfaces [25].

It is widely accepted that health and housing are related. In Victorian England, for instance, people hypothesized links between poor housing and ill health and were looking for solutions; indeed, better sanitation and slum clearance did much to improve health. Soon many countries followed suit, Italy among them. A growing body of knowledge about infectious diseases and illnesses made people more aware that the quality of housing is an important factor for physical and mental wellbeing. This has been recently reaffirmed by the WHO and vividly reminded by the COVID-19 pandemic. The built environment, and in particular housing, where people spend lots of time, is a significant source of indoor pollutants, especially in bad-quality housing generally occupied by very low income households. WHO 2011 estimates attribute 13 deaths per 100,000 inhabitants to low indoor temperatures, 2–3 to radon, and 7 to environmental tobacco smoke (ETS) per year globally. In terms of disability-adjusted life years (DALYs), 40 DALYs per 100,000 children are annually lost due to mold in homes, 577 DALYs per 100,000 children younger than five are caused by solid fuels as an energy source in homes, 31 DALYs per 100,000 inhabitants are lost each year due to traffic noise exposure, and 22 DALYs per 100,000 inhabitants due to lack of home safety features. The use of solid fuels in homes is also responsible for 17 deaths per 100,000 children [26].

COVID-19 lockdowns attended by economic shutdown and social isolation have disrupted individual lifestyles and society's priorities with serious sustainability implications. Grounded planes, as well as lower vehicle traffic flows and industrial activity reduced society's ecological footprint, as homebound families turned to non-commercialized leisure modes and social interactions. However, social isolation has hit mental and physical health, and economic recession has also caused adverse effects exacerbating issues of underconsumption and poverty [27]. The pandemic, as some sustainability researchers believe, could potentially speed up the progress towards a future of more social fairness and better environment protection [27,28]. We have been given a rare opportunity for putting together a sustainable transition towards broadly-adopted low-carbon solutions with both shifts in individual lifestyles and systemic-institutional reforms driven and implemented by multiple stakeholders [27,29]. The changes caused by COVID-19 are a source of both worry and hope for organizations engaged in the advancement of sustainable development. The source of hope have been palpable short-term environmental benefits such as pollution decreases [27,30] brought about by government measures. These events have demonstrated that policy makers can and have the will to introduce systemic changes away from an endless work-spend cycle and non-stop consumerism [8,31]. Unfortunately, counter-pandemic measures have also led to adverse effects with serious sustainability consequences: they have unsettled sustainable development goals reversing, for the first time in 30 years, the progress towards lower poverty and misery [27]; deprived millions of children of access to education; led to social isolation to the detriment of mental and physical health [27,32,33]; and undermined the efforts to make people less dependent on the use of plastics [8] and individualized modes of transport [34], among others.

Faced with the devastating COVID-19 pandemic, people were suddenly forced to change many aspects of their usual lifestyles—an unprecedented event. However, besides adverse effects, the COVID-19 pandemic can also push individuals towards environmental responsibility. The authors of this study provide a comprehensive analysis of shifts in pro-environmental beliefs and behavior catalyzed by the COVID-19 pandemic with a focus on the comparison between recycling and consumption reduction pre-COVID-19 with intentions post-COVID-19. The authors analyze a survey conducted during the national March–April 2020 lockdown imposed in Israel and validate the behavioral model using a generalized ordered probit estimated on a sample of 296 respondents. The findings show that shifts in behavior towards pro-environmental approach are driven by threat and coping appraisal [35].

To contain the spread of a new and unknown highly contagious virus with relatively high mortality rates, humanity seems to have no choice but to limit social contacts and put an emphasis on personal hygiene. The pandemic has hit a heavy blow to the world economy; the energy sector suffered as well. As people are forced to stay at home, energy and water consumption in the residential sector has gone up. Using EnergyPlus software packages (U.S. Department of Energy's (DOE) Building Technologies Office (BTO)), this study looks at a household in Kragujevac, Central Serbia, and analyzes four simulated scenarios for the month of March 2020 to discover correlations between the way people behave and the residential consumption of natural gas, electricity, and water in unforeseen circumstances, such as the COVID-19 pandemic. The behavior of people was tracked at a one-minute time step, taking into consideration the number of household members, their habits, occupation, age, lifestyle (in line with socio-economic and cultural circumstances), and the pandemic-related measures taken by the Government of Serbia. Energy consumption at the level of Kragujevac for the past three years has also been analyzed, based on the data available from public utility companies distributing natural gas, thermal energy, water, and electricity, as has the quality of air for the same time period, in view of its dependence on mobility and energy consumption patterns [36].

All areas of socio-economic life have been affected by the COVID-19 pandemic and the world has been changing rapidly in recent months with concerted efforts focused on ensuring public health, and then, in the next phase, looking for means to jumpstart economic recovery by resuming the human activities. Adequate housing has proved to be an important means of ensuring the well-being and health of the population. At the same time, housing is a point of stability from which all efforts start. This research, based on data provided by the National Institute of Statistics, the Quality-of-Life Research Institute, Eurostat, and reports from specialized European organizations, aims to call attention to a number of housing affordability problems in the general picture of housing at the national level in Romania, looking at both the issues that existed before and new issues related to the COVID-19 pandemic. The role these issues play in access to affordable and adequate housing is analyzed, the emergence of new risk groups with limited access to housing discussed, the impact of the pandemic on the ability of households to pay their bills examined, and evidence that the effects of the crisis amplify housing insecurity provided [37].

3.2. Necessary Changes in Built Environment during the Pandemic towards Sustainable Living

The COVID-19 pandemic forced people to stay indoors and work from home, but even before this health crisis they spent around 90% of their time in buildings. We need a radically new take on the design and operation of buildings. When Indoor Environmental Quality (IEQ), which directly affects the well-being and comfort of occupants, is compromised, occupants become more exposed and vulnerable to many diseases that can be exacerbated by both economic and social factors. The estimated annual cost linked to sick building syndrome in commercial workplaces is between \$10 billion and \$70 billion in the United States alone. We need to understand ways we can ensure proper design of parameters that drive IEQ, as well as ways to operate buildings achieving ideal health-benefiting IEQ. IEQ offers many research opportunities, but now more than ever we need a systematic understanding of the way IEQ factors work for or against occupant health. Extreme events, a global pandemic among them, call to provide occupants, facility managers and designers with pragmatic guidance on ways to mitigate health risks in buildings. This research gives answers to ten questions related to the effects of buildings on occupant health and can serve as a basis for future work offering insights for new lines of research and discoveries [38].

In research on housing, one of important parts is looking at health-related aspects in indoor environment. This research presents an overview of the latest research on occupant health evaluation in residential buildings and examines some of the key impacts people experienced during the lockdowns. The authors analyze satisfaction and dissatisfaction across ten UK housing typologies, representative in this and other contexts. Lack of regular physical exercise, lack of vitamin D from sunlight, excessive food consumption, mental health, lack of good air circulation indoors, and issues with indoor air quality are the general health concerns in this extended period of lockdowns and restricted mobility. Excessive noise from upper floors in blocks of flats or from shared walls and gardens/communal spaces in closely-spaced residential areas, and issues of privacy to maintain social distancing measures are the other concerns discussed. Accessibility to the nearest outdoor spaces (a backyard or garden), noise and privacy issues, adequate indoor air circulation, adequate natural indoor lighting, opportunities to do physical exercises, and impacts on general health are evaluated. The earlier reports from various housing studies suggest that user satisfaction is important in indoor environments. As the COVID-19 pandemic hit, this field of research seems to have grown in importance as people are forced to spend long hours indoors and their thermal comfort and general comfort have to be maintained [39].

A year has already passed since the first cases of COVID-19 were detected and the novel SARS-COV-2 virus identified. The world has responded with a range of decisions. A few of the things we have learned from this complex COVID-19 crisis with interlinked political, social, public health, and economic dimensions, testing the world's ability to take measures, have a direct relevance to the climate crisis we are facing and our aims to

achieve broader advances in sustainable development. First, the scientific community actively contributed to the handling of the COVID-19 pandemic and proved its ability to generate great quantities of new practical knowledge in a record short span of time. By 13 October, Pubmed, a database of research papers focusing on health sciences and biomedicine, offered over 63,000 hits for the search term “COVID-19” and the number of publications keeps growing. The number of search hits for “climate change” is, in contrast, only 53,000 papers since 1975—a sign of huge differences in scientific and societal priorities. However, faced with a sense of urgency, priorities and incentives can be aligned to push the scientific community towards producing new knowledge on climate change at the same pace and scale as in the case of COVID-19. Second, COVID-19 has shown that scientific research needs robustness even when we face an emergency. Hasty research of poor quality risks contributing more noise than actionable knowledge and can mislead public opinion or decision makers on vital issues; the Retraction Watch database has so far identified over 35 retracted COVID-19 publications. Third, COVID-19 has been a notable example of blurred lines between science and policy, at least in countries where leaders were keen to base their decisions and communication strategies on science, rather than disregard it. COVID-19 is striking not only because of the scale and pace of scientific production—the speed of putting new knowledge to action has also been impressive. Nonetheless, mere behavior changes among people during the COVID-19 period has been shown to be insufficient. Governments must engage in ambitious and sustained policies in their pursuits of structural emission reductions. One such example might be an acceleration pertinent to the development and deployment of cleaner energy [40].

The natural environment can suffer negative effects from construction activities and the concept of sustainability has, therefore, been introduced in the construction industry. The construction industry, according to the United Nations Environment Program, generates 33% of CO₂ emissions, 25% of waste production, and 30% of all annual waste products. It is, therefore, important to ensure sustainability in residential buildings with an aim to reduce air pollution and greenhouse gas emissions and improve the quality of life and health outcomes. The drive towards sustainability in construction and buildings creates new jobs and business opportunities, boosts energy security, and productivity, and has also resulted in the promotion of assessment systems to increase sustainability, declarations to preserve the environment, and the development of various international policies [41].

Sustainability is an integrated part of construction processes and the building itself, and construction companies have a range of building sustainability assessment tools (BSATs) available to promote economic, environmental, and social sustainability by meeting design and construction requirements. The number of registered tools is currently more than 400 [42]. Over the last three decades many green buildings have been certified, and each new case makes the issue of the development of sustainable residential buildings more prominent, starting a virtuous circle. The Leadership in Energy and Environmental Design (LEED), the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), the Building Research Establishment Environmental Assessment Method (BREEAM), and the Wellness (WELL) Building Standard are already established and recognized green building certification systems (GBCSs) that assist the construction industry in mitigating the environmental impact of buildings and achieving better performance throughout their lifetime [43]. Most of these certification systems, however, have been designed with a specific region in mind and different climate conditions, geographical features, and government policies may lead to sustainability differences across regions [41]. To address this issue, many researchers are already trying to transpose recognized green building rating systems to developing countries adapting them to their specific features, with examples ranging from Kazakhstan [44] and Iran [45] to countries in sub-Saharan Africa [46] and Qatar [47]. Rapid changes in the living conditions around the globe mean that existing green building rating systems need to be constantly updated in this respect, too. The COVID-19 pandemic and the related lockdowns hit our societies everywhere, disrupting almost every part of daily life, including business, lifestyles, healthcare

systems, education, economy, and tourism. Such unexpected changes, with people stuck at home for long durations, brought us to a new reality. This new reality should be analyzed and taken into account in future decision-making. Since the COVID-19 pandemic and the changes it brought will likely stay with us even when the pandemic is over, many people in academic circles are re-examining the current sustainability approaches pushing towards new horizons [41]. Mohammadian et al. [48] argue that four new sustainability pillars, directly or indirectly interrelated, namely, educational, cultural, technical, and political ones, should be added to the conventional group of three, which includes economic, environmental, and social pillars. Other researchers state that the main focus in LEED, BREEAM, and other current sustainability rating systems is the environmental aspect of sustainable development (indoor environment, and energy), whereas the social aspect lacks proper attention [49]. Possible effects of the current pandemic on the short-term and long-term transition of sustainability have been analyzed by Kuzemko et al. [50]. They predict a fall of electricity prices and demand in the energy sector. Investments could move away from current industries and carbon-intensive fuels. Globalization and interconnectivity conventions could be challenged, leading to changes in politics and multi-scalar policies. The pandemic could also be an opportunity and impetus to move away from unsustainable practices towards more sustainable ones, for example, to exchange driving for walking. It is not the first epidemic to leave a mark in the built environment: cholera and plaque pushed towards the development of green spaces and new wastewater routes; a fight with tuberculosis led to the increase of sunlight in housing units; and the SARS-COV-1 outbreak led to the improvement of ventilation systems [21,41].

4. Green Housing

The real estate industry was severely affected by the COVID-19 in both the residential and the commercial sectors due to travel and site-visit limitations, rent sustainability issues, and a decrease of or higher uncertainty about disposable income [51]. The real estate market, as for other productive and commercial sectors, in the short and mid-run, will not tend to move independently from the context of economic variables [52]. During the lockdown, houses became more important. It can be assumed that household preference of a new demand could emerge after this crisis making households looking for more comfortable houses since this asset will increase its importance for living and working. Similarly, the commercial real estate sector will change due to lower rent sustainability. However, the main expected change is related to the building type and the standards requested by tenants in the new economic environment. Household investment prospects will change. Housing demand will need products (new or recovered) suitable for the times—high-quality properties capable of offering a safe and healthy living and working environment. The COVID-19 emergency highlighted that domestic spaces have become obsolete from a functional point of view, especially in current times of smart-working and minors being forced into social and home isolation due to unpredictable health emergencies. Residential and office real estate sectors, once distinct, today tend to overlap with each other. The housing market will be stable, but the change in commercial real estate markets will accelerate [53]. For real estate and property owners and users, there may be changes in credit usage, rental, and contracts.

COVID-19 put the spotlight on health protection in buildings [54]. Existing efforts combined with new transformations may help address urban health inequalities stemming from socio-spatial structural injustices for the benefit of cities and all their residents to make them better prepared for, and more resilient to, COVID-19 and other similar crises we may face in the future [55].

Tokazhanov et al., argue that the COVID-19 pandemic has given us lessons, and changes in sustainability requirements for residential buildings should be expected and evaluated [25]. After COVID-19, new designs of living spaces may be introduced in sustainability requirements for residential buildings with emphasis on protective indoor

health and safety measures, more intimate and greener spaces, new touchless technologies, better communication technologies for remote services, and improved control of light, humidity, air quality, temperature, etc. For now, the building sustainability rating methods in existence have primarily favored “environmental impact” and “energy performance”. A significant shift is expected towards an emphasis on “social and health” aspects. The authors suggest sustainability requirements for residential buildings need a review with a marked shift towards “social and health” aspects in sustainability rating methods for buildings, possibly with the support funds from expected COVID-19 stimulus measures for construction and current, as well as future green stimulus packages. Sustainable technologies mainly need to tackle the specific issue of improving the record regarding increased consumption of energy and water as a response to environmental needs. “The development of novel building codes and green certificates for the post-pandemic residential buildings and/or the modification of existing codes and certificates considering particular pandemic needs” are seen as future efforts driven by requirements with a view to resilient design solutions and possible pandemic scenarios [25].

To cover special pandemic-related requirements, this research [41] proposes a particular set of sustainability indicators. The focus on particular sustainability pillars is different in various GBCs (BREEAM, LEED, WELL, and CASBEE), as has been their response to pandemic resilience requirements. Some green certificates (GBCs) have placed a lot of attention in a human-centered assessment of the sustainability of both residential and non-residential buildings and a reflection on the benefits of green buildings in the COVID-19 period is addressed [56].

Insufficient readiness for waste and wastewater management has been noted in all GBCs and they all need modifications to improve their adaptability to pandemic conditions in line with existing and emerging post-pandemic requirements. A realization has dawned that modern life is possible without drastically harming the environment. It has involved taking a look at what the globe might look like without the use of fossil energy sources. This has encouraged hope that people could survive this pandemic while ending up in a healthier, cleaner world [41].

Air pollution, air quality improvements, wildlife, global migration, sustainability waste management, and waste fires were the focus of the researchers [53] who analyzed a summary of the existing reports on the impact of the COVID-19 pandemic on the environment. Many regions—Italy, France, Spain, Los Angeles, and Wuhan in China among them—observed a noticeable drop in air and water pollution. The crisis saw a rapid growth in health waste threatening the environment [53].

An analysis of occupant health in buildings by Awada et.al [38], covering both normal times and extreme events, the COVID-19 pandemic among them, shows that undermined Indoor Environmental Quality (IEQ) may expose occupants to a higher risk of catching many diseases exacerbated by both economic and social forces. The estimated annual cost linked to sick building syndrome in commercial workplaces is between \$10 billion and \$70 billion in the United States alone. During a global pandemic and other extreme events, occupants, facility managers, and designers need pragmatic guidelines on ways to reduce health risks in buildings. An interdisciplinary approach may help, and common standards and frameworks should be established with occupants rather than the building as the main focus. We should find ways to design buildings that support health and happiness [38].

The ability to recreate in public green spaces was seriously affected by the COVID-19 pandemic. To compensate this restriction and feel like they are away while at home, people turned to houseplants and outdoor green views. Research shows that exposure to more greenery had positive effects on the mental health of students forced by COVID-19 to spend most of their time at home [54].

The COVID-19 pandemic has hit many industries, with solar energy among them. Malaysia, in its efforts towards low carbon society beyond COVID-19, has plans to install rooftop solar panels, new grids, and LED street lights and earmarked about US\$2.9 billion for that purpose. To accomplish this vision, the government, businesses, and small players

should work hand in hand [55]. Consequently, this article has undertaken a review of the current status pertinent to renewable energy in Malaysia. Furthermore it also reviews the initiatives taken to promote solar photovoltaic (PV) technology before the pandemic for meeting energy demands via a low-carbon pathway.

Energy demand is often uncertain, and the COVID-19 pandemic has only made things worse. Researchers [56] investigate the impact of the COVID-19 confinement measures on energy demand in buildings and use Urban Modelling Interface to simulate various scenarios. The COVID-19 outbreak comes in waves and a few more of them are possible. We should prepare for their impact by understanding related seasonal energy patterns and performance and with appropriate new policies able to withstand future long-term shocks. It is vital to set new building standards for extreme crisis conditions with guidelines for building design, ventilation rates, and lighting/equipment power density in an effort to support city—or even region-level policymaking for planning new areas, their energy supply systems and infrastructure, design of confinement measures, and energy system options to make sure different buildings will not be short of energy [56].

Urban design will inevitably be affected by the current COVID 19 pandemic highlighting the need for scalable smart city solutions, emphasizing the importance of public health and safety and exposing the need to invest more in public health care and infrastructure in the built environment [57]. This study [38] shows that architecture and urbanism have a potential in epidemics control and prevention and can actively contribute to human health. The authors investigate links between the scale in the built environment, epidemiology, and proxemics, as well as between population density and mortality rates. Solutions through architecture and urbanism are possible at multiple levels from individuals to shopping, transport and mobility ideas. They can be individual distancing and isolation; building-scale hygiene solutions; humidifying, ventilation, and filtering for indoor air control; social interaction solutions in the form of public spaces between buildings; intermediate housing; the scale and distribution of remote work; smaller shops closer to home; autonomous taxis, shared rides, bicycling, and walking; and mixed solutions spanning entire neighborhoods. We need to determine the role for architecture and urbanism in pandemic-related social resilience management.

Kapecki [58] examines the impact of humanitarian, financial, and environmental crises on sustainable development with a focus on housing. Crisis-hit economies, at local scale or globally, suffer economic, ecological, financial blows, and now, because of the latest COVID-19 crisis, a humanitarian emergency. Because of that the development of a sustainable economy, and sustainable construction in particular, is left on the sidelines [58].

The author believes that this catastrophe will teach us a lot and will leave us more open to all activities. Among the activities, sustainable construction should play an important role. In the housing industry, green and sustainable, energy efficient construction so far makes only a small share of total residential construction, but in public buildings sustainable construction has dominated the market. There are wide gaps between residential and public construction and lack of green housing may make competing with the achievements in public architecture difficult. As countries imposed lockdowns one after another, some of them plunged into economic stagnation. The lockdowns also revealed a lack of safe housing so important for survival during the pandemic [59].

5. Countries, Cities, and Housing in the Era during and Post COVID-19

There would be considerable benefit in having more interdisciplinary researches focusing on the analyses of three-way interactions pertinent to COVID-19. The interest is on the impact the related housing policies of countries/cities have on green housing and the betterment of the lifestyles for their residents. Conversely, it is also important to investigate how the residents themselves as well as the housing policies impact the dispersion of COVID-19. Such analyses need to treat all the named components as interacting and, thereby, have an integrated methodology as their bases.

5.1. Real Estate Policy in Countries and Cities: Responses and Challenges

COVID-19 disrupted the normal flow of life in the United States, with state and local governments issuing orders to stay at home and allowing only essential businesses and services to stay open. Communities across the country were affected. With no vaccines or medical treatments available, social distancing interventions were a necessary move to contain the virus, but they also meant crushing economic costs to businesses and people. Among the direct impacts are job losses, reduced hours and incomes, food and housing insecurity, and permanently closed businesses. Even ordered to stay at home, people still could go out for outdoor exercise. In their effort to give residents spaces for safe exercising (and commuting) in view of the two-meter social distancing recommendation, several cities, including New York City, banned vehicular traffic from certain streets leaving them exclusively to pedestrians and bikers. New Yorkers were offered about 11 kilometers of open streets in and around parks. Recently the city announced new plans to add 160 more kilometers, add additional bike lanes and widen sidewalks in May. Similar measures have been introduced in Seattle, Oakland, and San Francisco [60].

Some experts even suggest that telework becoming a new normal will make living in a large city less desirable and people, no longer attached to their old offices, will prefer less populous, and thus more affordable, places. Politico, a political journalism company, published an article titled “The Death of the City”, which argues: “For the first time since the earliest cities emerged in the Fertile Crescent some 6000 years ago, concentrated urban centers no longer have a monopoly on the economic and cultural connections that make civilizations tick forward” [61].

In an attempt to make tenants, and sometimes landlords, less burdened, many countries have introduced changes in their real estate policies [62]:

- The United States is a country where state and local authorities are in charge of many decisions, and evictions have been temporarily prohibited in at least 34 states. The federal government also prohibited evictions from a property with a federally backed mortgage loan or federally subsidized housing for a term of 120 days. Citigroup, JPMorgan Chase, and other major mortgage lenders suspended mortgage payments. Construction has been suspended on all projects in some U.S. states, with a few exceptions, medical facilities among them.
- Some countries in Europe are providing temporary mortgage relief, have suspended evictions or both, France, Germany, Italy, and the U.K. among them. Mortgage and rent payments have been suspended both for commercial and residential tenants in various European countries. France, Italy, and other countries have suspended construction. Official tax reliefs have been granted to retailers in Europe, while banks have been urged to be lenient and refrain from foreclosures for late payments.
- Some countries in Asia, Singapore among them, are thinking of new laws to grant six-month protection to commercial tenants who cannot pay rent. Some Asian landlords have offered temporary rental rebates and rent discounts.

Tenants, owners, and other entities have been offered a range of support measures around the world. These include a freeze of rent increases, rent reductions, suspended evictions, rent payment subsidies, and rental contract extensions for tenants; deferred taxes, suspended foreclosures, assisted bank lending, mortgage forbearing, and mortgage payment support for owners; and, in general, emergency shelter, support for construction industry and utility bill payment support [63].

In response to COVID-19, countries introduced a range of crisis-response measures in their housing policies, such as suspended or limited rent payments, tax reliefs for mortgage borrowers, suspended evictions or extra rules regulating landlord–tenant relations, eased macroprudential policy settings, expanded public capital spending on affordable housing supply, increased housing allowances, and relaxed land-use restrictions. Main-

tained for a long period, these measures may discourage from the expansion and maintenance of the housing stock, and put barriers restricting mobility, both labor and residential, in the longer term. Financial and economic resilience may also suffer [63].

In the ongoing COVID-19 crisis, cities are the first line of response. Measures are introduced nationally, but each city is a key to their implementation. They also act as laboratories of innovative and bottom-up recovery strategies. The shift towards green, inclusive, and smart cities was already in progress before COVID-19, but the pandemic has sped up this trend. In our efforts to build back better cities, this policy note offers 10 key lessons learned from the crisis [64]:

1. Various countries suffered different impacts from COVID-19, but policy responses were often very similar across the world. It is important to customize approaches with local situation and the needs of local people in mind.
2. The health crisis has hit economic and social life hard with various cities suffering different consequences. Their recovery options and possibilities depend on their openness to trade, labor market structure, and industrial composition.
3. A shift from the emphasis on increasing mobility towards expanded accessibility was already happening, but this rediscovery of proximity offers an opportunity to speed up the process by looking at urban design and planning and public spaces from a new angle.
4. The pandemic laid bare striking inequality across places and people, and this inequality was particularly glaring in large cities, where vulnerable groups such as the elderly, women, the poor, and migrants have been disproportionately affected.
5. Urban density is not the key factor in this health problem—the quality of urbanization and structural inequalities are. Thus, tighter clustering will likely continue to be a source of benefits rather than concern.
6. A shift towards digital life, especially prominent and of great significance during the pandemic, will become entrenched as part of a “new normal”, although remote work possibilities vary both within and across countries.
7. As people are becoming more environmentally aware, thanks to the “Greta effect” and “Zoom effect”, circular economy and clean mobility have become more acceptable goals for transition, both socially and politically.
8. Governance has also been affected by COVID-19, due to changing trust in authorities, especially local politicians. In some countries people trust them more, but less in others.
9. Resilience needs more emphasis, as the disrupting effects of COVID-19 show. To achieve resilience, cities need to prepare for future shocks better by setting guidelines what persons have to take action, what their actions should be, at what scale measures should be applied and how to proceed in case of a crisis.
10. Strategy, policy, planning, and budget need an overhaul, and global agendas such as the Sendai Framework, the Sustainable Development Goals (SDGs), and the New Urban Agenda can help with this aim.

After the initial short-term responses to manage the crisis, including local service delivery, workplace and commuting, social distancing, vulnerable groups, citizen engagement, support to business and other aspects, cities now have turned to long-term recovery strategies aiming to become greener, smarter, and more inclusive ones [64]:

- Moving towards recovery, cities have taken many inclusive measures to address structural inequality and close the gap. Their measures include support to vulnerable households, construction and renovation of affordable housing, and local business support and employment.
- Looking forward to the future after COVID-19, many cities are already planning and making investments to ensure economic recovery is accompanied by environmental sustainability with a focus on energy efficiency and green modes of urban mobility.
- As digitalization has been one of the key emergency responses to the pandemic, many cities are adopting smart city tools and making their use a more permanent

aspect, at the same time monitoring the risk of spreading infection and staying alert. As cultural resources, municipal services, information, and participation are moving online, the virtual space is becoming more and more integral.

Even when the COVID-19 pandemic is over, COVID-19 will likely stay with us. The pandemic is a public health emergency with attempts to protect the health of people and limit the spread of disease. At the same time, the pandemic and its aftermath is prompting cities to look for new ways to deliver services, plan spaces and resume economic growth. In the context of the COVID-19 pandemic, 33 latest city strategies to achieve long-term recovery and ensure resilience to future shocks are summarized as broad categories of inclusive recovery and green recovery [64]:

- Inclusive recovery. Social inequality has existed before, but the COVID-19 crisis puts an additional emphasis on the importance to address this issue. The crisis has revealed shortages of affordable housing for low-income people and families, as well as the risks of infection the inadequate housing poses in lacking communities. For that purpose, many cities launched public policy or investment initiatives with an aim to address the shortage of affordable and adequate housing and make disadvantaged residential areas better.
- Green recovery. As communities start recovering from COVID-19, cities will have many opportunities to emphasize ecological solutions in their economies, which, in addition to pathways to new jobs and long-term local economic growth, can also bring lower CO₂ emissions, make communities better prepared for climate related risks (e.g., heatwaves or flooding) in the future, and improve urban environments (e.g., higher biodiversity, and lower air pollution). As one city after another across the globe imposed lockdowns, car traffic significantly dropped in most cases, which, in turn, led to cleaner air and lower CO₂ emissions. Regions with lockdowns saw a 50–75% decrease in road traffic flows and major cities experienced drops in rush-hour traffic congestion as high as up to 95%.

During the pandemic cities are upgrading various urban solutions to achieve maximum energy efficiency and reduce energy costs in their buildings after COVID-19. Experience shows that investment in energy efficiency and retrofitting not only reduces emissions but can also drive economic activity and job creation in the construction sector [65]. Urban density and urban form (compact or sprawl) are the advantages that could be used by all levels of government towards green urban economies with climate-resilient and low-carbon urban infrastructure. Designing and construction of green buildings and streets, renewable energy production and procurement, where feasible, and other similar solutions of spatial and land use planning with future in mind would help to achieve the goal [64].

The COVID-19 and the related pandemic caused serious disruptions in the construction industry hurting the housing sector. Households were also suddenly struggling with income shortages hitting their ability to pay for shelter. In response, governments introduced many different protection and support measures for tenants, mortgage-holders, lenders, and builders [66]. To visualize the fallout of the crisis in the construction industry better, [66] looks at web-search data. Having then reviewed the measures taken by governments, Organisation for Economic Co-operation and Development (OECD) [66] concludes that, in addition to benefits, some of those relief measures might create inadvertent inefficiencies and make housing supply less responsive to the evolving needs of society and changing demand; hence, the measures have to be phased out as planned. Recent empirical findings led [66] to a conclusion that immediate rescue measures should transition gradually to recovery-oriented policy settings that can support the development of sustainable, inclusive, and efficient housing markets.

As COVID-19 was spreading, the pandemic hit the real estate sector around the globe. With countries scrambling to contain the virus, work in construction sites in many places stopped completely or to some extent, leading to loss of income and revenue for households and enterprises alike. Because of that various segments of the property market

faced gloomy prospects to different degrees, as some countries introduced stricter lockdowns than others and at different times, and the public health crisis was also of different severity. The housing sector suffered a particularly serious blow, but governments were quick to introduce a wide range of measures to mitigate the adverse effect of the crisis on lenders, borrowers, builders, and tenants. Among them are measures that aim to preserve near-term affordability. If maintained for an extended period, however, they may discourage businesses from the expansion and maintenance of the housing stock, and because of that, in the longer term, residential and labor mobility may suffer. Economic and financial resilience is another area that may be undermined. Kept up for too long these measures—most, if not all, meant to be temporary—can cause difficulties with achieving a robust recovery. They can also make the housing market less responsive to the evolving needs of society. As emergency support measures went into force, eviction procedures were suspended, mortgage and rent payments deferred for a time, and utility payments in some cases postponed. During lockdowns, most national as well as local governments introduced certain measures to provide shelter for the homeless [63].

To facilitate the recovery of homebuilding and ensure that the supply of housing matches evolving demand and the needs of society better, land-use restrictions need to be eased. Greater benefits can be achieved if such reforms are part of an integrated spatial planning framework spanning various hierarchies and government sectors. The reforms should promote housing construction, make housing more affordable, as well as improve neighborhoods and avoid excessive differences in the access to social infrastructure, transportation systems, and public services across different urban areas. Another benefit of the promotion of new residential construction is that a requirement for new buildings to comply with certain environmental standards could speed up the move towards low-carbon economy. The COVID-19 crisis may lead to lasting interrelated changes in housing demand and work organization that could be accommodated by facilitating construction and redevelopment. Living in lower-density areas and working remotely could be new preferences. Urban–rural divergences then would slow down or even be reversed relieving the current demand pressures in very dense areas. A growing uptake of remote work with flexible workplace would also mean that some office spaces in city centers would be free for conversion to residential units if land use permits the change. Such shifts could help reduce the gap between regional home prices and, in turn, residential segregation [63].

5.2. COVID-19 and Its Possible Effects on Future Homes

Affordable housing movements and the COVID-19 crisis are changing the definition of “quality housing”. Alternative ways to organize and use living spaces and new models have been proposed [67]:

1. New or adjusted forms of shared living, co-living models in particular. Issues such as human connection, flexibility, and cost could be addressed by making this form of housing available to everyone.
2. In light of the blurring lines between work and home life, homes could become multipurpose spaces where people live, work, and spend their free time.
3. Private Rented Sector (PRS), Build to Rent (BTR), multifamily schemes and other models of managed rentals. Technology could also facilitate real-time residential management.
4. Lease-to-own, co-investment, ownership unbundling, collaborative forms of the reverse-annuity-based French viager system, and other tenancy–ownership options to access new housing.

In times of the COVID-19 pandemic, our homes are no longer just living spaces. They are now places where we work and exercise, and where our children attend lessons or lectures. They have made room for new hobbies and hosted happy hours at home. Real-estate experts speak about changing homebuyer preferences due to COVID-19 and predict possible shifts in home design in view of this new normal [68].

As the COVID-19 pandemic hit, almost every aspect of our life has changed, including preferred locations and forms [69]:

- Suburbs give way to exurbs. With many people forced to work from home, commuting is no longer a tying factor limiting the choice of housing. Thus many people now prefer to leave cities with their soaring prices behind and favor more remote areas. Since telework and remote learning have settled indefinitely as typical forms, many have no intention of coming back. Closer suburbs are still popular too, but low supply and large groups of motivated buyers are driving a sprawl. Among attractive features we still find proximity to the city, sidewalk-lined centers, and accessibility to shops.
- Notable changes have happened in the condo market. Condos are declining in popularity. One of the reasons is that the shared areas previously presented as added value in many condo buildings are now seen as risky inconvenience. Figuring out how to stay two meters apart in an elevator is too bothersome. People are now giving up their condo homes and moving to single-family houses: the range of amenities may be smaller, but you can remove the face mask as soon as you are inside. Another factor is the price, because even the cheapest city condos cost more than suburban homes where you also get more space. Both more space and a lower price can motivate the move.

COVID-19 has changed housing interior trends and Rizzato [70] analyzes a few of them:

- Soundproofing and privacy. Big open plans seem to have fallen out of favor. No more kitchens, sitting rooms, dining rooms, and leisure rooms combined in one space.
- Healthier spaces. Germ-resistant flooring and surface materials, smart toilets, air purifiers, new air and water filtration systems, indoor air quality monitoring, in-furniture auto-cleaning technologies, automatic cleaning, and ultraviolet lamps.
- Voice Control and user-friendly technologies. A shift caused by the need to avoid touching the buttons of an elevator and other surfaces.
- New spaces for new functions. Online shopping, drone deliveries, and dedicated package drop-off areas for home deliveries.
- Greenery. A boom of indoor gardening and vertical gardens is expected. They can improve indoor air quality in our homes and reduce stress [70].

The COVID-19 pandemic has forced limited or zero access to common areas and non-essential amenities in residential buildings. More and more people, however, expect luxury amenities in multifamily communities [71]:

- Health-related amenities. A gym or fitness center, membership to local gym (discount or free), building-wide social distancing measures, contactless food delivery, free masks and gloves, and hand sanitizer stations.
- Entertainment-based amenities. Outdoor grill areas, recreation rooms, rooftop deck or patio, basketball and/or tennis court, pool, and movie theatre rooms.
- Convenience-based amenities. Free broadband internet and cable TV, in-building convenience store, package lockers, electric car charging stations, exclusive meal services and/or a virtual restaurant, video intercom systems, package alerts and mailrooms with mailroom management software, valet services, dog run, or park.

Around four out of ten workers took up remote working for the first time; thus, many people are spending much more time at home. For families with children homes have also become makeshift playgrounds and schoolrooms. The current stock of housing, with issues such as a lack of personal space, high-speed internet, outdoor space, or natural light, poses the question of the adequacy of our homes. COVID-19 is not the first and hardly the last public crisis that may disrupt our everyday lives, and remote work may become prevalent in view of its current relative success. Public authorities should, therefore, review their planning guidelines with homes as places to truly live in, rather than just eat and sleep, in mind. As over the medium-term (at least) private developers of housing are likely to be in partially

suspended mode, waiting to see the direction the market takes, ready-to-implement public housing projects are a great opportunity for nations to restart construction work, making sure it is safe to bring workers back on site, and this way to give their economies a much-needed boost. In the current climate of economic and financial uncertainty and rock-bottom bond yields, residential properties can be seen as an attractive investment for prospective private landlords looking for ways to convert their cash to sources of rental income. The post-COVID period could, therefore, see the monetization of housing, prevalent since the financial crisis of 2007–08, keeping up and going further [72].

Ogunnusi et al. [73] examine the effects of COVID-19 on real-estate-related deals and the prospects of the construction industry by means of quantitative measures. Built asset procurement professionals were surveyed and the results of this survey reveal certain issues with workflow and supply chain disruptions, new policies, workforce anxiety, as well as COVID-19 vs. Force Majeure revisions in standard construction contracts. The necessity for virtual working and unique design considerations, however, presents new opportunities to modern procurement planning. The research by Ogunnusi et al. [73] can serve as a basis for those developing additional contingency plans and a new working strategy in situations of social distancing caused by the pandemic. The study by Gamil and Alhagar [74] looks at the effect of COVID-19 on the survival of the construction industry and classifies the impacts into different groups, including human and economic resources. The biggest impacts of COVID-19, as the study by Gamil and Alhagar [74] shows, are labor impact and job loss, the suspension of projects, cost overrun, time overrun, and financial implications. Bailey et al. [75] look at the impact of COVID-19 pandemic and its management with focus on construction projects where the pandemic has been slowing processes and leading to disruptions and delays. Legal implications, however, vary between contracts and across countries. Some projects were suspended and delayed. Businesses must assess health and safety risks in line with medical, scientific, and government guidelines. In indoor spaces, for instance, people face higher risk than those working outside. Whereas no one could foresee COVID-19 and its outcomes, it can be considered a case of force majeure, which in any standard form of contract (FIDIC among them) usually affords contract extension spanning the duration of the pandemic with no compensation for cost [75]. The findings by Shibani et al. [76] show that lockdowns and social distancing rules caused by the COVID-19 pandemic provided a serious hit to construction companies involved both in residential and commercial projects. In response, construction companies chose the strategy to stay on good terms with their suppliers and ensure the safety of construction teams [76]. Ataei et al. [77] review the immediate response of the construction industry to the COVID-19 pandemic and the challenges it poses looking at the impacts on projects related to timetables, delays, financial difficulties, as well as new and shifting regulations. Hook [78] argues that this pandemic may force some engineering and construction companies to look for funding and streamline debt, or they risk bankruptcy. Engineering and construction companies face new realities in the future with changing markets and public infrastructure investment, as governments look for ways to jump-start recovery [78].

In the times of the ongoing COVID-19 crisis, Zillow has presented the Top 10 housing trends for 2021 related to life in this environment in the nearest future. Zillow's top housing trends for 2021 are as follows [79]:

- “Zoom Rooms”. Zillow surveyed Americans and discovered that the top reason they would consider a move, if they were to continue working remotely at least occasionally, is that they would prefer a home with a dedicated office in such case. In 2021, employers will give a clearer message about the possibilities of remote work in the future, and this could encourage people to look for homes with more space, as tired of working in their kitchens people will want more permanent solutions for their work at home—to have a quiet dedicated corner. As of November, an increase of 48.5% was recorded year-over-year in the number of listings mentioning “home office” or “Zoom room”.

- “Homecation” Amenities. As people are forced to stay home and have lots of time, they are thinking up creative solutions to make themselves a vacation at home. In 2020, “pool” was the most popular search term at Zillow, with “waterfront” and “dock” also in the top ten. Homeowners may also be looking for ways to add a touch of luxury at home with a relaxing rain shower or spa-like bathtub, and home buyers, according to Zillow, paid extra for amenities that make their home feel like a resort. A mention of a free-standing tub typically meant the listing sold for a price 5.5% higher than expected, while the keyword “spa-inspired” added a 1.8% price premium. The rise of telecommuting means that more people will be able to take permanent residence in their favorite vacation destination. Key West, the Jersey Shore, and Cape Cod are just a few of areas typically considered vacation destinations with page views of for-sale listings there up nearly 50% compared to previous year.
- Intergenerational Living. This form of living will become more popular as, for financial and health reasons, both young and old people move in with family. Today about 16% of Americans, according to Generations United, live in households of more than one generation, and the share of young people (Millennials and Gen Z, especially among renters) moving back in with their parents reached historical heights in 2020.
- Gourmet Kitchens. With fewer opportunities to eat out, the year 2020 inspired people to look for new things they can bake in their kitchens. In 2021, homeowners will want to go further in this endeavor and level-up with more new culinary masterpieces. As a result of social distancing recommendations, 41% of people value a well-equipped kitchen more than before, according to a previous Zillow survey. In the next year, more people are likely to prefer better-equipped space for their new culinary skills.
- Backyard Oasis. Social distancing recommendations have highlighted the importance to have a safe and functional yard and 41% of people, according to a Zillow survey from the Harris Poll, now value a large outdoor space more. A few easy touches and your backyard can become a relaxing oasis for the whole family with an additional benefit of a higher resale value of your home. Listings mentioning “fire-pit” sold at a 2.8% price premium, and “outdoor kitchen” added extra 4.5% to the price, according to Zillow. An addition of outdoor lighting and/or smart sprinkler systems also makes your backyard look more attractive to potential home buyers and may speed up the sale of your home up to 15 days.
- Smart and Safe Tech. Home disinfection has become a vital part of our daily lives, and smart-home technology is rushing to the rescue with products such as self-cleaning toilets, bidets, and touchless appliances. These are often still niche products, but gradually they will become standard fixtures in home design. When social distancing rules will be lifted and guest visits will become a normal thing again, more and more homeowners will look for creative solutions to keep their spaces clean, but also chic. By incorporating thoughtful innovation into home products, robotic vacuums, electronic-assistant controlled lights, voice-activated faucets, and other features have brought into homes new ways of cooking and cleaning. Buyers increasingly see smart home technology as an attractive option. Listings mentioning a smart light sold seven days faster than expected, and those with a smart thermostat mentioned in their description sold six days faster than expected, according to Zillow. Looking for ways to keep their families safe and germ-free, homeowners will be more likely to add a new touchless faucet and similar fixtures and fittings to their homes.
- Small City Living. With ever more telecommuting opportunities, many people looking for a new home now have new ideas of where and how they want to live. As the need to be close to jobs in cities is falling, smaller, more affordable communities and wide open spaces may become the main preference for homebuyers in 2021. Search traffic data is already showing this trend. Pierre in South Dakota, Borger in Texas, Vernal in Utah, and other similar small cities contributed most to the growth in out-of-town search traffic, compared to the previous year; out-of-town search traffic in a dozen markets such as Jackson in Wyoming, Pierre in South Dakota, and Hudson in

New York doubled this year. In case of small cities, with populations between 54,000 and 137,000, newly pending sales have increased 34.3% since last year, and YOY pending sales have been positive since July. The preference to live in small cities will only keep growing as remote work becomes a more established practice and give renters opportunities to become homeowners.

- **Health and Wellness at Home.** Nationwide, people were quick to adapt to new restrictions, setting up mental wellness spaces or fitness clubs right at their home. In November, health and wellness areas were mentioned in 4.1% of homes listed for sale on Zillow. The number of listings mentioning “health and wellness” has been increasing since early summer and peaked in November with lockdown orders renewed and fewer daylight hours for outdoor activities because of the approaching winter. Physical health, however, is not the only priority homeowners have. Isolated from social activities and loved ones, people will be more inclined to set up their own private areas for their mental wellbeing activities such as meditation and reflection. According to Berks Homes, the number of homes with an extra bedroom in the basement or over the garage has increased this year. These new private spaces added to homes may be converted to meditation rooms or become a quiet space to spend some time away from chaotic life.
- **Pet-Friendly Living.** Telecommuting gave many people the opportunity to spend all their day at home and better ability to take care of pets. Twenty percent of respondents surveyed by Nielsen in July said they had adopted one or more cats or dogs between March and June, compared to less than 5% over the same period last year. As more furry new best friends join families, the demand for pet-friendly rentals is growing and landlords use these added benefits to entice renters. According to Zillow, 73.1% of residential properties listed for rent allow pets. Because the number of families with pets is growing, Zillow reckons they will expect pet-friendly features in their next home. In 2020, Zillow analyzed available data and found that listed properties with a fenced backyard mentioned in their description sold 6.8 days faster than expected and those with a pet shower or dog wash mentioned added a 5.1% price premium over similar homes with no such amenities.
- **Rise in Demand for New Construction.** Zillow has observed a significant increase in traffic of people looking for new construction homes, up 82% in the third quarter of 2020 YOY. This means more homebuyers are interested in the ability to personalize their home and want to live in a clean, new space. Surveyed by Zillow in 2020, over a quarter of households who bought a new construction home said their choice was determined by the wish to customize home features, while another 37% based their decision on the fact that everything in the home was new and never used.

BIM means that each building has a virtual counterpart used throughout its lifecycle—from its design and construction through its operational life until its demolition. This virtual counterpart makes it possible to track and analyze environmental metrics, energy consumption, and human activity patterns. Efficiency thus can be improved and desired outcomes (e.g., social distancing) promoted. Soon virtual counterparts will be used in the planning of and, later, adding adjustments to entire neighborhoods and cities. However, equity should be front and center when this point-of-no-return will be reached [61].

The COVID-19 pandemic pushed up the demand for more space and less dense living environments among consumers. With the U.S. housing market bustling this year as Americans encouraged by extremely low mortgage rates and remote work opportunities are looking for places to relocate, the condo market has not gained much. During the coronavirus pandemic, people looking for a new home preferred more space and privacy of single-family homes to dense cities. An exodus from cities to the suburbs in search of more space has been observed [80].

A new report by Zillow shows that more than a third (34%) of potential sellers prefer to stay out of the market for now, faced with uncertainties, mostly caused by COVID-19. An important role is played by financial anxiety: of the homeowners who are thinking of

selling their current home in the next three years 31% say they are discouraged by the current precarious or uncertain financial situation, with 27% reporting recent employment changes with fewer hours or lower pay, and 17% mentioning a job loss or furlough; these reasons could make people less inclined to look for a new home. Another contributing factor is the uncertainty surrounding the place of work. A survey by Zillow shows that homeowners started to work from home more often in the past six months and this new arrangement is the most common change. Another survey by Zillow shows that two-thirds of people teleworking during the pandemic would consider looking for a new home if the ability to work from home occasionally stays after the pandemic. While homeowners wait for a clear signal from their employers when (or if) they will have to return to the office, however, those plans may be on the backburner. Almost 40% of the homeowners who are thinking of selling their current home in the next three years say they expect a more favourable sale price if they wait, suggesting they do not think now is the only time to get a good price, despite all-time high median sale prices, up nearly 11% YOY for the week ending 5th September. Sellers are once again optimistic, too: a Fannie Mae survey in September found a majority (56%) of people think now is a good time to sell, up from 29% with the same opinion in the spring. Potential sellers believe that home prices have not peaked yet. They are likely correct, but there is no clear "right time" to sell, because prices always tend to rise in the long run [81].

Density is usually associated with higher rates of mortality from, infection with, and transmission of, highly contagious diseases, COVID-19 among them [82,83]. An opposite conclusion can be drawn, however, from a U.S.-wide analysis of the relationship between COVID-19 infection and mortality rates and density in 913 metropolitan counties [84].

Connectivity makes a serious impact on COVID-19 infection and death rates. More in-depth research on measuring connectivity in cities and its impact on the spread of pandemic is, therefore, important. Future studies could reveal new aspects by developing and using more sophisticated internal connectivity measures; for instance, location-based social networks [85].

Confirmed virus infection rates are not related to density but confirmed virus death rates are inversely related to it. This fact is unexpected, important, and very serious with implications for transportation expenditures, regional planning, community design, urban redevelopment, congestion pricing, affordable housing, tax policy, smart growth, and almost all other urgent issues important to planners. It goes against ideas that, without data and analysis, might question the foundation of modern city planning that density is preferable to sprawl, at least in some places such as urban and suburban centers [86].

The number of studies looking into the impact of density on highly contagious new infections is not high. In theory, people living in densely populated areas have more interactions with others, which may contribute to the rapid spread of contagion. However, dense areas may also mean better access to health care facilities and higher adoption of social distancing practices and policies [84]. The findings by Hamidi et al. [84] suggest the spread of the COVID-19 pandemic is facilitated more by connectivity than density. The most vulnerable locations are large metropolitan areas with tight economic, social, and commuting links with a higher number of counties. With higher movement of people (tourists, businesspeople) both inside such areas and with outside locations, the risk of cross-border infections is also higher [81].

Every aspect of urban planning practices has been affected by this pandemic. With high unemployment rates, its economic impact is already obvious. Months of social distancing, staying at home, and the economic crisis will lead to societal impacts. Environmental impacts are also expected: both positive ones from changed behaviors and, without the right measures in place, recovery-related negative ones from rebuilding the economy. The severity of all impacts combined will determine political impacts. Finally, technological impacts may open new opportunities to find ways to respond and prepare for this new future [87].

Facebook expects to see half of its employees working remotely by the end of the decade, and this expectation is not tied to the pandemic. Meanwhile, seven in ten Microsoft employees would like to continue teleworking after the pandemic ends. Among surveyed employers, 94% stated that productivity did not suffer due to teleworking, 27% noted an improvement in productivity, and 73% expect that at least a quarter of employees will work remotely indefinitely, with close to half of those reckoning that 50% of their employees will continue teleworking even when offices are safe to return to. Various surveys predict a shrinkage of office footprints, which, in turn, will open new ways to solve longstanding urban problems as transportation and land-use patterns shift. Downtown areas often lack housing, so some of the empty offices might be converted to residential units. Such endeavors will demand extensive investments from building owners. Government incentives and zoning changes are likely to be required making it a long-term effort [61].

Although a home in the U.S.A. typically costs about \$263,000, a sharp increase in the number of “million-dollar cities”, according to Zillow, was recorded in 2020, adding 45 new U.S. cities to the pool of those with a typical home value of at least \$1 million. No larger increase has been observed in at least a decade. The number of million-dollar cities is now 312, compared to 104 five years ago. The significant increase over the course of 2020 is the testimony of considerable activity in the market last year and surging demand through most of 2020 caused by demographic trends and the pandemic, with home values going up almost 7.5% annually in November. The year before, in contrast, saw the lowest rate of home value appreciation since 2013. The list of million-dollar cities is typically dominated by areas with attractive natural surroundings, such as mountains or the ocean nearby. A great media package, including 3D imaging, virtual staging, and a floor plan with dimensions, give sellers a competitive edge [88].

Cities are making moves to protect homeless people. Among them, Chicago and Los Angeles, where resources have been prioritized for emergency shelters, Baltimore, where vulnerable homeless residents aged over 62 are being relocated from emergency shelters to motels, and New Orleans, where homeless people were also moved to a hotel. Various modes of transport have been impacted by the COVID-19 pandemic and the impact is huge. With transit use declines of about 97% in Chicago and San Francisco, and 87% for subways, and 70% for buses in New York, most transit agencies have cut their services down to hedge against financial loss. Other modes of transport also suffered with rider numbers at Uber 60–70% down in Seattle, and zero rides in New York where this type of services has been banned. Across major cities, Uber suspended its UberPool, a ride-share service. The story of bike sharing is different. Divvy in Chicago and other similar companies, in partnership with cities, offer their members attractive discounts during the pandemic. People increasingly are choosing biking over using transit as a safer option. Philadelphia is going with the trend and, to make its cyclists safer, has closed a 7-km street to vehicles; biking in Philadelphia is up more than 150% [60].

The impacts of digitalized workplaces will go along with, and be reinforced by, the digitalization of education, shopping, and entertainment. More people will regularly shop for basic goods online and brick-and-mortar retail stores will be mostly devoted to offering experiences. These trends driven to new levels by the pandemic will result in huge areas of obsolete asphalt. Perhaps we are not going to see autonomous cars taking over roadways anytime soon and it might take several decades for this future to arrive, but the ever more popular ideas for converting parking areas to serve other purposes may be implemented sooner rather than later. The Christmas rush plays an important role in setting parking requirements, but this phenomenon may move increasingly online. In that case, the supply of parking spaces will exceed demand considerably. All these no-longer-needed paved spaces could then be converted for other uses such as urban green spaces or affordable housing. As people spend more time at home, they are likely to ask for more activities—from green landscapes to entertainment options—within a walking distance. How does the concept of land use change when people do everything at home: live, work, shop, study, and produce things? Does the concept of a residential district still have a

meaning? How is it different from an office district, a commercial district, or an industrial district? The land zones set in the past may no longer correspond to the way people are actually living and working in the future. A more inclusive and flexible system will be required where people will be able to adapt. This trend opens many opportunities [61].

Industry 5.0 expects to resolve the increasing need for personalization, since Industry 4.0 was unable to accomplish such [89]. Industry 5.0 endeavors to personalize its products and services on *masse*, like never before. The experiences of its clients are also included in this process. Japan describes Industry 5.0 as “Society 5.0”—a revolution of “human touch”—as follows: “A society that orients towards the human being balances between a system of economic advancement and social problem resolution, which integrates cybernetic and physical spheres very well” [90]. “Vital entrepreneurship” and “vital marketing” are the activated goals of personalization including those companies that are constantly able to foresee and react to ever-changing client needs (by gathering and analyzing data in real time). Such companies become a part of the daily lives of their clients [91].

Industry 5.0 is now seemingly progressing towards harmonious technological and societal systems that deliver a customization of products and services *en-masse*, which are all personalized [92]. An increased human–machine interaction is the primary difference between Industry 4.0 and Industry 5.0, according to [93]. It encourages personalized expressions among people by their use of personalized products and services. The emphasis in the work by Yin et al. [94] that regards the future of technology and personalization revolves around human centrality.

Unfortunately, there is very slow movement of the Internet of Things towards humanization. This has inspired Kaklauskas et al. [95] to foster the idea of humanizing the Internet of Things among academic and business communities. Analyzing the affective Internet of Things, smart homes, ambient intelligence, affective computing, BIM, smart and interactive buildings, and smart building systems constitute the presentation of the humanization of the Internet of Things by this research [96].

A number of researchers have also engaged in scientific studies focusing on individual thermal comfort and indoor air quality [97–106]. Personal comfort systems (PCS) are analyzed next as an example. PCSs in laboratory and field studies can appear in different forms, such as ceiling fans, radiant or convective heaters, and temperature-controlled surfaces on chairs, desks, and floors. Certain systems and devices have been designed to address individual thermal variability by permitting people to control their own thermal status. Thereby people are able to adjust temperatures to the degree of comfort for themselves. The warming and cooling stimuli on surface bodily areas can affect the entire body’s thermal sensation [100,107–109]; thus such systems are effective. A unique approach to PCS appears in the work by Wang et al. [99], who assess leveraging the time-dependence of human thermal perception. *Embr Wave*, which is a 6.25 cm² wearable device, supplies dynamic, cooling, or warming waveforms to the inner wrist. A substantiating work of research is by Wang et al. [99], which concludes that this wearable device running on low power betters the thermal phenomenon, comfort, and satisfaction over the entire body. Meanwhile a study by Lopez et al. [110] discovers that a whole-body thermal sensation works more efficiently by cyclic heating rhythms than it does by continuous heating.

6. Conclusions

This review presents analysis under three hypotheses: articles give a specific perspective on the green housing before, during, and post COVID-19 area.

There is a methodological integration of the Topic Model, Environmental Psychology Theory, building life cycle method and certain elements of Bibliometrics, Webometrics, Article Level Metrics, altmetrics, and scientometrics for deriving the Green Housing Topic Model.

The reviewed literature only came from some of the countries affected by the pandemic. Thus, the studies are not comprehensive of all parts of the world now suffering from this virus. The other countries also affected, especially those with highly vulnerable

populations, additionally require coverage. Despite this shortcoming, this review looks over proposed policies so it can indicate certain main guidelines aimed at the green housing research community and its overall sector.

There was no detailed investigation to date on how COVID-19, the housing policies of countries and cities during COVID-19 impact green housing, and the wellbeing of their residents. Furthermore no investigation has taken place on how the residents and a housing policy impact the dispersion of COVID-19. Additionally an analysis on green buildings is markedly more effective, when the life process of a green building, participating interest groups that have their own goals for implementation, the COVID-19 situation, and the external micro- and macro-level environments are analyzed comprehensively, as a singular entity. These are the two reasons, why the research was undertaken, in an effort to close the gap between knowledge about green housing before, during and after COVID-19.

The research in the area of the relationship between green housing and COVID-19 is yet limited, but promising. This paper reviews a selection of such studies with an aim to take a look at the research on housing development during the COVID-19 crisis, focusing on the response from the green building sector. It is a rapidly emerging field with ever more new research. The preferred choice were last year's peer-reviewed journals dedicated to urban studies, construction, buildings, energy, economics, civil engineering, management, business, indoor air, environmental sciences, and environmental studies. A range of keywords were applied in this review, including energy-efficient retrofitting, green construction, sustainable building, efficient use of resources throughout the life cycle of buildings, comfort, occupant behaviour, COVID-19, health effects, economy, and profit. This review focuses on the period of the COVID-19 pandemic and on green housing and its value. The articles for this analysis were selected based on the aforementioned keywords.

Certainly, green housing and location choices can be under the influence of a number of issues. What distinguishes the research results presented here are the interactions between COVID-19, the housing policies of countries and cities, and the behaviors of residents as being key regarding green housing requirements. Thus, this analysis is intended to serve the different stakeholders involved in making green housing decisions pertinent to micro- and macro-level circumstances and needs.

The studies that were accessed contain worthwhile evidence containing a great many clarifications and proposals that can prove valuable for all green housing stakeholders, such as those presented next.

The pandemic resulted in many problems for the housing sector, especially for green buildings. These difficulties for the sector are expected to continue for a considerable time. Some consider rentals to be such a difficulty during the upswing of COVID-19. Relationships of influence must be understood for an appropriate focus on pandemic policies and their responses. Housing outcomes and their coordination constitutes another topic regarding policies of concern during the COVID-19 outbreak. Relationships between landlords and renters become a major consideration during and after the pandemic. The entire green building concept must be reconsidered. It is now over a year where lockdowns have been initiated in very many locations. This has meant that all life's functions—sleeping, eating, working, exercising, and socializing—must take place at home. There can be only one outcome. Living spaces need to be larger and to overlook greenery. That needs to be the goal of any green housing design strategy.

Housing improvements have become a challenge in many countries currently, which are crying for adequate solutions. There are many aspects regarding micro-, mezzo-, and macro-environments relevant to housing during the COVID-19 pandemic. For one, at home work has become a crucial issue, which require appropriate environments. The home of the future after COVID-19 will have to show resource efficiency over the entire lifecycle of a building. It will also require larger than usual lots. Its interior must contain smart bathrooms and bidets. Multi-generational homes will now include unique spaces that were previously expendable like extra rooms and more bathrooms. The home of the future will have to be healthy and energy-efficient, not merely a smart home. More open

spaces will be needed in every floor plan. Office use will need to be part of every design for a home. Infrastructural facilities will need management teams, and technical facilities will need smaller teams than before. Designs will be simplified to handle daily hygienic needs on-site. Day-to-day needs for health and security will get handled by means of checklists. Digital risk monitoring on construction and work sites can be handled by BIM and other digital means that are needed to fight COVID 19. Data analysis, alerting, video surveillance, IoT, and non-invasive temperature monitoring could prove adequate systems. Competent execution for remote diagnoses and health reporting needs to be included in daily plans. Facilities management is an area PropTech can adapt on a step-by-step basis by involving wellbeing in workplaces, efficiencies in the use of energy, and optimal use of available space and data management.

Many countries are now facing multiple challenges and are looking for solutions to improve their housing stock. As many people now work from home, they need appropriate environment. After COVID-19, new requirements will inevitably emerge for future homes. Smart bathrooms and bidets, efficient use of resources throughout the life cycle of buildings, and larger lots are just a few examples. Multi-generational homes will have new aspects, with a need for more rooms, more bathrooms, and unique spaces. To be a smart home will not be enough for future homes—they will need to be energy-efficient homes, healthy homes and include more open spaces.

An analysis of research articles shows that housing choices have undergone a significant shift due to the COVID-19 pandemic. The preference is moving towards green buildings, better for human well-being and health.

The following factors, then, make the biggest impact on green/sustainable buildings: building hygiene and wellbeing, indoor environment, design concept, built environment, the COVID-19 pandemic, social environment and lifestyle, human behaviour, and household energy source.

In the times of the pandemic, housing researchers focus on occupant health. For better understanding of the ways buildings affect health, an interdisciplinary approach is needed. Since the COVID-19 has caused many different uncertainties, research efforts span many areas. Various stakeholders need pragmatic instructions on ways to reduce indoor risks. In response to changing sustainability requirements for residential buildings, residential interior design can also change in the upcoming years. The COVID-19 pandemic is expected to cause changes in sustainability requirements for residential buildings; a specific set of sustainability indicators will be proposed, including specific sustainability requirements for a pandemic, and the need to revise current building codes and certification processes taking into account specific pandemic-related needs. A significant shift in building sustainability assessment methods will happen with an emphasis on “social and health” aspects.

Two innovative elements distinguish this current study in comparison to the most advanced studies that have been available on green housing before, during and after COVID-19. How COVID-19, housing policies of countries and cities pertinent to COVID-19 impact green housing, and the wellbeing of their residents comprises the first innovation of this analysis; and how the residents and a housing policy impact the dispersion of COVID-19. Furthermore, this investigation has established that an analysis on a green building is markedly more effective, when there is a comprehensive analysis of the life process of a green building, the participating interest groups that maintain their own goals for implementation, the COVID-19 situation, and the external micro- and macro-level environments treated as a singular entity.

Some very fragmented research involves three-way interactions between COVID-19, the housing policies of pertinent countries/cities and green housing coupled with wellbeing of their residents. Therefore a comprehensive investigation is required for adequate understanding of these three components.

The micro-level (building) and macro-level (city, country) aspects of green housing during and after the COVID-19 era are discussed in this article. For the micro-level (building) aspect, the analysis centered around multi-functional spaces (home-office-classroom), luxury amenities, nature-inspired views, backyard oases, greenery, larger lot sizes, healthier areas, and health-related amenities that are integrated in designs for interiors. These also include convenience-based amenities with new spaces for new functions, entertainment-based amenities, privacy and soundproofing functions, security focus, sanitation, and automation. Furthermore it also encompassed antimicrobial materials, a return of the mudroom, smart homes, industry 5.0, and customization along with virtual tours and self-guided showings. Meanwhile, for the macro-level (city, and country) aspect, the analyses of countries involved crisis-response measures, support measures for tenants and owners, recovery strategies, and other means and of cities, crisis-response measures, support measures for tenants and owners, recovery strategies and other means. All these constituted housing policy responses during and after the COVID-19 era. New models were also analyzed pertinent to alternative ways for using and organizing living spaces, co-living, lower-density properties, growth of suburban sunbelts, and such.

The Figure 1 submits current, green housing trends, including those like renewables, zero energy dwellings and carbon footprint simulators for products; product transparency and green housing certifications; prefabricated dwellings, reasonably priced sustainability, healthy dwellings, living green walls and roofs, an environmentally friendly yard, well-organized spaces, mass timber applications, water-efficient, recycled, resilience, smart dwellings, and BIM.

A brief analysis was undertaken pertinent to the performance of an ongoing, three-way process of interactions between COVID-19, green housing (at the micro-level), and housing policy responses by countries and cities (at the macro-level) during and after the COVID-19 pandemic. This work concentrates on the means by which COVID-19, the housing policies of countries and cities impact green housing and the wellbeing of residents. Furthermore the work also looks at how the residents and a housing policy impact the dispersion of COVID-19 (see Figure 1). The entire analysis emphasizes the objective and subjective factors of green housing, its neighboring environment, and the wellbeing of its residents.

Sections 3–5 describe policy implications comprehensively. One proposal, for example, is to apply information in practice on how COVID-19, the housing policies of countries and cities pertinent to COVID-19 impact green housing and the wellbeing of their residents as well as how the residents and a housing policy impact the spread of COVID-19. An additional proposal is to constantly analyze the life process of a green building in practice comprehensively along with its participating interest groups with their own goals for implementation, the COVID-19 situation, and the external micro- and macro-level environments as one, singular entity.

Interdisciplinary research is still required for a more comprehensive analysis regarding the interactions between COVID-19, the housing policies of relevant countries and cities, and the behaviors of their residents along with their demands for green housing.

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References

1. IMF. *IMF Annual Report 2020. A Crisis Like No Other. Swift Action Helped Fight the Pandemic and Limit the Damage to People's Lives and the Global Economy*; IMF: Washington, DC, USA, 2020.
2. Hall, D.; Jurafsky, D.; Manning, C.D. Studying the history of ideas using topic models. In Proceedings of the Conference on Empirical Methods in Natural Language Processing—EMNLP '08, Honolulu, HI, USA, 25–27 October 2008; pp. 363–371, doi:10.3115/1613715.1613763.
3. Rosen-Zvi, M.; Griffiths, T.; Steyvers, M.; Smyth, P. The author-topic model for authors and documents. In Proceedings of the 20th Conference on Uncertainty in Artificial Intelligence, Arlington, VI, USA, 7–11 July 2004; pp. 487–494.
4. Griffiths, T.L.; Steyvers, M. Finding scientific topics. *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 5228–5235, doi:10.1073/pnas.0307752101.
5. Yin, Z.; Cao, L.; Han, J.; Zhai, C.; Huang, T. Geographical topic discovery and comparison. In Proceedings of the 20th International Conference on World Wide Web, Hyderabad, India, 28 March–1 April 2011; pp. 247–256, doi:10.1145/1963405.1963443.
6. Newman, D.J.; Block, S. Probabilistic topic decomposition of an eighteenth-century American newspaper. *J. Am. Soc. Inf. Sci. Technol.* **2006**, *57*, 753–767, doi:10.1002/asi.20342.
7. Chang, J.; Gerrish, S.; Wang, C.; Blei, D.M. Reading Tea Leaves: How Humans Interpret Topic Models. In Proceedings of the 23rd Annual Conference on Neural Information Processing Systems, Vancouver, BC, Canada, 7–10 December 2009; pp. 288–296.
8. Lamba, M.; Madhusudhan, M. Mapping of topics in DESIDOC Journal of Library and Information Technology, India: A study. *Science* **2019**, *120*, 477–505, doi:10.1007/s11192-019-03137-5.
9. Almind, T.; Ingwersen, P. Informetric analyses on the World Wide Web: Mythological approaches to Webometrics. *J. Doc.* **1997**, *53*, 404–426.
10. Björneborn, L.; Ingwersen, P. Toward a basic framework for webometrics. *J. Am. Soc. Inf. Sci. Technol.* **2004**, *55*, 1216–1227, doi:10.1002/asi.20077.
11. Biometrics. The Guidelines Project. Available online: <http://www.guidelines.kaowarsom.be/bibliometrics> (accessed on 15 December 2020).
12. Lin, J.; Fenner, M. Altmetrics in Evolution: Defining and Redefining the Ontology of Article-Level Metrics. *Inf. Stand. Q.* **2013**, *25*, 20, doi:10.3789/isqv25no2.2013.04.
13. Article-Level Metrics. Springer. Available online: <https://www.springer.com/gp/authors-editors/journal-author/journal-author-helpdesk/article-level-metrics/23400> (accessed on 15 January 2021).
14. What Are Article Level Metrics? University Libraries Health Science Library. Available online: <https://guides.lib.unc.edu/measure-impact/article-metrics> (accessed on 17 December 2020).
15. Bornmann, L.; Haunschild, R. To what extent does the Leiden manifesto also apply to altmetrics? A discussion of the manifesto against the background of research into altmetrics. *Online Inf. Rev.* **2016**, *40*, 529–543, doi:10.1108/oir-09-2015-0314.
16. Priem, J.; Taraborelli, D.; Groth, P.; Neylon, C. Altmetrics: A Manifesto, 2011. Available online: <http://altmetrics.org/manifesto> (accessed on 17 December 2020).
17. Vega-Muñoz, A.; Arjona-Fuentes, J.M. Social Networks and Graph Theory in the Search for Distant Knowledge. In *Advances in Computer and Electrical Engineering*; IGI Global: Hershey, PA, USA, 2020; pp. 397–418.
18. Stevenson, M. Evaluating topic coherence using distributional semantics. In Proceedings of the 10th International Conference on Computational Semantics (IWCS), Potsdam, Germany, 19–22 March 2013; pp. 13–22.
19. Newman, D.; Lau, J.; Grieser, K.; Baldwin, T. Automatic evaluation of topic coherence. In Proceedings of the Human Language Technologies: The 2010 Annual Conference of the North American Chapter of the Association for Computational Linguistics, Stroudsburg, PA, USA, 2–4 June 2010; pp. 100–108.
20. Harris, Z.S. Distributional Structure. *WORD* **1954**, *10*, 146–162.
21. Pinheiro, M.D.; Luís, N.C. COVID-19 Could Leverage a Sustainable Built Environment. *Sustainability* **2020**, *12*, 5863, doi:10.3390/su12145863.
22. D'alessandro, D.; Gola, M.; Letizia, A.; Marco, D.; Fara, G.M.; Rebecchi, A.; Gaetano, S.; Capolongo, S. COVID-19 and living space challenge. Well-being and public health recommendations for a healthy, safe, and sustainable housing. *Acta Biomed.* **2020**, *91*, 61–75, doi:10.23750/abm.v91i9-S.10115.
23. Signorelli, C.; Capolongo, S.; D'alessandro, D.; Fara, G.M. The homes in the COVID-19 era. How their use and values are changing. *Acta Biomed.* **2020**, *91*, 92–94, doi:10.23750/abm.v91i9-S.10125.

24. Amerio, A.; Brambilla, A.; Morganti, A.; Aguglia, A.; Bianchi, D.; Santi, F.; Costantini, L.; Odone, A.; Costanza, A.; Signorelli, C.; et al. COVID-19 Lockdown: Housing Built Environment's Effects on Mental Health. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5973, doi:10.3390/ijerph17165973.
25. Tokazhanov, G.; Tleuken, A.; Guney, M.; Turkyilmaz, A.; Karaca, F. How is COVID-19 Experience Transforming Sustainability Requirements of Residential Buildings? A Review. *Sustainability* **2020**, *12*, 8732, doi:10.3390/su12208732.
26. D'Alessandro, D.; Appolloni, L. Housing and health: An overview. *Ann. Igiene* **2020**, *32*, 17–26.
27. Echegaray, F. What POST-COVID-19 lifestyles may look like? Identifying scenarios and their implications for sustainability. *Sustain. Prod. Consum.* **2021**, *27*, 567–574, doi:10.1016/j.spc.2021.01.025.
28. Cohen, M.J. Does the COVID-19 outbreak mark the onset of a sustainable consumption transition? *Sustain. Sci. Pr. Policy* **2020**, *16*, 1–3, doi:10.1080/15487733.2020.1740472.
29. Markard, J.; Rosenbloom, D. A tale of two crises: COVID-19 and climate. *Sustain. Sci. Pr. Policy* **2020**, *16*, 53–60, doi:10.1080/15487733.2020.1765679.
30. Le Quéré, C.; Jackson, R.B.; Jones, M.W.; Smith, A.J.P.; Abernethy, S.; Andrew, R.M.; De-Gol, A.J.; Willis, D.R.; Shan, Y.; Canadell, J.G.; et al. Temporary reduction in daily global CO₂ emissions during the COVID-19 forced confinement. *Nat. Clim. Chang.* **2020**, *10*, 647–653, doi:10.1038/s41558-020-0797-x.
31. Anantharaman, M.; Alpert, J.; Brown, H.; Fischer, D.; Vergragt, P. SCORAI in the pandemic and post-pandemic world. Provocation for the SCORAI Strategy Session. In Proceedings of the SCORAI International Conference 2020 (Fully Virtual Conference), 10–12 June 2020.
32. Torales, J.; O'Higgins, M.; Castaldelli-Maia, J.M.; Ventriglio, A. The outbreak of COVID-19 coronavirus and its impact on global mental health. *Int. J. Soc. Psychiatry* **2020**, *66*, 317–320, doi:10.1177/0020764020915212.
33. Banerjee, D.; Rai, M. Social isolation in Covid-19: The impact of loneliness. *Int. J. Soc. Psychiatry* **2020**, *66*, 525–527, doi:10.1177/0020764020922269.
34. Corwin, S.; Zarif, R.; Berdichevskiy, A.; Pankratz, D. The Future of Mobility after COVID-19 19, Deloitte Insights, 2020. Available online: <https://www2.deloitte.com/us/en/insights/economy/covid-19/future-of-mobility-after-covid-19-transportation-scenarios.html> (accessed on 10 December 2020).
35. Tchetchik, A.; Kaplan, S.; Blass, V. Recycling and consumption reduction following the COVID-19 lockdown: The effect of threat and coping appraisal, past behavior and information. *Resour. Conserv. Recycl.* **2021**, *167*, 105370, doi:10.1016/j.resconrec.2020.105370.
36. Cvetković, D.; Nešović, A.; Terzić, I. Impact of people's behavior on the energy sustainability of the residential sector in emergency situations caused by COVID-19. *Energy Build.* **2021**, *230*, 110532, doi:10.1016/j.enbuild.2020.110532.
37. Lăzărescu, L.-M.; Stefan, C.; Diacon, D.L.; Efras, V.; Horodnic, V.-D. Housing Affordability in the Context of Covid-19 Pandemic—New Challenges for Romania. In Proceedings of the International Conference Innovative Business Management & Global Entrepreneurship (IBIMAGE 2020), Warsaw, Poland, 4 September 2020; Volume 14, pp. 294–311, doi:10.18662/lumproc/ibmage2020/22.
38. Awada, M.; Becerik-Gerber, B.; Hoque, S.; O'Neill, Z.; Pedrielli, G.; Wen, J.; Wu, T. Ten questions concerning occupant health in buildings during normal operations and extreme events including the COVID-19 pandemic. *Build. Environ.* **2021**, *188*, 107480, doi:10.1016/j.buildenv.2020.107480.
39. Cheshmehzangi, A. Housing and health evaluation related to general comfort and indoor thermal comfort satisfaction during the COVID-19 lockdown. *J. Hum. Behav. Soc. Environ.* **2020**, 1–26, doi:10.1080/10911359.2020.1817225.
40. Tonne, C. Lessons from the COVID-19 pandemic for accelerating sustainable development. *Environ. Res.* **2021**, *193*, 110482, doi:10.1016/j.envres.2020.110482.
41. Tleuken, A.; Tokazhanov, G.; Guney, M.; Turkyilmaz, A.; Karaca, F. Readiness Assessment of Green Building Certification Systems for Residential Buildings during Pandemics. *Sustainability* **2021**, *13*, 460, doi:10.3390/su13020460.
42. Nguyen, B.K.; Altan, H. Comparative Review of Five Sustainable Rating Systems. *Procedia Eng.* **2011**, *21*, 376–386, doi:10.1016/j.proeng.2011.11.2029.
43. Illankoon, I.C.S.; Tam, V.W.; Le, K.N.; Shen, L. Key credit criteria among international green building rating tools. *J. Clean. Prod.* **2017**, *164*, 209–220, doi:10.1016/j.jclepro.2017.06.206.
44. Akhanova, G.; Nadeem, A.; Kim, J.R.; Azhar, S. A Framework of Building Sustainability Assessment System for the Commercial Buildings in Kazakhstan. *Sustainability* **2019**, *11*, 4754, doi:10.3390/su11174754.
45. Zarghami, E.; Azemati, H.; Fatourehchi, D.; Karamloo, M. Customizing well-known sustainability assessment tools for Iranian residential buildings using Fuzzy Analytic Hierarchy Process. *Build. Environ.* **2018**, *128*, 107–128, doi:10.1016/j.buildenv.2017.11.032.
46. Olawumi, T.O.; Chan, D.W.; Chan, A.P.; Wong, J.K. Development of a building sustainability assessment method (BSAM) for developing countries in sub-Saharan Africa. *J. Clean. Prod.* **2020**, *263*, 121514, doi:10.1016/j.jclepro.2020.121514.
47. Ferwati, M.S.; Al Saeed, M.; Shafaghat, A.; Keyvanfar, A. Qatar Sustainability Assessment System (QSAS)-Neighborhood Development (ND) Assessment Model: Coupling green urban planning and green building design. *J. Build. Eng.* **2019**, *22*, 171–180, doi:10.1016/j.job.2018.12.006.
48. Mohammadian, H.D.; Wittberg, V.; Castro, M.; Bolandian, G. The 5th Wave and i-Sustainability Plus Theories as Solutions for SocioEdu Consequences of Covid-19. In Proceedings of the 2020 IEEE Learning with MOOCS (LWMOOCS) 2020, Antigua Guatemala, Guatemala, 30 September–2 October 2020; pp. 118–123.

49. Awadh, O. Sustainability and green building rating systems: LEED, BREEAM, GSAS and Estidama critical analysis. *J. Build. Eng.* **2017**, *11*, 25–29, doi:10.1016/j.jobe.2017.03.010.
50. Kuzemko, C.; Bradshaw, M.; Bridge, G.; Goldthau, A.; Jewell, J.; Overland, I.; Scholten, D.; Van de Graaf, T.; Westphal, K. Covid-19 and the politics of sustainable energy transitions. *Energy Res. Soc. Sci.* **2020**, *68*, 101685, doi:10.1016/j.erss.2020.101685.
51. Mattarocci, G.; Roberti, S. Real Estate and the Effects of the COVID-19 Pandemic in Europe. In *A New World Post COVID-19*; Edizioni Ca Foscari: Venice, Italy, 2020; pp. 177–190.
52. Del Giudice, V.; De Paola, P.; Del Giudice, F. COVID-19 Infects Real Estate Markets: Short and Mid-Run Effects on Housing Prices in Campania Region (Italy). *Soc. Sci.* **2020**, *9*, 114, doi:10.3390/socsci9070114.
53. Tanrıvermiş, H. Possible impacts of COVID-19 outbreak on real estate sector and possible changes to adopt: A situation analysis and general assessment on Turkish perspective. *J. Urban Manag.* **2020**, *9*, 263–269, doi:10.1016/j.jum.2020.08.005.
54. Wang, Q.; Guozhu, L.; Chong, M.; Linna, X.; Maolin, L.; Rongxin, Z. *The Contribution of Green Buildings in the Fight Against COVID-19*; International Union of Architects: Beijing, China, 2020.
55. French, M.; Ramirez-Lovering, D.; Sinharoy, S.S.; Turagabeci, A.; Latif, I.; Leder, K.; Brown, R. Informal settlements in a COVID-19 world: Moving beyond upgrading and envisioning revitalisation. *Cities Health* **2020**, *1–4*, doi:10.1080/23748834.2020.1812331.
56. Deng, Y.; Wu, J. Economic returns to residential green building investment: The developers' perspective. *Reg. Sci. Urban Econ.* **2014**, *47*, 35–44, doi:10.1016/j.regsciurbeco.2013.09.015.
57. Rupani, P.F.; Nilashi, M.; Abumalloh, R.A.; Asadi, S.; Samad, S.; Wang, S. Coronavirus pandemic (COVID-19) and its natural environmental impacts. *Int. J. Environ. Sci. Technol.* **2020**, *17*, 4655–4666, doi:10.1007/s13762-020-02910-x.
58. Kapecki, T. Elements of Sustainable Development in the Context of the Environmental and Financial Crisis and the COVID-19 Pandemic. *Sustainability* **2020**, *12*, 6188, doi:10.3390/su12156188.
59. Farha, L. How Can Billions of People 'Stay Home' to Beat Covid-19 Without a Safe Place to Live? Guardian (last Updated 29 April at 8.33 BST). Available online: <https://www.theguardian.com/society/2020/apr/29/how-can-billions-of-people-stay-home-to-beat-covid-19-without-a-safe-place-to-live> (accessed on 31 May 2020).
60. Hamidi, S.; Porter, K.M.P. How Cities Are Taking Action on COVID-19. Planning Magazine. American Planning Association. 2020. Available online: <https://www.planning.org/planning/2020/jul/how-cities-are-taking-action-on-covid-19/> (accessed on 10 November 2020).
61. Barth, B. Increased Remote Work Could Mean Big Changes for Cities. Planning Magazine. American Planning Association. 2021. Available online: <https://www.planning.org/planning/2021/winter/increased-remote-work-could-mean-big-changes-for-cities/> (accessed on 20 January 2021).
62. La Salle, J.L. COVID-19 Global Real Estate Implications: Paper II. JLL Research Report. 2020. Available online: <https://www.us.jll.com/en/trends-and-insights/research/covid-19-global-real-estate-implications#download> (accessed on 15 January 2021).
63. Cournède, B.; Ziemann, V.; De Pace, F. Impact of COVID-19 on Housing: How Can Policies Support a Healthy Recovery? OECD Economics Department. 2020. Available online: <https://oecdecoscope.blog/2020/08/03/impact-of-covid-19-on-housing-how-can-policies-support-a-healthy-recovery/?print=print> (accessed on 10 January 2021).
64. Akhmouch, A.; Taylor, A. Cities Policy Responses. OECD, 2020, p. 97. Available online: https://read.oecd-ilibrary.org/view/?ref=126_126769-yen45847kf&title=Coronavirus-COVID-19-Cities-Policy-Responses (accessed on 15 January 2021).
65. Dechezlepretre, A.; Kozluk, T.; Elgouacem, A.; Kruse, T. COVID-19 and the Low-Carbon Transition: Impacts and Possible Policy Responses. 2020. Available online: <http://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-low-carbon-transition-impacts-and-possible-policy-responses-749738fc/> (accessed on 12 January 2021).
66. OECD. Housing amid Covid-19: Policy responses and challenges. In *OECD Policy Responses to Coronavirus (COVID-19)*; OECD: Paris, France, 2020.
67. The Urban Land Institute. Covid-19 and the Future of Affordable Housing. 2020. Available online: <https://medium.com/curiosityiskeysfr/covid-19-and-the-future-of-affordable-housing-fbe3c9cf1c7d> (accessed on 15 January 2021).
68. Anas, B. This is How COVID-19 Could Affect Homes of the Future. 2020. Available online: <https://www.marketwatch.com/story/this-is-how-covid-19-could-change-our-homes-in-the-future-2020-06-29> (accessed on 5 November 2020).
69. Rivera, S. Three Major Effects Coronavirus Is Having on the Boston Housing Market. Home&Property. 2020. Available online: <https://www.bostonmagazine.com/property/2020/08/27/coronavirus-real-estate-market-greater-boston/> (accessed on 15 November 2020).
70. Rizzato, E. 8 Future Interior Trends for the Homes Driven by the Corona Virus. 2020. Available online: <https://www.italianbark.com/future-interior-trends-interior-design-corona-virus/> (accessed on 15 November 2020).
71. Multifamily Housing Trends 2020. Available online: <https://2ndkitchen.com/apartments/multifamily-housing-trends/> (accessed on 17 October 2020).
72. Van Styvendael, C. How Will the COVID-19 Crisis Affect Housing in Europe? 2020. Available online: <https://www.friendsofeurope.org/insights/how-will-the-covid-19-crisis-affect-housing-in-europe/> (accessed on 15 November 2020).
73. Ogunnusi, M.; Hamma-Adama, M.; Salman, H.; Kouider, T. COVID-19 pandemic: The effects and prospects in the construction industry. *Int. J. Real Estate Stud.* **2020**, *14*, 120–128.
74. Gamil, Y.; Alhagar, A. The Impact of Pandemic Crisis on the Survival of Construction Industry: A Case of COVID-19. *Mediterr. J. Soc. Sci.* **2020**, *11*, 122, doi:10.36941/mjss-2020-0047.

75. Bailey, J.; Bouchardie, N.; Madalena, I. *COVID-19: The Current Impact on Construction and Engineering Projects*; White & Case: New York, NY, USA, 2020.
76. Shibani, A.; Hassan, D.; Shakir, N. The Effects of Pandemic on Construction Industry in the UK. *Mediterr. J. Soc. Sci.* **2020**, *11*, 48, doi:10.36941/mjss-2020-0063.
77. Ataei, H.; Becker, D.; Hellenbrand, J.R.; Mehany, M.S.H.M.; Mitchell, T.E.; Ponte, D.M. *COVID-19 Pandemic Impacts on Construction Projects*; American Society of Civil Engineers (ASCE): Reston, VA, USA, 2021.
78. Hook, J. Engineering & Construction in a Post-COVID World: Weathering the Storm. Available online: <https://www.pwc.com/gx/en/issues/crisis-solutions/covid-19/engineering-construction-post-covid-world.html> (accessed on 13 November 2020).
79. Gerrity, M. Top 10 U.S. Home Buying Trends for 2021 Revealed. *The World Property Journal*. Residential Real Estate news. 2020. Available online: <https://www.worldpropertyjournal.com/real-estate-news/united-states/seattle/real-estate-news-top-housing-trends-for-2021-housing-predictions-for-2021-zillow-housing-reports-for-2021-covid-19-impact-on-home-sales-how-coronavirus-has-changed-home-designs-12275.php> (accessed on 3 September 2020).
80. Barley, D. COVID Forcing Condos to Sell at Record 17 Percent Discount to Homes in U.S. *The World Property Journal*. Residential Real Estate News. 2020. Available online: <https://www.worldpropertyjournal.com/real-estate-news/united-states/miami-real-estate-news/real-estate-news-condo-versus-single-family-home-sales-data-for-2020-redfin-coronavirus-housing-report-covid-19-impact-on-condo-sales-in-2020-consumer-real-estate-buying-trends-in-2020-12253.php> (accessed on 9 October 2020).
81. Rachid, M. COVID-19 Causing Unexpected Impacts to U.S. Housing Inventory. *The World Property Journal*. Residential Real Estate News. 2020. Available online: <https://www.worldpropertyjournal.com/real-estate-news/united-states/irvine/real-estate-news-covid-19-impact-on-us-home-sales-zillow-2020-housing-data-coronavirus-impact-on-housing-inventory-2020-home-selling-data-12198.php> (accessed on 17 September 2020).
82. Olsen, H. The United States Might Have a Secret Weapon Against Coronavirus. *The Washington Post*, 20 March 2020.
83. Rosenthal, B. Density is New York City's big "Enemy" in the Coronavirus Fight. *The New York Times*. Available online: <https://www.nytimes.com/2020/03/23/nyregion/coronavirus-nyc-crowds-density.html> (accessed on 23 March 2020).
84. Hamidi, S.; Sabouri, S.; Ewing, R. Does Density Aggravate the COVID-19 Pandemic? *J. Am. Plan. Assoc.* **2020**, *86*, 495–509, doi:10.1080/01944363.2020.1777891.
85. Andris, C. Integrating social network data into GISystems. *Int. J. Geogr. Inf. Sci.* **2016**, *30*, 1–23, doi:10.1080/13658816.2016.1153103.
86. Park, K.; Ewing, R.; Sabouri, S.; Choi, D.-A.; Hamidi, S.; Tian, G. Guidelines for a Polycentric Region to Reduce Vehicle Use and Increase Walking and Transit Use. *J. Am. Plan. Assoc.* **2020**, *86*, 236–249, doi:10.1080/01944363.2019.1692690.
87. Hurtado, P. COVID-19, Communities, and the Planning Profession. American Planning Association. Available online: <https://planning.org/blog/9198765/covid-19-communities-and-the-planning-profession/> (accessed on 11 December 2020).
88. Gerrity, M. Million Dollar Cities in U.S. See Massive Surge from 2020 Pandemic. *The World Property Journal*. Residential Real Estate News 2021. Available online: <https://www.worldpropertyjournal.com/real-estate-news/united-states/san-diego-real-estate-news/real-estate-news-zillow-housing-data-for-2020-luxury-housing-report-for-2021-los-angeles-luxury-home-sales-chris-glynn-miami-luxury-condo-sales-data-12314.php> (accessed on 3 September 2020).
89. Driven by IoT and AI. Available online: <https://www.intellias.com/industry-5-0-whitepaper/> (accessed on 12 November 2020).
90. Selvaraj, A. Role of Humans in Industry 5.0. Available online: <https://www.columbusglobal.com/en/blog/role-of-humans-in-industry-5.0> (accessed on 17 November 2020).
91. Why Brands Must Embrace Hyperpersonalisation. Available online: <https://www.raconteur.net/retail/personalisation-customer-ex> (accessed on 19 November 2020).
92. Bednar, P.M.; Welch, C. Socio-Technical Perspectives on Smart Working: Creating Meaningful and Sustainable Systems. *Inf. Syst. Front.* **2020**, *22*, 281–298, doi:10.1007/s10796-019-09921-1.
93. Ozkeser, B. Lean Innovation Approach in Industry 5.0. *Eurasia Proc. Sci. Technol. Eng. Math.* **2018**, *2*, 422–428.
94. Yin, Y.; Stecke, K.E.; Li, D. The evolution of production systems from Industry 2.0 through Industry 4.0. *Int. J. Prod. Res.* **2018**, *56*, 848–861, doi:10.1080/00207543.2017.1403664.
95. Kaklauskas, A.; Lill, I.; Puust, R.; Ubarte, I. *Affective Internet of Things*; Elsevier BV: Amsterdam, The Netherlands, 2020; pp. 203–233.
96. Kim, J.; Zhou, Y.; Schiavon, S.; Raftery, P.; Brager, G. Personal comfort models: Predicting individuals' thermal preference using occupant heating and cooling behavior and machine learning. *Build. Environ.* **2018**, *129*, 96–106, doi:10.1016/j.buildenv.2017.12.011.
97. Li, J.; Niu, J.; Mak, C.M.; Huang, T.; Xie, Y. Assessment of outdoor thermal comfort in Hong Kong based on the individual desirability and acceptability of sun and wind conditions. *Build. Environ.* **2018**, *145*, 50–61, doi:10.1016/j.buildenv.2018.08.059.
98. Liu, W.; Lian, Z.; Zhao, B. A neural network evaluation model for individual thermal comfort. *Energy Build.* **2007**, *39*, 1115–1122, doi:10.1016/j.enbuild.2006.12.005.
99. Wang, Z.; Warren, K.; Luo, M.; He, X.; Zhang, H.; Arens, E.; Chen, W.; He, Y.; Hu, Y.; Jin, L.; et al. Evaluating the comfort of thermally dynamic wearable devices. *Build. Environ.* **2020**, *167*, 106443, doi:10.1016/j.buildenv.2019.106443.
100. Cao, B.; Zhu, Y.; Li, M.; Ouyang, Q. Individual and district heating: A comparison of residential heating modes with an analysis of adaptive thermal comfort. *Energy Build.* **2014**, *78*, 17–24, doi:10.1016/j.enbuild.2014.03.063.

101. Zhang, H.; Arens, E.; Huizenga, C.; Han, T. Thermal sensation and comfort models for non-uniform and transient environments, part II: Local comfort of individual body parts. *Build. Environ.* **2010**, *45*, 389–398, doi:10.1016/j.buildenv.2009.06.015.
102. Jung, W.; Jazizadeh, F. Comparative assessment of HVAC control strategies using personal thermal comfort and sensitivity models. *Build. Environ.* **2019**, *158*, 104–119, doi:10.1016/j.buildenv.2019.04.043.
103. Li, Z.; Loveday, D.; Demian, P. Feedback messaging, thermal comfort and usage of office-based personal comfort systems. *Energy Build.* **2019**, *205*, 109514, doi:10.1016/j.enbuild.2019.109514.
104. Cottafava, D.; Magariello, S.; Ariano, R.; Arrobio, O.; Baricco, M.; Barthelmes, V.; Baruzzo, G.; Bonansone, M.; Console, L.; Contin, L.; et al. Crowdsensing for a sustainable comfort and for energy saving. *Energy Build.* **2019**, *186*, 208–220, doi:10.1016/j.enbuild.2019.01.007.
105. Zhai, Y.; Miao, F.; Yang, L.; Zhao, S.; Zhang, H.; Arens, E. Using personally controlled air movement to improve comfort after simulated summer commute. *Build. Environ.* **2019**, *165*, 106329, doi:10.1016/j.buildenv.2019.106329.
106. Lu, S.; Wang, W.; Lin, C.; Hameen, E.C. Data-driven simulation of a thermal comfort-based temperature set-point control with ASHRAE RP884. *Build. Environ.* **2019**, *156*, 137–146, doi:10.1016/j.buildenv.2019.03.010.
107. Arens, E.; Zhang, H.; Huizenga, C. Partial- and whole-body thermal sensation and comfort—Part I: Uniform environmental conditions. *J. Therm. Biol.* **2006**, *31*, 53–59, doi:10.1016/j.jtherbio.2005.11.028.
108. Arens, E.; Zhang, H.; Huizenga, C. Partial- and whole-body thermal sensation and comfort—Part II: Non-uniform environmental conditions. *J. Therm. Biol.* **2006**, *31*, 60–66, doi:10.1016/j.jtherbio.2005.11.027.
109. Zhang, H.; Arens, E.; Huizenga, C.; Han, T. Thermal sensation and comfort models for non-uniform and transient environments, part III: Whole-body sensation and comfort. *Build. Environ.* **2010**, *45*, 399–410, doi:10.1016/j.buildenv.2009.06.020.
110. Lopez, G.; Tokuda, T.; Oshima, M.; Nkurikiyeyezu, K.; Isoyama, N.; Itao, K. Development and Evaluation of a Low-Energy Consumption Wearable Wrist Warming Device. *Int. J. Autom. Technol.* **2018**, *12*, 911–920.