

Article

Readiness Assessment of Green Building Certification Systems for Residential Buildings during Pandemics

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Abstract: One of the consequences of COVID-19 pandemic is the momentum it has created for global changes affecting various aspects of daily lives. Among these, green building certification systems (GBCs) should not be left behind as significant potential modifications may be required to ensure their versatility for residential buildings due to the new pandemic reality. The present study aims to evaluate the readiness of chosen GBCs for a proper assessment of existing residential housing sustainability in a post-pandemic world. Based on a literature review of the state-of-the-art data sources and round table discussions, the present study proposes a particular set of sustainability indicators covering special sustainability requirements under pandemic conditions. Then, those indicators are used to evaluate the readiness of selected GBCs (BREEAM, LEED, WELL, CASBEE) to meet new pandemic-resilient requirements based on their responses to the indicators. The assessment shows that none of the reviewed GBCs are fully ready to cover all the proposed indicators. GBCs have differing focuses on particular sustainability pillars, which also affected their responses to pandemic-resilient categories. For instance, WELL rating system successfully responded to the health and safety category, whereas LEED showed better preparedness in terms of environmental efficiency. BREEAM and CASBEE systems have a more evenly distributed attention to all three pandemic-resilient categories (Health & Safety, Environmental Resources Consumption, and Comfort) with an accent on the Comfort category. On a specific note, all GBCs are insufficiently prepared for waste and wastewater management. In the future, GBCs should be modified to better adapt to pandemic conditions, for which the current work may provide a basis. As an alternative, brand new standards can be created to face newly arising and evolving post-pandemic requirements.

Keywords: BREEAM; CASBEE; COVID-19; LEED; residential building sustainability; SARS-CoV-2; urban sustainability; sustainability requirements; WELL



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1. Introduction

Construction activities may adversely affect the natural environment; as a result, sustainability has been a well-recognized concept in the construction industry. According to the United Nations Environment Program, 25% of waste production, one-third of CO₂ emissions, and 30% of all annual waste products are generated by the construction industry [1]. Hence, the sustainability of residential buildings plays a crucial role in assisting the sector in decreasing greenhouse gas emissions, reducing air pollution, improving health outcomes, and improving quality of life. Sustainability in construction and buildings creates new business opportunities and working places and increases productivity and energy security [2]. This attention to sustainability in the construction sector has also resulted in the development of various international policies, declarations to preserve the environment, and the promotion of assessment systems to increase sustainability [3].

Sustainability assessment systems for buildings integrate sustainability into construction processes and the building itself. Various building sustainability assessment tools (BSATs) are used as a benchmark for construction companies to promote sustainability by meeting the required construction and design challenges under three main sustainability pillars: economic, environmental, and social pillars [2,4].

An increased focus and attention on the development of sustainable residential buildings has led to the certification of various green buildings during the last three decades [5], which attracts further attention and popularity as time passes. Currently, there are more than 400 registered sustainability assessment tools for buildings [6]. Moreover, several green building certification systems (GBCs) such as Building Research Establishment Environmental Assessment Method (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Leadership in Energy and Environmental Design (LEED), and WELL Building Standard have already established themselves as well-known and recognized systems. These systems help the construction sector decrease the impact of buildings on the environment and increase their performance quality throughout their lifetime [7]. However, it is essential to note that most green building certification systems are designed to evaluate the sustainability of buildings in a specific region, whereas variations in sustainability may occur due to factors such as climate, geographical features, and government policies [1,2,8]. Hence, a lot of researchers are already trying to adapt established green building rating systems for developing countries, examples including Kazakhstan [1], Iran [9], sub-Saharan African countries [5], and Qatar [10].

As different countries require an adaptation of existing green building rating systems to each region's specific features, similarly, rapid global changes in humanity's living conditions also require an adaptation of existing green building rating systems to current living conditions. A novel coronavirus disease, also known as COVID-19, hit the whole globe overwhelming our societies and crucially affecting almost every part of our life, including healthcare systems, economy, education, business, lifestyles and conditions, and tourism [11,12]. Almost everyone has experienced lockdowns during quarantines, facing difficulties stemming from being stuck at home for long durations [13]. Such unexpected changes in our life brought us to a new reality, which should be analyzed and considered for future decision-making processes.

Since the changes brought by COVID-19 pandemic affect our life not only until the end of the epidemic but possibly permanently, a lot of researchers are rethinking the current sustainability approaches, pushing the boundaries of sustainability [12]. For example, Mohammadian et al. (2020) [14] mentions that there should be more sustainability pillars than the conventional three. They state that seven pillars, directly or indirectly related to each other, should be included to maintain sustainable development: environment, economic, social, educational, cultural, technical, and political. Other researchers elucidated that the current sustainability assessment rating systems like LEED, BREEAM, etc. are mainly focused on the environmental (energy, indoor environment) pillar of sustainable development whereas the social aspect of sustainability is given the least attention [15]. Kuzemko et al. (2020) [16] studied how the current pandemic could affect the transition of sustainability in the short-term and long-term. They concluded that in the energy sector, the prices along with demand for electricity would fall. There might be a decrease in investments in current industries and carbon-intensive fuels. Established conventions regarding globalization and interconnectivity could be questioned, affecting the politics and multi-scalar policies. The pandemic is also seen as an opportunity and an important potential driver to shift from unsustainable practices like 'driving' towards more sustainable practices such as 'walking'.

Previous epidemics have already significantly impacted the built environment, and the major examples include: development of green spaces and reconsideration of wastewater routes as a response to cholera and plaque; increase of sunlight in housing units as an anti-tuberculosis measure; and improvement of ventilating systems after SARS-COV-1 outbreak [17]. Facilities for remote working are predicted to become more important in

the design of future homes [18]. Rume et al. (2020) [19] highlighted the positive and negative consequences of COVID-19 pandemic: the positive environmental outcomes have been reported as the reduction of air, water, and noise pollution and the ecological restoration of touristic zones, whereas the negative environmental outcomes are associated with biomedical and solid waste generation as well as a reduction in waste recycling, concluding that COVID-19 might play a crucial role for uniting the globe towards sustainable development. In our previous study [20], we reported how the current pandemic would change residential buildings' sustainability requirements based on the latest ideas from various stakeholders (architects, engineers, academicians, general public, etc.). Residential buildings will play a way more important role in the future since it will have to satisfy more human needs than it used to. Quarantines made everyone realize that our homes have become more than just a place where we sleep and rest. For most, it is now a place where we have to spend almost all of our time including working hours, meaning that our health and social well-being now more closely depend on the quality of our homes. The future design of residential buildings should consider not only environmental, social, and economic pillars of sustainability but also the health, comfort, and safety of their residents and should assure their proper social well-being and mental state.

New touchless and automated technologies along with innovative surface materials could help avoid virus propagation within a residential building, and more green spaces could help maintain the healthy mental state of residents. The comfort of the residential buildings could be further supported by communication technologies such as remote controls. Also, smart innovations could automatize the control of indoor environmental parameters such as air quality, temperature, light, and humidity [20]. Therefore, BSATs and GBCs will serve as one of the essentials of the construction sector through the promotion of planning for the needs of a pandemic reality. A better sustainable design of living spaces should consider the functionality for individual and social needs as well as health and provide favorable conditions for working from home as people would spend most of their time isolated in built spaces. There is a knowledge gap on how GBCs address such pandemic requirements, which first requires to perform systematic assessments to evaluate their readiness and response levels for the pandemic to adapt to this new reality. The critical question raised here is whether the sustainability topics affected by the pandemic is going to be pushed forward and lead to permanent changes or this sudden rise in sustainability awareness is going to be lost with the end of the pandemic.

The present study aims to evaluate the readiness of several chosen GBCs for the new reality of living in residential housing in a post-pandemic world. Firstly, it suggests a new set of sustainability indicators addressing the requirements of the post-pandemic reality. These indicators are then used to assess the responses from GBCs to meet the sustainability requirements under pandemic conditions. For this assessment, BREEAM, LEED, WELL, and CASBEE building certification systems are selected. They have then been analyzed quantitatively and by ordinal prioritization for their readiness to assess the sustainability of residential buildings under pandemic conditions. A comparison based on the quantitative assessment relying on the total and partial points, as well as weights of matching responses, was provided. Simultaneously, an assessment method of prioritizing orders has been carried out based on an ordinal importance scale to measure the quality of suggested responses to pandemic-resilient indicators.

2. Methods

The indicators of the present study mainly focused on two sustainability pillars: environmental and social. However, some indicators may be perceived beyond the scope of the three conventional sustainability pillars (environmental, social, and economic) as they are mostly related to residents' health and safety. The indicators were categorized into subcategories, while subcategories were classified into three main categories: Health & Safety, Environmental Resources Consumption, and Comfort. They were used to measure the readiness of the GBCs for pandemic conditions and targets to existing buildings. The ab-

abbreviations are used as a representation of each subcategory (e.g., PVP—Prevention of Virus Propagation), and the number after each abbreviation represents the indicator that belongs to that subcategory (e.g., PVP1—use of smart/innovative air quality control technologies).

2.1. Identification of Pandemic Response Categories, Subcategories, and Indicators

The selection of categories, subcategories, and indicators has been realized via a two-step process: (a) literature review, (b) round table expert discussion with creative brainstorming activities. The literature review process covered all up-to-date available information sources regarding COVID-19 and its effects on residential buildings and their sustainability. It included sources such as peer-reviewed scientific journals, news (web), reports, and blogs. For data sources search, multiple resources including Google Scholar, ScienceDirect, Scopus, and Web of Science have been used. The keywords used included “green building certification systems”, “SARS-CoV-2”, “COVID-19 pandemic effects”, “coronavirus prevention”, and “safety measures in residential buildings during a pandemic”. Following the literature review, brainstorming activities have been conducted to identify the critical indicators representing a building’s sustainability under pandemic conditions. As a result, thirty-three indicators have been identified and were further allocated into ten subcategories, which are divided into three main categories. Description of these indicators along with references to state-of-the-art sources can be read in Section 3.1.

2.2. Assessment Method for Green Building Certification Systems

To review different GBCSs and to identify the level of their response to pandemic-resilient factors, four common green building standards from different continents were considered: BREEAM, LEED, WELL, and CASBEE. Among these standards, BREEAM, LEED, and CASBEE are deemed to be the most prominent among other green rating systems, as they had been used in more than 500 projects, each has been cited more than 20 times in scientific articles, and their primary focus is set on buildings [21]; whereas WELL has been among the first standards that focus on health and well-being of occupants [22]. Furthermore, these standards are comprehensive in terms of their coverage of all three pillars of sustainability (along with varying focus areas for each). Finally, they could be deemed to represent the majority of GBCSs relatively well in terms of their coverage, assessment mechanics, and evaluation approaches.

Each selected GBCS has been carefully evaluated to understand how their criteria matched and responded to pandemic resilience indicators. The assessment part covered quantitative and ordinal prioritization analyses of the selected GBCSs. In the quantitative assessments, the total and partial points and weights of matching responses have been calculated and then compared. Simultaneously, an ordinal prioritization assessment method has been carried out based on an ordinal importance scale, which aimed to measure the quality of suggested responses to pandemic-resilient indicators. The quality rating consisted of four orders—from 0 to 3—(Table 1) without delving into how much quantitative weight is given for each. Both assessments have been employed in combination to judge better the readiness of the selected GBCSs for a pandemic.

Table 1. The ordinal scale of scores for comparison of the GBCS credits with the pandemic-resilient indicators.

Order	Meaning
0	GBCS does not address any pandemic-resilient indicator
1	GBCS vaguely mentions pandemic-resilient indicator(s)
2	GBCS indirectly addresses pandemic-resilient indicator(s)
3	GBCS directly addresses pandemic-resilient indicator(s)

3. Results

Current experience with the COVID-19 pandemic has disclosed social and technical aspects of living experience. Quarantine has especially exposed several major needs of occupants that were stuck in residential buildings. For example, buildings are full of touching surfaces [23]. Thus, existing residential buildings are highly vulnerable to the pandemic, which is clearly seen from policies of closing whole buildings for quarantine in the case of finding an infected occupant there [24]. Residents locked in these buildings were complaining about lack of local food and medicine reserves, which has driven us to development of “local services” sub-category [25,26]. Increase in sense of loneliness during the COVID-19 pandemic [27] has led us to add indicators for enabling communication with safety measures at residential buildings to improve mental state during pandemics. Also, due to the pandemic, household energy consumption has globally increased due to people spending most of their time at home, at the same time leading to increased peaks in consumption [28–30]. The energy surge leap can be explained by the wide use of information and communication technologies (ICTs), entertainment technology, cooking, laundry, more frequent showering at home, etc. [29,31]. Nevertheless, whereas the commercial energy use has decreased, this has only partially been balanced by an increase in residential consumption [32]. This experience brings the need to develop criteria for energy management. In addition, during the pandemic, household water consumption has increased. This can be linked to more frequent hand washing, laundry, and other cleaning/disinfection practices, and more frequent home cooking [31,33]. This experience develops a need for buildings to (1) develop access to alternative water sources in case of water scarcity and to (2) use efficient appliances and fixtures. Wastewater could also pose a considerable health risk in terms of pathogen transmission. SARS virus outbreak experience has shown that the feces of infected people could contain a virus and thus contaminate the wastewater [34]. The traces of COVID-19 virus have been found in hospital sewage pipes [35] and in community wastewater, thus may pose a risk to public health [36]. Waste management experience during COVID-19 has faced a vast increase of single-use medical waste (e.g., masks, gloves) [37], global misunderstanding about recycling practices, and rising use of packaging to protect the products (especially, food) from viruses [38]. These findings of social and technical lessons learned of COVID-19 pandemic has brought us to the development of the following sub-categories: prevention of virus propagation, water and energy consumption, personal comfort, air quality, waste and wastewater management, energy and water use management, personal comfort, and self-dependent local services. These findings are consistent with other studies of social and technical aspects of living in residential buildings through pandemic [23,39–41]. The following pandemic-resilient indicators are developed for broad type of residential buildings, and their implementation (when possible) is suggested to improve life of residents during pandemics.

3.1. Pandemic-Resilient Indicators

A total of 33 pandemic-resilient indicators have been identified based on the literature review and consistent with three sustainability pillars—environment, social, and economic factors (Table 2). They were categorized into three pillars: Health & Safety, Environmental Resources Consumption, and Comfort, as suggested by the previous research [20].

Table 2. Pandemic-resilient indicators.

Category	Subcategory	Indicators
Health & Safety	Prevention of Virus Propagation (VP)	PVP1. Use of smart/innovative air quality control technologies
		PVP2. Use of touchless technologies
		PVP3. Self-cleaning spaces
		PVP4. Proper selection of indoor materials
		PVP5. Natural light
		PVP6. Adjustability of indoor temperature and humidity
	Mental Health (MH)	MH1. Availability of greenery and gardens
		MH2. Availability of outdoor spaces in the building
		MH3. Access to common building spaces with sufficient safety and social distance
		MH4. Household-level activity/sport spaces
	Air Quality (AQ)	AQ1. Efficiency of air filtration systems against pathogen propagation
		AQ2. Monitor and control indoor air pollution
		AQ3. Control the airflows in micro spaces
		AQ4. Level of natural ventilation
	Water Quality and Availability (WQ)	WQ1. Safety measures of drinking water and/or tap water from contamination.
		WQ2. Maintenance and/or decontamination of the building water system for infection
Wastewater Management (WWM)	WWM1. Specific measures to limit virus propagation at household level	
	WWM2. Availability of separate toilets for infected	
	WWM3. Separation of greywater	
Environmental Resources Consumption	Energy Use (EU)	EU1. Access to backup energy sources
		EU2. Promotion of sustainable and alternative energy sources
		EU3. Use of energy-efficient appliances
	Waste Management (WM)	WM1. Proper segregation of medical waste
		WM2. Disinfection of household waste
		WM3. Management of an increased amount of waste
	Water Consumption (WC)	WC1. Access to alternative water sources
		WC2. Use of water-efficient appliances and fixtures
	Comfort	Personal Comfort (PC)
PC2. Levels of indoor space adjustability		
PC3. Personal space		
PC4. Design level adjustments on noise insulation and acoustics		
Local Services (LS)		LS1. Availability of self-dependent services in the residential complexes
		LS2. Urban/community farming

3.1.1. Health & Safety

COVID-19 is responsible for approximately 3% of the worldwide death toll [42]. Considering the large health risks associated with infections, this category includes indicators that addressed occupants' health & safety in residential buildings and is subdivided to address virus propagation risks, mental health risks, air, water, and wastewater quality issues.

(i) Prevention of Virus Propagation (VP)

Healthcare systems of numerous countries have faced a crisis during the COVID-19 outbreak [43]. The main goal of the systems was to “flatten the curve” of infected people,

which could only be achieved by preventing virus propagation. This category addresses the indicators that can help to obstruct the contagion transmission.

PVP1. Use of new smart/innovative technologies: Using smart and innovative technologies can help promote a healthier atmosphere in the residential buildings as they can diminish human involvement, improve remote control, and thus minimize the risk of virus propagation [44]. Some possible smart technologies that can be installed in residential houses are motion sensors or thermal detectors and air/temperature/humidity regulators. Special attention should be given to CO₂ monitors as, when detecting carbon dioxide amount exceeding 1000 ppm, they also indicate a poor level of ventilation and a potential presence of other air pollutants indoors [45]. The increase in time spent at homes during a pandemic makes these monitors even more important for residents' short- and long- terms of health risks.

PVP2. Use of touchless technologies: Touchless technologies are crucial in achieving a healthier environment inside residential complexes as they remove the necessity to contact surfaces, which will help stop the spread of pathogens. They include (but are not limited to) the following: motion sensors for door opening, keycard swiping, voice control, face recognition, and other artificial intelligence-based smart technologies [46]. Internet of things can also help to reduce the need to touch the surfaces inside the housings by, for instance, connecting smartphones with elevators or doors via dedicated applications serving as remote control [47,48].

PVP3. Self-cleaning spaces: The spread of COVID-19 has developed a need for proper and continuous sanitation and disinfection of the spaces in housings, exacerbated by the fact that many people had a home quarantine after coming abroad or when exhibited mild symptoms that might be associated with contagious diseases. Residential complexes have been cleaned more frequently either by cleaning services (in common spaces) or by residents themselves [33]. The cleaning involves mostly people conducting the works; thus, it can contrarily increase the spread of disease. Therefore, an ideal housing is suggested to sanitize areas without any human contact, especially in apartments with occupants having/suspected to have an infection and in common spaces such as at public restrooms. For example, this can be done via spraying down disinfection [48]. The active ingredients should be efficient disinfectants and also able to clean the coronavirus.

PVP4. Proper selection of indoor materials: Healthy environment inside buildings is also dependent on the quality of indoor materials. Mainly, the propagation of a virus is dependent on the medium on which it has settled, and depending on the type of material, viruses have various survival times. For example, copper and its alloys (such as bronze) are able to kill pathogens [46,49]. Another example is cardboard material, which, due to its porous structure, is able to stop the movement of the virus [50]. Finally, there are several examples of innovative antiseptic materials such as Lapitec or Krion [51–53]. Pemmada et al. (2020) has studied specific types of coating materials that can inactivate viruses. They highlight three main potential antiviral coating materials: antiviral polymers, metal ions/oxides, and functional nanoparticles. Also, such coating can possibly be used for the optimization of face masks to eliminate the SARS-CoV-2 like viruses [54].

PVP5. Natural light: This indicator suggests designing residential houses to allow sufficient natural light to illuminate the most area of an apartment. This is linked to the findings that radiation emitted by sunlight is able to kill pathogens and thus prevent their activity [55,56]. Although some sources argue that sunlight cannot kill specifically SARS-CoV-2 [20], sunlight can still help create a healthier environment at home, such as by preventing the viability of bacteria in household dust [57]. As quarantines worldwide have led people to spend a majority of their time at home, the ability of natural light' to impede the spread of certain pathogens makes it a crucial factor in establishing a healthier indoor environment.

PVP6. The adjustability of indoor temperature and humidity: Humidity and temperature are claimed to be among the most important home characteristics that could impact virus propagation [58]. Humid places and warm temperatures both as single and

combined factors are claimed to reduce the chance for virus transmission [59]. In addition, existing literature shows that humid and warm countries indeed could reduce COVID-19 propagation; nevertheless, this cannot be achieved solely by temperature and humidity, but with a combination of different factors including temperature and humidity [60]. This can be explained by larger droplet sizes that capture viruses and fall more often on the ground, i.e., without staying in the air for a long time. On the contrary, dry air and cold temperature allow virus-containing aerosols remain in the air for a long time while at the same time making the nose more susceptible to viruses. Nevertheless, some studies claim that increased humidity can also facilitate virus propagation [61,62]. For that reason, and also due to subjectivity of temperature and humidity (i.e., dependence on occupants perception) [63], implementation of adjustable controls is suggested.

(ii) Mental Health (MH)

Home quarantines have forced people to spend weeks, and at times, even months at home—working, studying, and spending leisure time indoors. Such a lifestyle can negatively affect mental health [64]; therefore, it is important to keep the psychological state healthy. This category is dedicated to establishing indicators beneficial for mental health.

MH1. Availability of greenery and gardens: Green spaces are claimed to positively affect the mental health of occupants of different ages [65]. The examples of green space include indoor gardens, green views from the windows, and small gardens in balconies [18]. These can help people decrease their level of anger, provide relaxation, and decrease the chance of stress-related diseases such as cardiovascular illnesses and depression [66].

MH2. Availability of outdoor spaces in the building: Accessible and livable outdoor spaces are important for the occupants' mental health. Residents who had habitable balconies in their apartments had less severe depression syndromes than those with no outdoor spaces [41]. During massive quarantines, outdoor spaces may still provide people the possibility to socialize while keeping a social distance. People have been observed to be singing, clapping, and even conducting concerts together while being on their balconies [67]. Accessible outdoor spaces can also use glass walls.

MH3. Access to common building spaces with sufficient safety and social distance: COVID-19 can quickly propagate by air and by surfaces contacted by infected people. At the same time, the public should have some shared spaces in residential buildings to maintain socializing. Therefore, common places for buildings should acquire special safety measures. These can include wider corridors for avoiding crowdedness or installing glass walls as a means of protection against virus propagation.

MH4. Household-level activity/sports spaces: Sports activities have a positive effect on mental health, which is especially vital during pandemics to build a stronger immune system and to reduce stress [68]. Therefore, buildings are suggested to implement activity spaces that could be used for household-level sports exercises and for fitness activities.

(iii) Air Quality (AQ)

AQ1. Efficiency of air filtration systems against pathogen propagation: High-efficiency filters should be installed to minimize the transmission of virus and bacteria through ventilation and air-conditioning systems. For example, HEPA filters have been claimed to provide the best protection from pathogens [69]. WHO [70] also recommends using the strongest air filtration.

AQ2. Monitor and control indoor air pollution: Indoor air pollution should be continuously inspected for levels of CO₂, PM_{2.5}, and PM₁₀ to ensure a healthy environment. As previously discussed in PVP1, CO₂ monitors can demonstrate ventilation efficiency. COVID-19 pandemic has worsened the indoor environment air quality by increasing indoor air pollutants mainly through cleaning products and via inadequate ventilation due to financial limits. Exposure to PM_{2.5} has been proven to deteriorate patients' course of COVID-19 [45].

AQ3. Control the airflows in micro spaces: The airflow between micro spaces (e.g., rooms) are recommended to avoid colliding (mixing with each other) to prevent the

potential propagation of pollutants and viruses. That is, if one micro space has pathogens in its air, the airflow needs to be prevented to move to another micro space. This can be achieved by various methods of ventilation systems that could develop fresh air circulation from outdoors to interior side of the residence. Old buildings can be implemented with ventilators having variable-speed (at least, in one room), thus, setting different airflows. Nevertheless, the risk of overpressure should be avoided [71,72].

AQ4. Level of natural ventilation: Natural ventilation is claimed to be a healthy preference for limiting SARS-CoV-2 concentration in air [70,72,73].

(iv) Water Quality and Availability (WQ)

WQ1. Safety measures of drinking water and/or tap water from contamination: Currently, tap water in most countries is not drinkable [74]. Nevertheless, home isolation highlights the need to develop measures to prevent drinking water contamination from pathogens. That is, taps in residential buildings are recommended to be specifically equipped with systems for cleaning and disinfecting from pathogens, chemicals, and other toxins.

WQ2. Maintenance and/or decontamination of the building water system for infection: This indicator covers the decontamination of water at the building level. WHO and UNICEF [75] recommend to clean water systems from coronaviruses by filtration, disinfection, and chlorination. Nevertheless, due to current limited amount of research and expertise on coronavirus removal from water, these methods still need careful experimentation for further certification and professional use.

(v) Wastewater Management (WWM)

WWM1. Specific measures to limit virus propagation at a household level: These measures could include the proper sealing of pipes, sinks, and air conditioning and water-cooling systems to prevent leakage and impeding the propagation of pathogens. Other methods can involve implementing negative pressure strategies to avoid water flow that could potentially transport pathogens. According to the Italian Institute of Health and US Center for Disease Control and Prevention, the genetic material of SARS-CoV-2 has been identified in urban wastewater, making wastewater a possible indicator of virus transmission [76–78]. Even though the virus in wastewater does not directly translate to infection, recent studies suggest that human stool could carry infectious viruses and transport them via wastewater systems [23]. Hence, a proper waste piping system becomes an issue of special importance.

WWM2. Availability of separate toilets for infected: WHO (2020) [79] recommends, when possible, using separate hygienic facilities in households to decrease the chance of virus spread.

WWM3. Separation of greywater: Due to insufficient data on the novel COVID-19, it is unknown at the time of the present study whether the virus can survive in greywater. Nevertheless, based on the experience of SARS and MERS coronaviruses, greywater can be advised to separate to limit pathogen spread [80].

3.1.2. Environmental Resources Consumption

During pandemics, human health is the priority consideration. Nevertheless, it is still essential to consider the environmental effects of residential buildings, namely, energy/water consumption and waste effects.

(i) Energy use (EU)

EU1. Access to backup energy sources: An increased pressure on energy sources along with larger peaks due to increased demand can create failures in energy provision. For comfortable home practices, a robust energy supply is essential. Thus, it is suggested to develop backup energy sources that could ensure supply in emergency cases.

EU2. Promotion of sustainable and alternative energy sources: An increased energy consumption will lead to further negative environmental impacts, which emerges the need to promote sustainable energy sources in residential housing.

EU3. Use of energy-efficient appliances: Another way to mitigate the increased energy consumption is to install energy-efficient appliances in households.

(ii) Waste Management (WM)

WM1. Proper segregation of medical waste: Protective equipment, such as masks or gloves, is being extensively used for safety measures. It also brings the need for developing specific management strategies while keeping safety measures [17]. For example, the development of a new category for household waste that would store protective equipment wastes only would be suggested.

WM2. Disinfection of household waste: An abundance of people has experienced home isolation after arriving from another country or having mild symptoms that may be related to a COVID-19 infection. In these cases, their household waste could potentially contain the infection; therefore, special strategies to adopt are suggested. A possible way is to keep the waste for approximately 72 h, thus allotting some time for the virus to decline [81].

WM3. Management of an increased amount of waste: Global lockdowns have resulted in increased amounts of household waste. Contributing examples include excessive use of single-use medical masks and gloves and more frequent delivery services that adopt single-use packaging [38].

(iii) Water consumption (WC)

WC1. Access to alternative water sources: Examples of alternative water sources are additional reservoirs with water reserves, rain, and stormwater, recycled water, ground-water, condensation of water during hot days by cooling water towers rooftops, or air devices [82]. Another way to generate water is to extract water from the vapor in the air, also called atmospheric water generation.

WC2. Use of water-efficient appliances and fixtures: Water-efficient appliances include (but are not limited to) low-flow showerheads and toilets, fixtures that transfer gray water from sink to toilet tank for further flushing, fixtures that notify the user about consumed amount through voice or on screen [83].

3.1.3. Comfort

(i) Personal comfort (PC)

PC1. Specific emphasis on household-level ICT infrastructure access: A robust high-speed internet connection is now deemed essential for pandemic and post-pandemic conditions in residential buildings due to an increased dependence on ICT technologies such as online studying/working, online medical consultations, food delivery services, etc. [18,84,85].

PC2. Levels of indoor space adjustability: Indoor space adapting technology can help to create when needed, special spaces for a home office, study room, leisure, or fitness; allowing occupants to share the same housing unit and independently do their chores without interfering with each other [86]. This requires removing strict architectural boundaries and allowing the residents to decide on the apartment layout themselves. Moreover, home adjustability technology facilitates the work organization process, which has been problematic during quarantine times [87].

PC3. Personal space: Private space is a crucial social indicator [18]. When all family members have been stuck at home during home quarantines, it has been very difficult for some people to establish their private space. It has been claimed that people who had sufficient personal space for work, exercise, and personal intimacy were happier and had lower stress as opposed to those living in houses with insufficient personal space [88].

PC4. Design level adjustments on noise insulation and acoustic: Acoustic comfort is essential for the occupants of residential buildings such that some researchers claim that occupants perceive it as more important than thermal comfort, light, and indoor air [89].

(ii) Local services (LS)

LS1. Availability of self-dependent services in residential complexes: Self-dependent services are essential for residential buildings, especially those supplying food and medicine. In many countries, when whole residential complexes were being closed, the residents suffered from a scarcity of local reserves [25]. Besides, quarantine measures in some places furthermore prohibited inter-city movement. The quarantine practices have negatively affected supply chains and created a need for shorter supply paths that also provide a lesser chance to spread the virus [90].

LS2. Urban/community farming: Resilient food systems with short travel paths can also be achieved by developing urban farming [91]. During the lockdowns, urban farming can help to replenish food reserves while keeping social distancing. Moreover, growing vegetables and fruits enhances mental well-being [92]. Urban farming can be practiced at different levels, such as city-level, residential complex gardens, or private apartments.

3.2. GBCS Readiness Assessments

In the following assessment sections, the standard criteria of the selected GBCSs (BREEAM, LEED, WELL, and CASBEE) have been compared with the identified pandemic-resilient indicators. At the end of each subsection, the quantitative and ordinal prioritization assessment scores of the GBCS responses have been summarized and then compared to find how much they are matching pandemic-resilience indicators.

3.2.1. BREEAM

BREEAM is a British system of assessing the sustainability characteristics of buildings based on environmental, economic, and social performance. It is a scorecard system with pre-defined percentages for each of its credits [93,94]. According to the guide, BREEAM can be applied to different types of buildings that are able to impact the environment or society. Nevertheless, its application for single homes should be consulted prior to start as they might not always significantly impact the environment and society. BREEAM has issued exceptional guidance related to COVID-19. However, it is mainly associated with the physical process of certification, not rating the buildings. For example, instead of the assessor gathering information during a site assessment, the assessment can be done by a specially appointed person from the site, while the information near the building site (exterior) could be gathered using alternative services, e.g., Google Maps [95].

(i) Health & Safety

Prevention of Virus Propagation (PVP). To start with, PVP1 was partially addressed in a BREEAM criterion “innovation,”—which aims to support any innovation that could bring potential sustainable benefits. This criterion is related to any stage of construction. It weighs 1%; however, it is treated as an additional point. This criterion somehow matched the pandemic-resilient indicator of using smart and innovative technologies to minimize virus propagation, but in a general and vague manner. Regarding PVP2 and PVP3 indicators, no related criteria have been found as a response. PVP4 is partially addressed by the criterion “Low impact materials” (weight: 2.7%)—it aims to lower the environmental effect by using greener materials. It addresses the importance of the impact of materials choice. However, BREEAM puts more focus on the environmental effect, whereas it does not specifically require a positive impact on public health and/or minimization of pathogens. “Microclimate” criterion responded to PVP5—it intends to create a convenient environment by regulating local climatic characteristics (weight: 1.8%). This criterion is comprised of several characteristics, such as temperature, natural light, air, dust, acoustics, and snow (each supposed to be 0.3%). Although this criterion mentions solar exposure mainly as a visual characteristic of comfort, increasing natural light indoors is beneficial for health. Like the previous indicator, PVP6 was also addressed by the “microclimate” criterion as it also includes characteristics of thermal comfort. With an approximate calculated weight of 0.3%, this criterion was assigned an order of 3, as it fully addressed the thermal comfort indicator.

Mental Health (MH). The criterion “Green infrastructure,” being a part of the social and economic well-being category, fully matched the indicator MH1, which aims to provide access to the natural environment for all the occupants (1.8%). Besides, MH1 was also addressed by the “demographic needs and priorities” criterion, which targets the public’s needs, including green spaces development (2.7%). “Enhancement of ecological value” criterion (1.1%) aims to maximize ecological value, which includes the planning of green infrastructure as a means of improving residents’ health and well-being. It comprehensively addressed the MH1 indicator. Summing up, the average score of MH1 indicator response in the BREEAM standard was 3. Regarding MH2, no related criterion was found; therefore, a score of 0 was assigned. MH3 and MH4 were mentioned in the “inclusive design” criterion. It is a part of the social and economic well-being category that aspires to develop inclusive and accessible facilities for most occupants (1.8% with four sub-criteria, each 0.45%). Delving further, 0.45% can be equally divided between MH3 and MH4 (i.e., each 0.225%). Sub-criterion 1 (CN1) requires the design of open spaces and sports and recreation spaces for the residents. With the MH3 indicator, this criterion was given an order of 2 because it mentioned common sports spaces but did not include safety measures. Whereas, with the MH4 indicator, this criterion fully addressed the goal of creating sports spaces.

Air Quality (AQ). AQ1 was not addressed in the BREEAM standard; therefore, a score of 0 was assigned. “Sustainable buildings” criterion can be referred to as AQ2 (namely, sub-criterion CN4). CN4 recommends preventing and mitigating sources of contamination. “Sustainable buildings” weighs 4.1%, with five sub-criteria, each 0.8%. The criterion vaguely mentioned pollution prevention, without clarifying whether air or water pollution was being discussed. As mentioned in the PVP5 indicator description, the “microclimate” criterion also included air direction, movement, and speed, which was consistent with AQ3. With an approximate calculated weight of 0.3%, this criterion was assigned order 3, as it fully addressed the control of airflows in the apartment spaces. The indicator AQ4 was partly covered by sub-criterion 1 (CN1) “energy strategy.” It describes the use of natural ventilation for energy conservation (4.1%) and has ten sub-criteria (each 0.41%). This criterion requires natural ventilation but does not directly address it as part of residents’ health and safety.

Water Quality and Availability (WQ). “Water pollution” (1.1%) aims to provide pollution-protective measures for local water sources. This criterion, although generalized, was compliant with the WQ1 indicator. However, it does not mention drinking water protection; therefore, it was given an order of 2. Similar content has another criterion, namely, “sustainable buildings” (4.1%), matching with CN4, preventing or mitigating contamination sources (with five sub-criteria, each to weigh 0.8%). This sub-criterion ambiguously describes pollution prevention, omitting the definition of pollution type or any other detail; therefore, an order of 1 is assigned. Thus, the average score of addressing the WQ1 indicator in the BREEAM standard was 1.5. Similar to the previous indicator, the “water pollution” criterion was also suitable for the WQ2 indicator was fully compliant; an order of 3 was given. Therefore, the weight of “water pollution” was equally distributed between WQ1 and WQ2.

Wastewater Management (WWM). BREEAM does not adopt any wastewater management strategies in its guidance; therefore, the order score of 0 was assigned to WWM1, WWM2, and WWM3.

(ii) Environmental resources consumption

Energy use (EU). “Energy Strategy” sub-criterion CN6 “accredited external renewables” targets to provide additional generation capacity. This definition was matching the pandemic-resilient indicator EU1. This criterion (4.1%) has ten sub-criteria (0.41% each) and does not explicitly discuss backup energy sources; the focus is on renewable energy sources that add capacity to the primary energy source; therefore, an order of 2 was assigned. EU2 was taken into account in “Energy strategy.” Namely, CN5 sub-criterion “renewable and low carbon installations.” As in the previous indicator description, its weight would be

0.41%. This sub-criterion fully addressed the aim of promoting sustainable energy sources (Order 3). EU3 requirement was partially satisfied in “Sustainable buildings” (4.1%) sub-criterion CN4—improve energy performance via efficiency. It did not specify how the efficiency should be achieved (through appliances or other technologies). There are five sub-criteria; thus, the approximate weight of CN4 would be 0.8%.

Water consumption (WC). Several BREEAM criteria are related to the WC1 indicator. For example, “Rainwater harvesting” (1.1%) targets rainwater as an alternative water source that could be further utilized for greywater needs, such as toilet flushing or washing machines. This criterion fully responded to the WC1 indicator. Another example is “Adapting to climate change” (2.7%); this criterion requires the minimization of climate change effects. It recommends utilizing reclaimed water, recycled water, and sustainable drainage systems for domestic greywater needs. It also precisely addressed the WC1 indicator. Thus, the average ordinal score of managing the MH1 indicator in the BREEAM standard was given as 3. Although the standard addressed different water-saving strategies, it did not specify any select appliances and fixtures.

Waste Management (WM). BREEAM does not adopt any waste management strategies in its guidance; therefore, the order of 0 was assigned to WM1, WM2, and WM3.

(iii) Comfort

Personal comfort (PC). BREEAM did not address PC1 or PC2 in its guidance. PC3 was partially considered in “Housing provision” (2.7%) as it tries to reduce social inequalities by providing proper housing space for the community members. It requires design according to minimum space standards and mentions providing every community member with some minimum space. Nevertheless, it did not explicitly address the need to provide personal space to the occupants. PC4 requirement was fully satisfied (order 3) in “Noise pollution”—as it aims to moderate the noise effect based on standards of background noise level, depending on day and night-time. The standard gives 1.8% weight to this criterion.

Local services (LS). LS1 and LS2 were fulfilled in “demographic needs and priorities.” This criterion aims to address local needs, including pharmacies, medical centers, food markets, and other local services. It weighs 2.7% (as already mentioned in MH1, it will be divided into all three pandemic-resilient indicators that it addresses, i.e., 0.9). This criterion addressed having an abundance of local services but did not mention the importance of their self-dependence. Also, it recommends assigning a special place for cultivating fresh fruits and vegetables.

To sum up, 23.25% of BREEAM criteria covered pandemic-resilient indicators. Table 3 sums up BREEAM Credits addressing the pandemic-resilient indicators and their assigned orders.

3.2.2. LEED

LEED (Leadership in Energy and Environmental Design) is a green building assessment system developed in the United States [96], aiming to become a guide and an assessment tool for different phases of buildings construction. While seeking to minimize the environmental effect of buildings, it also sets a target to improve the occupants’ health and well-being while building economically efficient structures. It has a points-based system (total of 110 points). Our assessment specifically referred to LEED Guide for Homes Design and Construction. Being one of the most widely used systems globally, LEED is claimed to better respond to pandemics than traditional construction [97]. As a response to COVID-19, LEED has issued several “pilot credits” regarding water systems, cleaning and disinfecting, indoor air quality, pandemic planning, and safety measures at the workspace, all of which award an additional one point [98]. Those pilot credits that correspond with pandemic-resilient indicators of residential buildings were also discussed.

Table 3. Summary of BREEAM credits addressing the pandemic-resilient indicators and the order assignments.

Indicators	Responding GBCS Indicator	Weight by BREEAM, %	Order (According to Table 1)
PVP1	Inn 01—Innovation	1	1
PVP2-PVP3	Not available (n.a.)	n.a.	0
PVP4	RE 05—Low impact materials	2.7	1
PVP5	SE 08—Microclimate	0.3	3
PVP6	SE 08—Microclimate	0.3	3
MH1	SE 11—Green infrastructure	1.8	3
	SE 02—Demographic needs and priorities	0.9	
	LE 04—Enhancement of ecological value	1.1	
MH2	n.a.	n.a.	0
MH3	SE 15—Inclusive design	0.225	2
MH4	SE 15—Inclusive design	0.225	3
AQ1	n.a.	n.a.	0
AQ2	RE 04—Sustainable buildings (CN4)	0.8	1
AQ3	SE 08—Microclimate	0.3	3
AQ4	RE 01—Energy strategy (CN1)	0.41	2
WQ1	LE 03—Water pollution	0.55	2
	RE 04—Sustainable buildings (CN4)		
WQ2	LE 03—Water pollution	0.55	3
WWM1-WWM3	n.a.	n.a.	0
EU1	RE 01—Energy strategy (CN 6)	0.41	2
EU2	RE 01—Energy strategy (CN5)	0.41	3
EU3	RE 04—Sustainable buildings (CN4)	0.8	2
WM1-WM3	n.a.	n.a.	0
WC1	LE 06—Rainwater harvesting	1.1	3
	SE 10—Adapting to climate change	2.7	
WC2	n.a.	n.a.	0
PC1-PC2	n.a.	n.a.	0
PC3	SE 05—Housing provision	2.7	2
PC4	SE 04—Noise pollution	1.8	3
LS1	SE 02—Demographic needs and priorities	0.9	2
LS2	SE 02—Demographic needs and priorities	0.9	3

(i) Health & Safety

Prevention of Virus Propagation (PVP). To start with, LEED supports innovative ideas that could improve the performance of buildings in the “Innovation” credit (5 points). It is consistent with PVP1; however, it did not mainly target to design innovations for stopping virus propagation. PVP3 was partially addressed in LEED Pilot Credit “Safety first: cleaning and disinfecting your space.” The pilot credit recommends checking the active components for their efficiency in cleaning coronavirus. “Low-emitting materials” credit (3 points) intends to minimize chemicals in the building materials and to reduce the impact on indoor air quality, health and well-being, and environment. It also aims to reduce VOC concentrations in the indoor environment, which comprehensively addressed PVP4. “Balancing of heating and cooling distribution systems” credit (3 points) aims to achieve better thermal convenience for different occupants along with energy savings.

LEED suggests developing multiple zoning of the apartment with thermal controllers in separate rooms, which fully matched PVP6. There were no matching credits in LEED for PVP2 and PVP5.

Mental Health (MH). There were no credits in LEED corresponding to the mental health category.

Air Quality (AQ). As a response to pandemic-resilient indicator AQ1, LEED has developed a prerequisite credit “Air filtering,” which does not have a weight. It targets to minimize particulate matter from the air supply schemes by implementing air filters with a given efficiency. The “Safety first: managing indoor air quality during COVID-19” pilot credit suggests using filters. Therefore, the highest order was given for thoroughly addressing the indicator. Talking about the AQ2 indicator, “No environmental tobacco smoke,” LEED credit (1 point) partially addressed it as it aims to minimize the susceptibility of indoor air environment to tobacco smoke. LEED has also developed a “Contaminant control” credit (2 points) to reduce contaminants carried from the outdoor environment to indoors and suggests using special walk-off mats and storage for shoes that were considered a partial response to the indicator AQ2. LEED Pilot Credit “Safety first: cleaning and disinfecting your space” refers to the careful use of disinfecting products and suggests checking active components to comply with the Environmental Protection Agency list (order 3). It also addressed the AQ3 indicator—controlling the airflows in micro spaces by following: “Compartmentalization”—a prerequisite (no weight) requires reducing chances of residents’ susceptibility to air pollutants by impeding air transfer between rooms. This prerequisite is entirely referred to as AQ3. Another credit, “Enhanced ventilation” (3 points) aims to reduce the issues of moisture and indoor pollutants by efficient ventilation or exhaust systems, partially matching the indicator. There are no credits in the conventional LEED guide that responded to pandemic-resilient indicator AQ4. Nevertheless, it is covered in “Safety first: managing indoor air quality during COVID-19” pilot credit (1 point) where it is suggested to allow natural ventilation in buildings as much as possible (up to 100%); Thus, an order of 3 was assigned.

Water Quality and Availability (WQ). There were no credits in the main guide that respond to such pandemic-resilient indicators as WQ1 or WQ2. Nevertheless, the pilot credit “Safety first: building water system recommissioning” (1 point) recommends developing a water quality management strategy, which should include testing, disinfecting, and maintaining building water systems. This pilot credit is consistent with the WQ2 indicator.

Wastewater Management (WWM). There were no credits in LEED that respond to WWM1, WWM2, or WWM3.

(ii) Environmental resources consumption

Energy use (EU). There were no credits in LEED that respond to pandemic-resilient indicator EU1 (developing access to backup energy sources). Nevertheless, LEED supports renewable energy technologies promotion in the credits “Renewable energy” (installation of renewables; 4 points), “Building orientation for passive solar” (develop solar technologies in buildings; 3 points), and “Active solar-ready design” (supports solar energy implementation; 1 point). All these credits effort to diminish conventional energy use and improve alternative sources, which is fully consistent with EU2. Several LEED credits addressed EU3 from different viewpoints, such as general energy use, HVAC, and lighting: “Annual energy use” credit (30 points), “High-efficiency appliances” (2 points), and “Lighting” (2 points) aim to enhance the energy efficiency of buildings and thereby reduce the negative environmental impact. It was assigned the order of 3 as it suggests different techniques to achieve energy efficiency, including proper insulation, efficient water heaters, efficient lighting systems, and others. LEED puts special attention to heating and cooling systems by developing such credits as “Efficient hot water distribution system” credit (5 points), targeting to decrease energy surge that is wasted on water heating, “Heating and cooling distribution systems” (3 points), “Space heating and cooling equipment” (4 points), “Efficient domestic hot water equipment” (weight already considered in PVP6), “Efficient domestic hot water

equipment" (3 points), "Efficient hot water distribution system" (3 points), "Heating and cooling distribution systems" (3 points), and "HVAC Start-up credentialing" (1 point). They aim to diminish energy losses associated with temperature control, water heating, leaks in heating/cooling systems and thus use energy-efficient HVAC systems. Another energy-saving credit is "Air infiltration" (2 points). It recommends avoiding energy losses due to air leakage associated with conditioning. It comprehensively addressed the EU3 indicator. All in all, the average prioritization order of 3 was given.

Waste Management (WM). There was no credit in LEED addressing the waste management category.

Water consumption (WC). LEED water efficiency credits "Total water use" (12 points) and "Indoor water use" (6 points) suggest saving water by alternative sources use (rainwater, reclaimed water) and by high-efficient fittings installation. These credits fully matched the pandemic-resilient indicators WC1 and WC2.

(iii) Comfort

Personal comfort (PC) & Local services (LS). There were no credits in LEED that respond to such pandemic-resilient indicators as PC1, PC2, PC3, PC4, LS1, or LS2.

All in all, 99 points of LEED for Homes Design and Construction (of the total 164 points) covered pandemic-resilient indicators, and an additional 3 points were granted due to pilot credits. Table 4 summarizes orders and weightings (converted to and presented as percents) of LEED credits.

3.2.3. WELL

WELL Building Standard is a points-based assessment system of people's wellness in buildings [22]. It aims to improve the built environment for the most beneficial effect on human health and wellness, and is the primary assessment standard that mainly focuses on occupants' well-being. The main guide itself focuses on the office type buildings, whereas residential buildings are considered in the "Multifamily Residential" pilot program [99]. The WELL Building standard has 110 points in total; however, only 77 are related to residential buildings and are applicable to the pilot program for residential buildings. WELL has also developed a pandemic-related "Health and Safety" rating system; however, it focuses on the management of different facilities (e.g., health service) than the residential buildings [100]. The present review included the reference to the "Multifamily Residential" pilot program.

(i) Health & Safety

Prevention of Virus Propagation (PVP). In WELL, five "innovation" credits partially addressed PVP1. They are awarded if the proposed innovations are validated by research, laws, and regulations, and support occupants' wellness. Another related criterion is "healthy entrance", which aims to prevent pollutants from outdoors using special floor systems that would seize pathogens and/or contaminants from shoes. PVP2 was not discussed in WELL. PVP3 was partially addressed by "cleaning protocol" credit, which recommends developing a particular cleaning plan. The "cleaning equipment" criterion fully addressed PVP3, as it suggests cleaning products and equipment (vacuum cleaners) to be certified for minimized harm to indoor air environment. The proper selection of indoor materials (PVP4) was fully responded by "VOC reduction", "fundamental material safety", "toxic material reduction", and "enhanced material safety" criteria. They advise carefully checking interior materials (paints, adhesives, floor materials, insulation, etc.) for their content of VOC, asbestos, lead, and other toxic compounds to comply with specific standards. "Antimicrobial surfaces" and "cleanable environment" require all surface coating to comply with antimicrobial requirements and not be susceptible to abrasion or corrosion for easier cleaning. WELL partially responded to the PVP5 indicator. "Daylighting fenestration" recommends the installation of windows that allow daylight entering the room, and there is no direct response to light being able to prevent virus propagation or about the size of the window. This indicator was also directly addressed by "right to light" and "daylight

modelling” credits that give recommendations on window size and sunlight exposure of the rooms. Finally, several criteria fully addressed PVP6: “thermal control”, “radiant thermal control”, “moisture management”, “humidity control”, and “outdoor air systems”. Some of these focus on thermal comfort, discuss compliance with ASHRAE standards, and mention implementing radiant technology for better thermal control independent of ventilation systems. Whereas “moisture management” and “humidity control” discuss mitigating the occurrence of wetting and dew by sealing and providing adequate humidity to the buildings based on expected humidity standards.

Table 4. Summary of the LEED Credits addressing the pandemic-resilient indicators and the order assignments.

Indicators	Responding GBCS Indicator	Weight by LEED, %	Order (According to Table 1)
PVP1	Innovation	3.05	1
PVP2	n.a.	n.a.	0
PVP3	Cleaning and disinfecting your space (pilot)	0.61	3
PVP4	Low-emitting materials	1.83	3
PVP5	n.a.	n.a.	0
PVP6	Balancing of heating and cooling distribution systems	1.83	3
MH1-MH4	n.a.	n.a.	0
AQ1	Air filtering (prerequisite)	n.a.	3
	Managing indoor air quality during COVID-19 (pilot)		
AQ2	No environmental tobacco smoke	0.61	3
	Cleaning and disinfecting your space (pilot)	1	
AQ3	Compartmentalization (prerequisite)	-	3
	Enhanced ventilation	1.83	
AQ4	Managing indoor air quality during COVID-19 (pilot)	0.61	3
WQ1	n.a.	n.a.	0
WQ2	Building water system recommissioning (pilot)	0.61	3
WWM1-WWM3	n.a.	n.a.	0
EU1	n.a.	n.a.	0
EU2	Renewable energy	2.44	3
	Building orientation for passive solar	1.83	
	Active solar-ready design	0.61	
EU3	Annual energy use	18.29	3
	High-efficiency appliances	1.22	
	Lighting	1.22	
	Efficient hot water distribution system	3.05	
	Heating and cooling distribution systems	1.83	
	Space heating and cooling equipment	2.44	
	Efficient domestic hot water equipment	1.83	
	Efficient hot water distribution system	1.83	
	Heating and cooling distribution systems	1.83	
	HVAC start-up credentialing	0.61	
	Air infiltration	1.22	
WM1-WM3	n.a.	n.a.	0
WC1	Total water use	5.49	3
WC2	Indoor water use	5.49	3
PC1-PC4	n.a.	n.a.	0
LS1-LS2	n.a.	n.a.	0

3.2.4. WELL

WELL Building Standard is a points-based assessment system of people's wellness in buildings [22]. It aims to improve the built environment for the most beneficial effect on human health and wellness, and is the primary assessment standard that mainly focuses on occupants' well-being. The main guide itself focuses on the office type buildings, whereas residential buildings are considered in the "Multifamily Residential" pilot program [99]. The WELL Building standard has 110 points in total; however, only 77 are related to residential buildings and are applicable to the pilot program for residential buildings. WELL has also developed a pandemic-related "Health and Safety" rating system; however, it focuses on the management of different facilities (e.g., health service) than the residential buildings [100]. The present review included the reference to the "Multifamily Residential" pilot program.

(i) Health & Safety

Prevention of Virus Propagation (PVP). In WELL, five "innovation" credits partially addressed PVP1. They are awarded if the proposed innovations are validated by research, laws, and regulations, and support occupants' wellness. Another related criterion is "healthy entrance", which aims to prevent pollutants from outdoors using special floor systems that would seize pathogens and/or contaminants from shoes. PVP2 was not discussed in WELL. PVP3 was partially addressed by "cleaning protocol" credit, which recommends developing a particular cleaning plan. The "cleaning equipment" criterion fully addressed PVP3, as it suggests cleaning products and equipment (vacuum cleaners) to be certified for minimized harm to indoor air environment. The proper selection of indoor materials (PVP4) was fully responded by "VOC reduction", "fundamental material safety", "toxic material reduction", and "enhanced material safety" criteria. They advise carefully checking interior materials (paints, adhesives, floor materials, insulation, etc.) for their content of VOC, asbestos, lead, and other toxic compounds to comply with specific standards. "Antimicrobial surfaces" and "cleanable environment" require all surface coating to comply with antimicrobial requirements and not be susceptible to abrasion or corrosion for easier cleaning. WELL partially responded to the PVP5 indicator. "Daylighting fenestration" recommends the installation of windows that allow daylight entering the room, and there is no direct response to light being able to prevent virus propagation or about the size of the window. This indicator was also directly addressed by "right to light" and "daylight modelling" credits that give recommendations on window size and sunlight exposure of the rooms. Finally, several criteria fully addressed PVP6: "thermal control", "radiant thermal control", "moisture management", "humidity control", and "outdoor air systems". Some of these focus on thermal comfort, discuss compliance with ASHRAE standards, and mention implementing radiant technology for better thermal control independent of ventilation systems. Whereas "moisture management" and "humidity control" discuss mitigating the occurrence of wetting and dew by sealing and providing adequate humidity to the buildings based on expected humidity standards.

Mental Health (MH). MH1 was fully responded to by "biophilia 1" and "biophilia 2" that advise incorporating greeneries in spaces. MH2 and MH3 were not considered in WELL. MH4 was fully addressed by "physical activity spaces" and "fitness equipment"—that aims to develop accessible spaces for physical activity and by "interior fitness circulation,"—that promotes the use of stairs and pathways to reduce the use of elevators.

Air Quality (AQ). AQ1 indicator was fully addressed by "air quality standards", "air filtration", "advanced air purification", and "air infiltration management". These criteria require a constant inspection of air systems and the maintenance of air filters for best efficiency. AQ2 was fully matched by "air quality monitoring and feedback," which endorses monitoring air quality and preparing a mitigation plan. Other criteria that fully address this indicator are "microbe and mold control" and "displacement ventilation", which guide the conduct of regular management of mold and bacteria and use technology to move the air pollutants upwards out of the breathing zone correspondingly. "Smoking ban" partially matched AQ2 by prohibiting any kind of smoking. "Ventilation effectiveness" and

“direct source ventilation” fully responded to the AQ3 indicator as they ensure adequate ventilation according to ASHRAE requirements and recommend providing direct exhausts to house spaces for lowering inter-spatial indoor pollution. “Ventilation effectiveness”, “operable windows”, and “increased ventilation” criteria require providing access to outdoor air and aim to increase outdoor air supply, thus fully matching the AQ4 indicator.

Water Quality and Availability (WQ). The criteria that fully responded to WQ1 are “fundamental water quality”, “periodic water quality testing”, “public water additives”, “drinking water promotion”, “inorganic contaminants”, and “organic contaminants” which advise testing water quality (including drinking and kitchen water) for turbidity and presence of bacteria, metals, and organic/inorganic contaminants. WQ2 indicator was fully responded to by “water treatment”—maintaining water filters according to the developed manufacturer recommendation.

Wastewater Management (WWM). The wastewater management category was not addressed in WELL.

(ii) Environmental resources consumption

WELL does not have any credits that responded to the category of environmental resources use.

(iii) Comfort

Personal comfort (PC). PC1, PC2, and PC3 were not considered in the standard. WELL fully addressed acoustic comfort indicator (PC4) by advising to install “sound barriers” and develop “internally generated noise” and “exterior noise intrusion” in building design for improvement of sound insulation by construction detailing, use of sound-absorptive surfaces, implement low background noise for better acoustic privacy, and set specific limits for impeding exterior noise coming inside of the building.

Local services (LS). WELL did not address the LS1 indicator. Nevertheless, it fully supported LS2 by “food production”—provide the building residents with the needed conditions (infrastructure, space) to grow their edible plants.

Summarizing, 50 points (out of 77) of WELL responded to pandemic-resilient indicators (Table 5, credit weights converted to percent).

Table 5. Summary of the WELL credits addressing the pandemic-resilient indicators and the order assignments.

Indicators	Responding GBCS Indicator	Weight by WELL, %	Order (According to Table 1)
PVP1	Innovation 101	1.3	2
	Innovation 102	1.3	
	Innovation 103	1.3	
	Innovation 104	1.3	
	Innovation 105	1.3	
PVP2	Healthy entrance	1.3	0
	n.a.	n.a.	
PVP3	Cleaning protocol	1.3	2
	Cleaning equipment	1.3	
PVP4	VOC reduction	1.3	3
	Fundamental material safety	1.3	
	Toxic material reduction	1.3	
	Enhanced material safety	1.3	
	Antimicrobial surfaces	1.3	
PVP5	Cleanable environment	1.3	3
	Daylighting fenestration	1.3	
	Right to light	1.3	
	Daylight modelling	1.3	

Table 5. Cont.

Indicators	Responding GBCS Indicator	Weight by WELL, %	Order (According to Table 1)
PVP6	Thermal control	1.3	3
	Radiant thermal control	1.3	
	Moisture management	1.3	
	Humidity control	1.3	
	Outdoor air systems	1.3	
MH1	Biophilia 1	1.3	3
	Biophilia 2	1.3	
MH2-3	n.a.	n.a.	0
MH4	Physical activity spaces	1.3	3
	Interior fitness circulation	1.3	
	Fitness equipment	1.3	
AQ1	Air quality standards	1.3	3
	Air filtration	1.3	
	Advanced air purification	1.3	
	Air infiltration management	1.3	
	Air quality monitoring and feedback	1.3	
AQ2	Microbe and mold control	1.3	3
	Displacement ventilation	1.3	
	Smoking ban	1.3	
AQ3	Ventilation effectiveness	0.65	3
AQ4	Ventilation effectiveness	0.65	3
	Operable windows	1.3	
	Increased ventilation	1.3	
WQ1	Fundamental water quality	1.3	3
	Periodic water quality testing	1.3	
	Public water additives	1.3	
	Drinking water promotion	1.3	
	Inorganic contaminants	1.3	
	Organic contaminants	1.3	
WQ2	Water treatment	1.3	3
WWM1-WWM3	n.a.	n.a.	0
EU1-EU3	n.a.	n.a.	0
WM1-WM3	n.a.	n.a.	0
WC1-WC2	n.a.	n.a.	0
PC1-PC3	n.a.	n.a.	0
PC4	Sound barriers	1.3	3
	Internally generated noise	1.3	
	Exterior noise intrusion	1.3	
LS1	n.a.	n.a.	0
LS2	Food production	1.3	3

3.2.5. CASBEE

CASBEE (Comprehensive Assessment System for Built Environment Efficiency) has been developed in Japan to evaluate environmental performance for all construction stages [101]. The CASBEE family has various standards for the pre-design (PD) stage,

new construction (NC), existing buildings (EB), and renovation (RN). The present review mainly focuses on the “CASBEE for New Construction” (CASBEE-NC) tool as it is suitable for environmental assessment during the design stage but can also be applied in remodeling cases. CASBEE-NC is ideal for different buildings; therefore, a careful review of those criteria which are related to residential buildings is conducted, it includes hospitals, homes, and apartments. CASBEE adopts two types of scoring: Q (Quality of environmental performance) and L (environmental Loading of a building). Results, combined on graphs, give a representation of the building’s environmental efficiency with scorings for Q and L criteria. Both Q and L have three categories, dividing further into criteria, sub-criteria, and in some cases, sub-sub-criteria. Thus, weights were calculated using category, criterion, sub-criterion, and, if needed, sub-sub-criterion weighting proportions. Table 6 summarizes the criteria matching pandemic-resilient indicators, their weighting coefficients (converted to percent), and assigned orders.

Table 6. Summary of the CASBEE criteria addressing the pandemic-resilient indicators and the order assignments.

Indicators	Responding GBCS Indicator	Weight by CASBEE, %	Order (According to Table 1)	
PVP1-PVP3	n.a.	n.a.	0	
PVP4	Materials of low environmental load (L)	2	2	
	Materials with low health risks			
PVP5	Lighting and illumination (Q)	3	3	
	Daylighting			
PVP6	Thermal comfort (Q)	14	3	
	Room temperature control			
	Humidity control			
	Type of air conditioning system			
	Local characteristics & outdoor amenity (Q)			(considered in MH3)
	Improvement of the thermal environment on site			
MH1	Preservation and creation of biotope (Q)	9	3	
MH2	n.a.	n.a.	0	
MH3	Local characteristics & outdoor Amenity (Q)	9	2	
	Attention to local character & improvement of comfort			
	Improvement of the thermal environment on site			
MH4	n.a.	n.a.	0	
AQ1	n.a.	n.a.	0	
AQ2	Air quality (Q)	5	3	
	Source control			
	Operation plan			
	Air pollution (L)			
AQ3	n.a.	n.a.	0	
AQ4	Air quality (Q)	1	3	
	Natural ventilation			
WQ1-WQ2	n.a.	n.a.	0	
WWM1-WWM3	n.a.	n.a.	0	

Table 6. Cont.

Indicators	Responding GBCS Indicator	Weight by CASBEE, %	Order (According to Table 1)
EU1	n.a.	n.a.	0
EU2	Natural energy utilization (L)	8	3
	Direct use of natural energy Converted use of renewable energy		
EU3	Efficiency in building service system (L)	12	2
WM1-WM3	n.a.	n.a.	0
WC1	Durability and reliability (Q)	0.2	3
	Reliability		
	Water supply and drainage		
	Water resources (L) Rainwater & gray water		
WC2	Durability and reliability (Q)	0.2	3
	Reliability		
	Water supply and drainage		
	Water resources (L) Water-saving		
PC1	Durability and reliability (Q)	0.4	3
	Reliability Communications & IT equipment		
PC2	Flexibility & adaptability (Q)	5.7	3
	Spatial margin Adaptability of facilities		
PC3	n.a.	n.a.	0
PC4	Noise & acoustics (Q)	1.5	3
	Background, equipment noise		
	Sound insulation (openings, partition walls, floor slabs)		
	Sound absorption		
	Noise, vibration & odor (L) Noise & vibration		
LS1-LS2	n.a.	n.a.	0

(i) Health & Safety

Prevention of Virus Propagation (PVP). PVP1, PVP2, and PVP3 were not addressed in CASBEE. It responded to indicator PVP4 with the “Materials with low health risks” sub-criterion (weight: 0.02) of the “Materials of low environmental load” criterion. It describes the need to use building materials that release chemical pollutants in quantities acceptable by standards. Nevertheless, it does not mention anything related to virus propagation prevention; therefore, a partial order was assigned. “Lighting and illumination” criterion addressed the PVP5 indicator. The only sub-criterion that was suitable to PVP5 response is “Daylighting” (amount of daylight accessible in the room space, set openings in a most efficient manner for daylight entering, use of daylight devices) (weight: 0.03). PVP6 was

matched by the “Thermal comfort” criterion (weight: 0.14). It has several subcriteria, such as “Room temperature control” (setting temperature to certain levels depending on the season, quality of heat infiltration), “Humidity control”, and “Type of air conditioning system” (minimization of vertical temperature variance and speed of air). CASBEE also partially addressed PVP6 by “Improvement of the thermal environment on-site” sub-criterion (weight: 0.045) of “Local characteristics & Outdoor Amenity,” which suggests providing different types of elements in buildings (e.g., greeneries) for conserving thermal comfort.

Mental Health (MH). “Preservation & creation of biotope” (weight: 0.09) fully matched MH1 through recommendations of outside area extensive greening, roofs and walls greening, and development of contact spaces between occupants and nature. MH3 was partially matched by “Local characteristics & outdoor amenity” (weight: 0.09). It suggests developing shared spaces and facilities for the occupant; however, it does not mention any of the safety measures. CASBEE did not cover the criteria MH2 or MH4.

Air Quality (AQ). CASBEE implements a particular “Air quality” criterion that responded to the overall AQ category. It has two sub-criteria that fully satisfied AQ2: “Source control” (weight: 0.05), that requires controlling of VOCs from construction materials, and “Operation plan” (weight: 0.02) that describes the control of carbon dioxide level and smoking indoors. The “Ventilation” sub-criterion fully addressed AQ4 by the measure of “Natural ventilation performance” (weight: 0.01). It recommends installing windows for a minimum of one-sixth of the floor area to allow the right level of natural ventilation. AQ2 was also addressed by the “Air pollution” criterion (weight: 0.03), which promotes efforts for controlling air pollutants within and outside the building, use air purifying equipment and plants for a healthier air environment. AQ1 and AQ3 were not covered by the standard.

Water Quality and Availability and Wastewater Management indicators were not covered by CASBEE.

(ii) Environmental resources consumption

Energy use (EU). EU1 was not addressed by CASBEE, whereas EU2 was fully matched by the “Natural energy utilization” criterion, via the “Direct Use of Natural Energy” and “Converted use of renewable energy” sub-criteria, as it suggests to promote natural light, natural ventilation, and geothermal energy; use solar heat and reuse any unused heat (weight: 0.08). CASBEE partially covered EU3 by “Efficiency in building service system” (weight: 0.12) by requiring efficient hot water appliances.

Waste Management (WM). The related indicators were not addressed by CASBEE.

Water consumption (WC). These indicators were addressed by the sub-sub-criterion “Water supply and drainage” of the “Durability & Reliability” criterion (weight: 0.004). WC1 was managed by different water source recommendations, such as using well and rainwater filtering systems for conversion to drinking water, development of water storages for emergencies by providing water pits and rainwater tanks. The recommendation of using water-saving equipment addressed WC2. Another criterion that fully responds to the WC category is the “Water resources” criterion. “Water-saving” sub-criterion (weight: 0.012) suggests using efficient equipment (e.g., water-saving toilets, faucets with controlled water volume, and others), thus, addressing WC2. Whereas, “Rainwater & Gray Water” (weight: 0.018) sub-criterion took WC1 by suggesting reusing rain and gray water.

(iii) Comfort

Personal comfort (PC). The “Communications & IT equipment” sub-sub-criterion of “Durability & Reliability” criterion fully addressed to PC1 (weight: 0.004). It recommends developing efficient and robust communication systems for residential buildings. PC2 was fully addressed by two sub-criteria of the “Flexibility and adaptability” criterion: “Spatial margin” and “Adaptability of facilities” (weight: 0.057). They describe building development to allow flexibility of story heights, adaptability of floor layout, and simplicity of changing ducts and pipes for air conditioning, water supply, electrical and communications wires, and other equipment if needed. CASBEE adopts the “Noise & acoustics” criterion

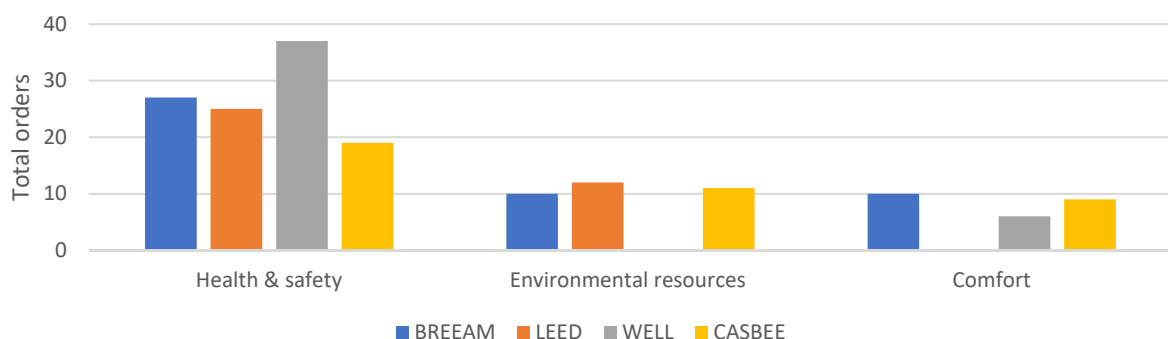
(weight 0.15) that fully addressed PC4. It has two sub-criteria: “Sound insulation” (control of noise from openings, partition walls, floor slabs) and “Sound absorption” (using materials able to absorb sounds). PC4 was also covered by the “Noise & vibration” sub-criterion (weight 0.015) of “Noise, Vibration & Odor.” It recommends implementing anti-noise measures (e.g., sound absorbers, trees, and walls with sound-impeding quality) that could control noise from equipment, wind, and cars. Any installed equipment is suggested to be of low vibration.

Local services (LS). strategy is not adopted by CASBEE.

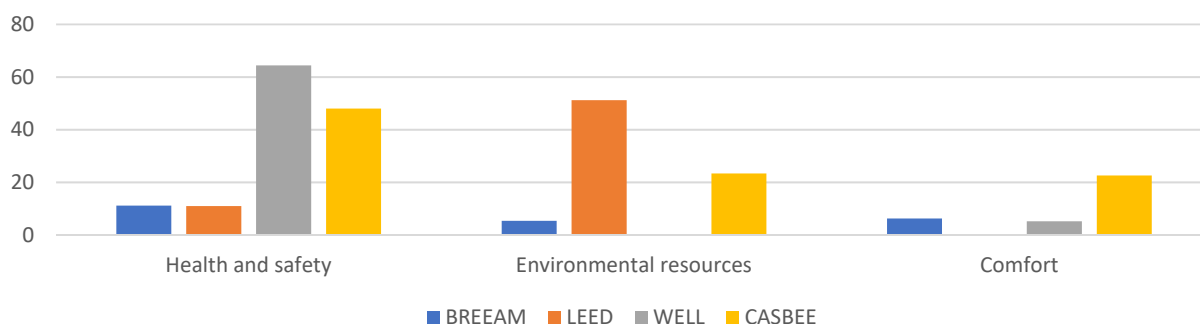
All in all, CASBEE’s 64.5% of the environmental quality of building criteria (Q) and 29.5% of the building’s environmental loading criteria (L) addressed pandemic-resilient indicators.

4. Discussion on Readiness Levels of Green Building Certification Systems

Our analysis of ordinal prioritization (Figure 1a) has shown that buildings complying with WELL Building Standard are the most prepared to provide “health & safety” during pandemics. Overall, CASBEE showed the least readiness. In contrast, using quantitative analysis (Figure 1b), when comparing the standards by total weightings addressed to the category, CASBEE presented the highest response. Moving to the “environmental resources consumption” category, both comparisons “by orders” and “by weightings” demonstrate that LEED mostly satisfied the pandemic-resilient indicators of this category. In opposite, WELL did not address any of the “environmental resources” indicators. CASBEE and BREEAM most successfully represented the “Comfort” category in quantitative and ordinal comparisons, correspondingly. Whereas, LEED did not point any related criteria to comfort, mainly concentrating on green technologies [102] rather than on occupants. In summary, BREEAM, LEED, WELL, and CASBEE showed diverse readiness levels to the pandemic-resilient categories, each leading in different categories.



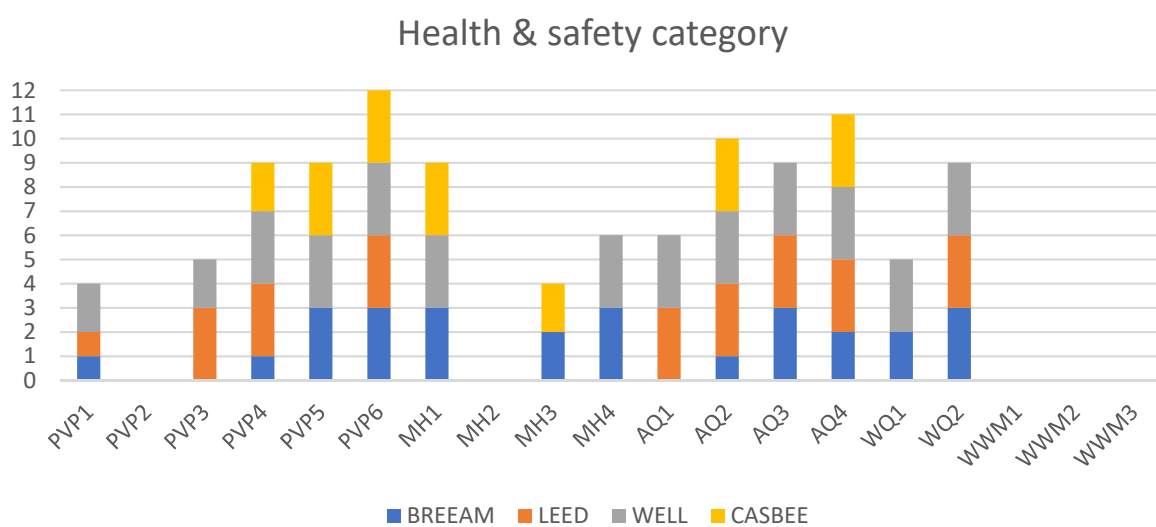
(a)



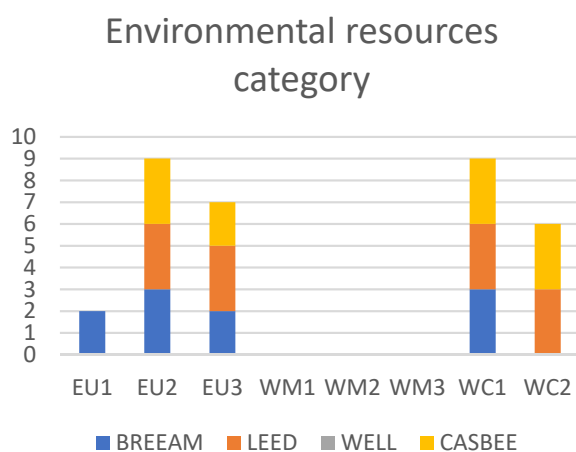
(b)

Figure 1. Comparison of BREEAM, LEED, WELL, and CASBEE addressing pandemic-resilient categories: (a) by total orders (ordinal prioritization), (b) by total weightings (quantitative).

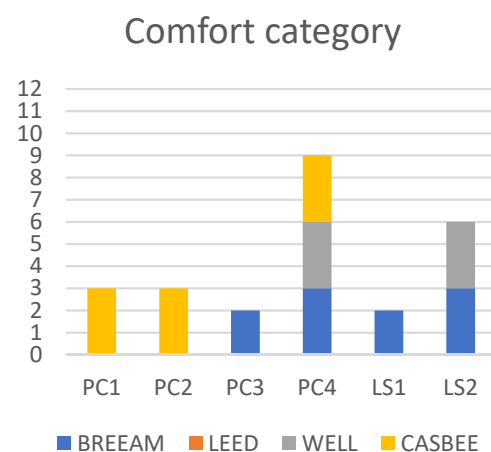
Delving into subcategories of “health & safety”; “prevention of virus propagation”, “water quality”, and “air quality” were also best represented by WELL criteria in both quantitative and ordinal analyses (Figures 2a and 3a), while “mental health” indicators were best addressed by BREEAM by orders comparison (Figure 2a) and by CASBEE when compared by weightings (Figure 3a). CASBEE also contributed substantial weight to “air quality” indicators. It is important to note that none of the reviewed GBCSs were ready for wastewater management tailored to pandemics. All the reviewed green standards adopted credits for temperature & humidity control and selection of indoor materials (PVP6 and PVP4 indicators). In contrast, none of them recommended employing touchless technologies that will help prevent virus spread (PVP2). Similarly, none of the reviewed systems discussed the importance of having balconies as a means of socialization during isolation periods (MH2).



(a)



(b)



(c)

Figure 2. Comparison of BREEAM, LEED, WELL, and CASBEE orders for addressing pandemic-resilient criteria by categories: (a) health & safety, (b) environmental resources consumption, (c) comfort.

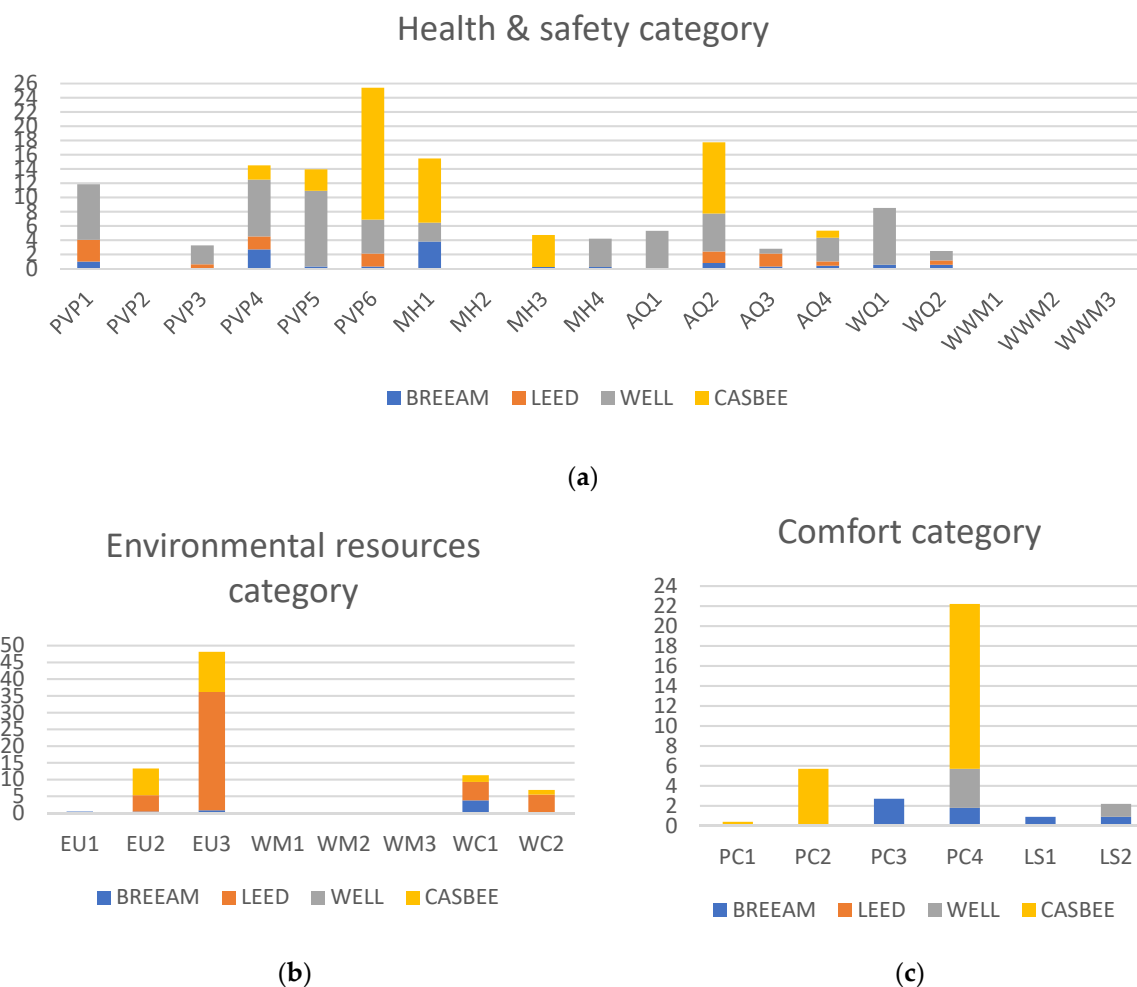


Figure 3. Comparison of BREEAM, LEED, WELL, and CASBEE weightings for addressing pandemic-resilient criteria by categories: (a) health & safety, (b) environmental resources consumption, (c) comfort.

As shown in Figures 2b and 3b, LEED had the highest orders and weightings for the “environmental resources use” category, namely, for energy and water consumption indicators. Whereas BREEAM demonstrated the least readiness both in ordinal and quantitative analyses. BREEAM, LEED, and CASBEE manuals gave special attention to sustainability; therefore, they all fully responded to the EU2 indicator—promotion of sustainable and alternative energy sources. Nonetheless, none of the four standards were ready for pandemic waste management: segregation of medical household waste (WM1), waste disinfection (WM2), and management of the increasing household waste during lockdowns (WM3). At the same time, WELL did not address any environmental resources indicators, being least responsive to this category. This can be related to its primary focus, put on the occupants’ well-being. Overall, LEED was more prepared for environmental resources use during a pandemic, and its success is anticipated due to its initial focus on environmental efficiency.

Analyzing the “comfort” category showed that BREEAM addressed most of the indicators in both subcategories and has the highest order (Figure 2c). However, CASBEE, while lacking response to “local services,” still gave a considerably higher weighting to “personal comfort” compared to BREEAM. WELL and LEED, which were minimally responding to the “comfort” category, with the former addressing only “noise management” and “urban farming” indicators, and the latter one not responding to any indicators at all.

Overall, WELL better responded to the “health and safety” category, LEED responded to “environmental resources consumption,” and “comfort” was better represented in BREEAM and CASBEE. In contrast to WELL and LEED that failed in addressing “envi-

ronmental resources” and “comfort” categories, BREEAM and CASBEE addressed criteria to each of three categories in their manuals. Still, among four reviewed GBCSs, there is no one absolutely leading in readiness to the pandemic and post-pandemic realities as there were some indicators (PVP2, MH2) and even subcategories (waste and wastewater management) which were without a response.

5. Conclusions

The COVID-19 pandemic has distinctly and diversely highlighted the deficiencies in health, comfort, and eco-friendliness features in residential buildings over the world. The present research attempts to demonstrate the importance and usefulness of pandemic-resilient indicators for sustainability assessment systems and demonstrates how green building certification systems ensure better sustainability for residential buildings during and after pandemics. The presented review and analysis of green building assessment standards has shown that among selected tools (BREEAM, CASBEE, LEED, WELL) no one standard could yet thoroughly address all pandemic-resilient indicators i.e., none of these standards could be considered as “fully ready for pandemics.” These tools focus on different features of sustainability, which explain their success in certain diverse subcategories for pandemic resilience. More specifically, WELL (oriented on social comfort) is most successful in responding to the “health & safety” category whereas it lacks a proper response to “environmental resources consumption”. LEED better tackles environmental efficiency and yet does not fully cover the “occupants’ comfort”. BREEAM and CASBEE are more generic and thus partially respond to all three categories of pandemic resilience; particularly addressing “occupants’ comfort” better than WELL and LEAD. All these four assessment systems lack responses to the subcategories of waste and wastewater management. The required future studies include the adoption of necessary changes to the existing green building certification systems as well as the development of all-new standards that would appropriately respond to all pandemic-resilient indicators. The presented study is limited by an analysis of four green building standards. Nevertheless, it can provide a general framework for the improvement of other existing standards (directions for amelioration) or for the design of new standards (what kind of criteria should be considered). Another limitation of the present study is the difference in GBCS’s approach to residential buildings—e.g., LEED considers multi-family residences as well as detached single units, while BREEAM’s applicability to single houses is conditional and should be priorly consulted. A final limitation is the extensive consideration of social and environmental sustainability pillars with limited reference to the economic aspect, which might affect the realization of some pandemic-resilient indicators developed in this study.

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