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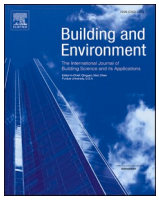

Theorizing security-pandemic aspects and variables for post-pandemic architecture

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ABSTRACT

"Theorizing security-pandemic aspects and variables for post-pandemic architecture" refers to creating propositions and theory systems for the security-pandemic aspects and variables in the presence of pandemic and health issues and the consequences of changing hybrid activities within living-working space. COVID-19 has caused changes in architecture, especially in the context of the security pandemic. Architecture needs different strategies to help prevent disease in the future. A theorizing theory involves classification and interpreted terms, network analysis, and creating propositions and theories based on aspects and variables. The findings are 3 new interpretations of aspects, 14 sub-aspects of security-pandemic theory, and 23 security-pandemic variables that can be used as strategies in architecture design. The interconnection between aspects (dynamics, distancing, and living-working pattern), sub-aspects, and variables are connected regarding control, prevention, and deterring patterns for disease spread through person-to-person and media/surface-to-person. These findings will support future research in preventive measures in post-pandemic architecture, creating innovative building and green code certifications for security-pandemic theory or modifying the existing codes and green certifications.

1. Introduction

The COVID-19 pandemic and traumatic experiences have consistently exerted an influence, compelling individuals to react, reconfigure their constructed surroundings, and adjust in a novel manner. Architecture explores various modes of living, wherein novel architectural ideas are crafted to accommodate evolving values, habits, and the demands of contemporary living spaces and work environments [1–4]. The field of architecture is anticipated to undergo significant changes due to the pandemic, as it assumes a crucial role in addressing and mitigating the transmission of infectious diseases [5–8].

The World Health Organization (WHO) formulated a strategic plan for the 2020–2024 health security concept in anticipation of the general spread of the pandemic's infectious diseases. This plan was documented in the Consolidated Report on Indonesia Health Sector Review [9]. Implementing the 2018 strategy involves enhancing surveillance systems, providing assistance to health laboratories [10], identifying and preventing potential transmission sources from individuals traveling internationally, such as those using air or sea transportation.

With the COVID-19 pandemic, the prevention of the entry and dissemination of Pandemic Infectious Diseases (PIEs) extends beyond the traditional approach of quarantining individuals traveling from foreign countries, changes in measures and strategies of detection, prevention, and protection in the built environment. The COVID-19 pandemic has significantly impacted the movement, organization, and user relationships within the physical built environment [11]. In addition to the impacts detailed above, people need to adapt to new ways of living and working to avoid disease effectively, minimize environmental effects, and maintain comfort while doing activities [8,12,13]. This paper aims to identify the consequences, strategies developed, and changes in security-pandemic theory in post-pandemic architecture.

1.1. Impact of recent pandemic (COVID-19) on security design and architecture

Before the outbreak of the COVID-19 Pandemic, numerous diseases had exerted influence on our environment. Throughout the history of pandemics, architectural design strategies have evolved by analyzing the potential virus spread, healing infected people, and understanding environmental conditions [14]. Over the past two centuries, significant

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improvements have been made in architecture and urbanism [13]. These significant improvements also have an impact on the security design and architecture. Therefore, it is essential for society to promptly adjust to these lifestyle shifts and implement stringent safety and security protocols in the built environment.

As part of health security, the theory of security within the built environment is a concept that encompasses the identification and detection of potential threats and the implementation of preventive measures to mitigate such risks and respond to such threats [15]. Security in architectural design is a fundamental aspect of basic human needs. This concept is also encompassed within the discourse surrounding the notion of person-environment/built environment and its impact on human behavior [16–18]. The concept of security encompasses the mitigation of fear, protection against natural hazards, defending against human threats, identifying and closing security vulnerabilities, safeguarding valuable assets, and managing risks. Security measures are vital to ensuring the safety and protection of the built environment, including resilience to possible upcoming disease outbreaks. Linda O'Shea (2009) asserts that the requirement for security has evolved into a mechanism capable of impacting several aspects of human health and well-being within the constructed environment.

Baldwin (1997) suggested several security principles are employed within the built environment to proactively anticipate potential threats and safeguard individuals utilizing the place [19]. Natural threats protocol concepts encompass several aspects of occupational safety, including safety from fires, floods, and other related natural hazards. Human threats, such as crime, terrorism, violence, and cyber-attacks, are already addressed with preventive protocol using the implementation of crime prevention through environmental design (CPTED). Based on the Security Assessment by Building Research Establishment (SABRE), resilience in architecture is seen as creating a better future for the environment and society by constantly mitigating evolving threats and reducing risk. The concept of resilience usually responds to sustainability and creating adaptable systems to avoid and reduce risks (incredibly natural risks). The case of COVID-19, which has inevitably become the "normality" that we were accustomed to, has exposed the limitations of our resilient city in adapting to this situation [20–23]. Before the COVID-19 pandemic, the proliferation of security concepts and resilient cities effectively addressed environmental hazards and security concerns arising from natural and societal phenomena such as natural disasters, terrorism, criminal activities, or assaults. Implementing a CPTED-built environment is utilized to address security concerns related to criminal threats. The security-pandemic concept for health risks and disease prevention in architecture has not been optimally developed.

The rapid spread of COVID-19 poses challenges for existing architectural designs, the dynamics of human interaction in public areas, and the perception of the significance of physical distancing [13,24]. The experience of the COVID-19 pandemic impacted the tactics employed in building construction. It necessitated that individuals predominantly reside within their residences as a precautionary measure against the transmission of the virus. It implies a significant and fundamental change in how buildings, especially residential ones, are designed and operated to face the challenges posed by pandemics.

The building design will undergo multiple alterations, encompassing the overall construction techniques and the meticulous arrangement of its particulars. The security concept in building design is leading to significant transformations in various aspects. Crowded environments are no longer desirable due to their propensity to facilitate the transmission of viruses. Consequently, to enhance the practice of social distancing, public areas have been temporarily closed on a global scale. Certain offices, universities, and schools remained closed, requiring individuals to engage in remote work and study activities from their residences.

These activities change space needs and adaptations within security design and architecture. The utilization of standardized prefabricated components in the modular construction concept enables us to effectively adjust to and fulfill the specific demands of healthcare buildings during periods of quarantine, the adaptive reuse of preexisting structures for the need of emergency facilities, and repurpose areas like sports complexes, fields, parking lots, and other open-space structures into makeshift medical facilities or hospitals. Buildings that will be planned with the potential for efficient, adaptable, and rapid conversion of the structure to meet specific requirements, such as those of hospitals and medical institutions, and using lightweight and adaptable construction. Post-pandemic architecture may incorporate hygienic building materials that possess the characteristic of being easily sanitized [7,13,24–27].

Apart from the changes in the architecture design, as mentioned above, new changes in activities and technology are emerging and impacting security and architecture design. The changes in activities and accelerated adaptation of online, digital, and remote technologies have forced the discipline of the built environment to deal with the technological, design, and spatial triad of architecture and urbanism promptly through pedagogy, practice, and research [28]. These adaptations include the need for multi-use architecture, a hybrid interior to create a combination of public-private interiors, hybrid activities that allow multi-layer users and use over time (users can be in the same interiors but at different times, or users are in different places but connected at the same time) and hybrid structures that overlap between virtual and physical spaces [29–31]. The need for safety and security to accommodate work activities in hybrid workplaces is higher than in residence. The safety and security in architecture are not for the physical health needs of the user but as a mechanism that influences the health and well-being within the built environment. Applying safety and security to adapt to changing needs and patterns of activity in hybrid workplaces becomes essential.

To effectively address the intricate issues of security and architecture post-pandemic, it is necessary to undertake theoretical developments throughout several disciplines related to architecture and the built environment. Salama (2020) presents a theoretical transdisciplinary framework that elucidates the implications of pandemics in urban design [32]. The first aspect is the impact of urban dynamics on the spread of disease and its influence on travel and transportation in urban areas (including the discipline of urban science, urban planning, and transportation techniques). The second aspect is social distances, which refer to how people perceive and use the urban environment (including the disciplines of environmental science, disasters, psychology, and health). The third aspect is the adaptation to evolving lifestyles and work practices (including disciplines such as ethnography, anthropology, information technology, and communication). These entail the need for comprehensive development and implementation of security concepts and strategies not only in urban design but also within architectural design (see Fig. 1) [33].

Therefore, this paper will address the following research questions: (1) how the implications and prevention of pandemics in security design and architecture context (in terms of changes in living-working patterns, dynamics, and distancing); (2) how the theories of security in architecture evaluated in the presence of pandemics and health issues; and the consequences of the change in hybrid activities in the workplace and living space. Ultimately, this paper will formulate a novel approach to addressing security aspects in post-pandemic architecture. Additionally, new variables will be added to the security-pandemic concept in the post-pandemic architecture.

2. Research methods

Based on the research questions in the previous introduction, this article used the architectural theorizing methodology to collect data and synthesize. A methodology was developed based on a systematic overview [34] and theorizing [18,35–37]. A systematic overview is a method for summarising literature and describing it systematically. This method

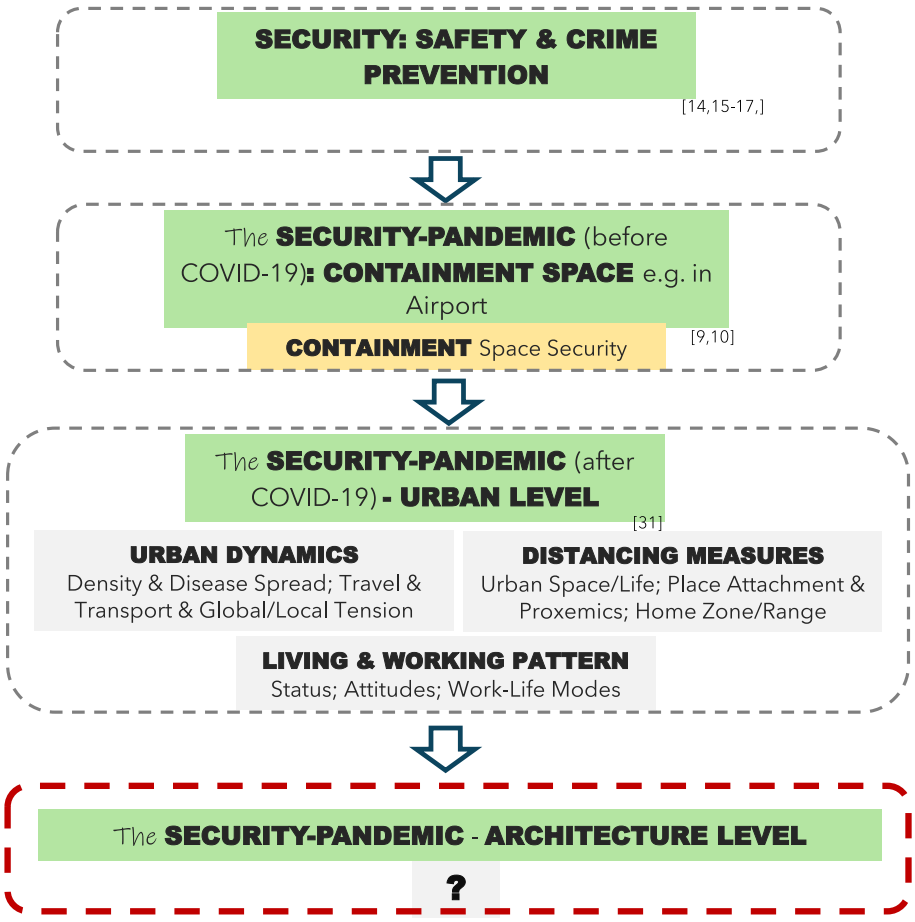

Fig. 1. Introduction and position of security-pandemic theory in architecture.

offers a thorough systematic search and literature summaries regarding the implications and prevention of pandemics in security design and architecture. The authors conducted a systematic literature search and review regarding the contexts of changes in living-working patterns, dynamics, and distancing in the authors' previous research. The data was collected from articles in platforms lens.org (an open-source platform that provides knowledge artifacts, including scholarly works and patents, with data from various partners such as CrossRef, ORCID, Microsoft Academic, etc.) with keywords "pandemic," "office" "hybrid" and "workplace" for living-working pattern; "pandemic" and "distancing" for the distancing aspect; and "pandemic" and "dynamic" for dynamic aspect. After data collection based on keywords for each aspect, screening based on field study using "architecture" and "built environment" and filtering articles that have open access color green or gold, eliminating the duplicated articles, and excluding the not written in English or Bahasa and non-conceptual studies, a total of n = 30 articles for living-working pattern, n = 39 for distancing, and n = 40 for dynamics were eligible and reviewed independently by the authors [38–40]. This review guided us to a process of systematic literature overview summaries and deep network analysis to create a theory regarding security-pandemic. The information and data flow related to security aspects for post-pandemic was collected from 2000 until April 2023. The source groups of research were summarized in Table 1, and the network analysis data was used to prepare for theorizing about the security pandemic.

After some study, the conclusion from a systematic literature search and review of the authors' previous research is that there was an adjustment in the concept of security in architectural design before and after the COVID-19 pandemic. Before the COVID-19 pandemic, security design in architecture focused on crime prevention and safety from

Table 1
Aspects and source groups of research.

Security-Pandemic Aspects	Keywords	Literature found in Field Study	Subtotal	Total
Dynamics	"pandemic" and "dynamic"	102	40	109
Distancing	"pandemic" and "distancing"	114	39	
Living-Working Pattern	"pandemic" "office" "hybrid" and "workplace"	81	30	

natural disasters [32,38–41]. Six sub-aspects of dynamics in a security pandemic are density, peripheries and spread, interaction, mobility, access-spatial standards and protocols, and antivirus building materials [38,42,43]. Five sub-aspects for social distancing in the security pandemic are: standard for integrating a healthy environment in architecture; relationship and interaction in users' patterns; environment design related to nature; spatial relationship proxemics; and place attachment for architecture [44–47]. Three sub-aspects of the living-working pattern: pattern of hybrid activities, new layout for hybrid activities, and changing of behavior and culture [28,38–40,43,48–51].

After some systematic literature search and review (summarized in Table 1), the next step is to adjust and theorize the security theory according to the security-pandemic theory. Mautner in Friedman (2003) defines theory as a set of propositions that give principles for analyzing subjects (the security-pandemic theory) [35,37]. Jon Lang (1987) stated that creating architectural theory or theorizing involved defining

variables, studying literature, interpreting terms and patterns of relationships, and conducting network analysis [18]. While Parson's and Shils's in Friedman (2003) stated that theorizing implies a hierarchy of classification systems, describing the relationship between categories, conceptual frameworks (propositions and explanations), and creating theory systems [35]. Based on these explanations, theorizing in this research involves (1) the classification systems and interpreted terms, (2) network analysis, which examines the patterns of relationships between aspects and variables, and (3) creating propositions and theory systems for the security-pandemic aspects and variables.

3. Results and discussion

This results and discussion section will show the steps in theorizing security-pandemic theory. The steps are classification, interpreting terms, analyzing networks, and creating propositions and theory systems.

3.1. Classification systems and Interpretation Terms of security-pandemic aspects and variables

The first step in theorizing security-pandemic theory is classification and interpreting terms. Classification and interpretation of terms for security-pandemic is a process of analyzing the interrelationship between variables and aspects and sub-aspects. The classification and interpretation of terms need to be done and presented below because there are new interpretations. The security-pandemic aspects and sub-aspects for post-pandemic architecture are presented below as classification systems into the following perspectives: (1) dynamics (with six sub-aspects), (2) social distancing (with five sub-aspects), and (3) living-working patterns (with three sub-aspects) (summarized in Table 2).

One way to design post-pandemic architecture is by considering the security-pandemic aspect as well as pandemic preparation approaches and solutions. Three main aspects of security pandemics are dynamics, social distancing, and living-working patterns, which make a foundation for security pandemics theory. Adapting current security variables and reconsidering pandemic preparation elements for architecture design is necessary.

3.2. Network Analysis of Security-pandemic aspects and variables

There are 23 security-pandemic variables' terms (16 new variables and 7 existing variables with terminology changes) that need to be connected, addressed, and adjusted according to the security-pandemic theory. Therefore, the second step in theorizing security-pandemic theory is network analysis (examining the patterns of relationships between aspects and variables). The 7 existing variables with terminology changes are access and movement, structure, surveillance, ownership,

Table 2
Summary of classification system and interpretation terms of security-pandemic aspects.

Security Post-Pandemic Aspect	Security Post-Pandemic Sub-Aspect	Ref	Interpretation Aspects Terms
Dynamics	Density	[50,51]	Control of air density for potential post-pandemic diseases' spread via aerosols in the air. Control user density for the potential spread of infectious diseases through humans via droplets.
	Peripheries and spread	[52–54]	Control through peripheries for reducing the possible spread of infectious diseases by improving indoor air quality limited user movement within the architecture.
	Interaction	[45,55,56]	Close interaction is an interaction that occurs between two or more people who know each other. Not-close interaction is an interaction that occurs between two or more people who do not know each other. Control in these interactions by providing separate areas for close-interaction users and different areas for not-close-interaction users.
	Mobility control	[57–59]	Control of the mobility of users, air movement, dew rate-humidity, natural sunlight, UV-C rays, and surface in building materials is necessary for preventing the disease spread through mutual contact, air, airborne and droplets and increasing users' health and body's immunity.
	Access control and prevention through standards and protocols -	[43]	Control and prevention through users' access are carried out by limiting user access within the architecture, creating new building standard protocols for post-pandemic architecture, and applying protocols for users' self-protection within the architecture.
	Antivirus Building Materials	[13]	Prevention via touchless technology and surface antivirus materials within architecture for the possibility of disease spreading through droplets.
Social Distancing	Standard for integrating healthy environment in architecture	[8,60–65]	Applying standard design layout and space to integrate a healthy environment through anthropometric design standards (designed considering the human body size) and the ergonomic design standard (designed considering humans' physical, mental and comfort during activity).
	Relationship and interaction in users' pattern activity	[45,66–70]	Limitation of user activity patterns through controlling social interaction (close and spontaneous) and social control, which means restricting the users' pattern of activity for social interaction through the presence of architectural elements to limit user interaction patterns, for example, the design of chairs that provide a secure social distance.
	Environment Design related to nature	[61,71–74]	Standard design layout and space that considers the principles of the natural environment to prevent and limit the spread of disease within architecture (for example, biophilic designs connected to nature have health impacts on users).
	Spatial relationship (proxemics)	[75–78]	Changes in standard design and spatial relationships (proxemic) for personal space, physical distance, and proximity for interpersonal relationships during interaction to prevent the disease from spreading within architecture.
	Place Attachment for architecture	[79,80]	Disease prevention spreads through users' safety and maintaining physical and mental health by applying environmental psychology and emotional attachment between the user and place in the home and workplace.
Living-Working Pattern	Pattern for hybrid activity	[47,48,81–84]	Deter the patterns for hybrid activity due to changes in the user's activity and help prevent the spread of disease within the workplace and at home.
	New Layout for hybrid activity	[28,46,85–87]	Deter the new standard for hybrid activities and layout changes in the workplace and home due to changes in user activity patterns, and to help prevent the spread of disease within the interior-structure scope, layouts need to be adaptable and flexible to changing activities and the need for hybrid activities.
	Changing behavior and culture	[28,29,48,88,89]	Changing in behavior and culture means detecting changes in user behavior and culture in the workplace and home. Detection of these changes is necessary so that the built environment can adapt and be flexible to user behavior and culture changes.

physical protection, activity, and management maintenance. The rest of the variables are new terms. The explanation of variable terms and network analysis between security-pandemic aspects, sub-aspects, and variables are presented below (summarized in Table 3 and Fig. 2).

3.2.1. Access and movement

Access and movement are places with well-defined routes, spaces, entrances (which can be for hybrid activity), and comfortable movement of people, air, and goods without sacrificing the safety of users (helping reduce the risk of transmission) inside the architecture [52]. In the previous security context, having good access and movement will make detecting unusual behavior in the room easier. In the security-pandemic context, good controls on access and motion areas will facilitate helping to reduce the risk of transmission inside the building, creating safe spaces and adaptability by controlling access to healthy users (with body temperature scans and user controls for masking and washing hands), limiting the capacity and number of users, controlling items entering so that they are virus-free, directing the movement of users and items in the room, and controlling user access for hybrid activities [43,53–58].

3.2.2. Structure

Structures are elements that aim to secure the user of the space to avoid conflict from disease or other users [52]. In the previous security context, a good structure ensures that the zoning and restriction of space through space-forming structures (such as floors, walls, and furniture) do not conflict with other users. In the security-pandemic context, reasonable control of the structure aims to protect the user of the space and avoid conflicts with other users, such as by marking a physical distancing sticker on the floor or restricting the movement of the user with furniture or walls [53,54,59–61].

3.2.3. Surveillance

Surveillance variables are all areas humans and technology can naturally monitor to reduce the risk of transmission within the internal structures [52]. In the previous security context, good natural surveillance of public areas could naturally be supervised by humans. In the context of security pandemics, good controls on surveillance, such as placing humans in strategic positions as natural surveillance and monitoring technologies that indirectly help monitor the behavior of users who are in space or are going to enter space or monitor user behavior to implement health protocols such as wearing masks well, including tracking through the digital world if there is a sicker [53,54,60,62–66].

3.2.4. Ownership/territory

Ownership is a place that supports a sense of ownership, respect, territory, responsibility, and community. Ownership is helping users become active in creating security in their spaces through the signs of territory within the interior structure [52]. In the previous security context, ownership helped users become active in creating security in their rooms through territorial signs in space, space limits, and personal spaces. In the security-pandemic context, clear limits on areas with ownership allow users to claim space they own, control others when using their spaces, and express identity and social status to limit the spread of disease. One way is to use design elements to create ownership and territory in the space, zoning and dividing the room into different areas according to the user's needs. Users can be flexible and adapt to their space to meet the room owner's requirements [53,54,60,67–69].

3.2.5. Physical protection

Physical protection is a security feature that protects users from virus threats and eliminates user concerns. In the previous security context, "physical protection" with security features helped users feel safe in their usual activities. For example, the dual-key feature inside the house made residents feel secure when leaving the house. In the context of the security pandemic, the security features used are those that can protect users from virus threats, such as devices that can automatically sterilize the room or a device that can filter the air inside, and evacuation planning features if there is an emergency [53,54,70–73].

3.2.6. Activity

Activities are places where human activity is carried out under the planned location. Some places help reduce the crime risk and always give a sense of security [52]. In the previous security context, activity helps users carry out activities as planned and required, e.g., the security guard only owns access to the security room. In a security-pandemic context, having the proper area planned for the suitable activity and clear restrictions on the appropriate activities will make users feel safe, limit users who are uninterested, not too crowded, create social distancing, or avoid sick users. One way to do this is to use the lobby activity outside the hall so that the hall isn't too crowded [53,54,60,66,67,74–78]. The activity provides places for appropriate user-interaction activities and clear area restrictions. Architecture must provide a space to support social resilience [79].

3.2.7. Management maintenance

Management maintenance is designed for treatment that supports reducing the risk of virus transmission within the internal structures. In the past security context, care management helped reduce the risk of non-crime occurrences in the present and future [52]. In the context of the security pandemic, there is a discussion about managing this treatment used to reduce the risk of transmission and spread of the virus now and in the future. One way is to maintain the elements in the building regularly to keep the space in good condition and reduce the risk of virus transmission; monitor the area regularly to help identify the potential spread of the virus; integrate technology; and provide an area for emergency preparedness [54,60,80–84].

3.2.8. Indoor Environmental Climate

Indoor environmental climate in the spaces concerned are indoor and outdoor air conditions that are comfortable for the user. Humans nowadays spend much of their time in closed spaces like homes, offices, schools, and other buildings (almost 90 %). During this time, humans are exposed to inhale indoor air pollutants that can affect their health [8,85–89]. In the context of pandemic security, climate-related discussions and natural indoor heating are used to reduce the risk of transmission and spread of viruses through air transmission and indoor air density. Improved heating quality inside buildings can be used to reduce the risk of respiratory infectious diseases [8,85,86,90]. One way is to increase ventilation and speed the airflow from outside into the room [12,13,85,86,91–95]. In interior space, virus spread can be reduced via air change or flow [79].

3.2.9. Humidity and temperature

The humidity and temperature refer to the conditions of the air moisture and temperature inside and outside so that the user is comfortable in activity and reduces the transmission of the virus. Based on some evidence, the spread of the virus at warm temperatures tends to be lower at relatively high but appropriate humidity. Virus transmission is higher at cold temperatures and low humidity [96]. In the context of the security pandemic, the availability of information related to indoor humidity and temperature is used to reduce the risk of transmission and spread of viruses through air transmission through the control and design of the HVAC system [12,86,87,94,95,97]. One way is to increase ventilation from the outside to the inside, which can increase indoor temperature and humidity to reduce virus transmission [98–100]. In interior space, humidity can reduce virus spread [79].

3.2.10. Natural lighting

Natural lighting means improving the quality of natural lighting that is comfortable for the user and helps reduce the risk of disease transmission. Based on some evidence, natural light has been shown to affect

Table 3
Explanation of security-pandemic variables and interconnection with security-pandemic aspects and sub aspects.

Security-Pandemic Variables Terms	Ref	Dynamics						Social Distancing					Living-Working Pattern		
		density	peripheries and spread	interaction	mobility	access-spatial standards and protocols	antivirus building materials	Standard for integrating healthy environment	Relationship - interaction in users' pattern	Environment Design - Nature	Spatial relationship (proxemics)	Place Attachment for architecture	pattern of hybrid activities	new layout for hybrid activities	changing of behavior and culture
Access-movement Path or object within the space that clearly defined the access-movement orientation for protecting individuals and containment of diseases.	[41,83,91–95]	✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓
Structure Structural elements of rooms for human motion throughout the space and ensure a conflict-free environment.	[70,82,91,92,96]				✓	✓		✓	✓	✓	✓		✓	✓	
Surveillance Natural surveillance for monitoring users' hygienic behavior within the layout and space.	[91,92,96–101]	✓	✓		✓	✓		✓	✓	✓	✓		✓		✓
Ownership Layout and furniture arrangement elements that incorporate elements such as hierarchy, ownership, limits, and personalization.	[77,91,92,96,102,103]		✓		✓	✓			✓		✓	✓	✓	✓	✓
Physical Protection A number of well-designed security features to improve personal protection and avoid contact effectively.	[91,92,104–107]							✓	✓	✓				✓	✓
Activity Building elements	[91,92,96,101,102,108–112]	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓

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Table 3 (*continued*)

Security-Pandemic Variables Terms	Ref	Dynamics						Social Distancing					Living-Working Pattern		
		density	peripheries and spread	interaction	mobility	access-spatial standards and protocols	antivirus building materials	Standard for integrating healthy environment	Relationship - interaction in users' pattern	Environment Design - Nature	Spatial relationship (proxemics)	Place Attachment for architecture	pattern of hybrid activities	new layout for hybrid activities	changing of behavior and culture
and arrangements for support users' activity mobility and access while protecting them.															
Management maintenance Management maintenance for maintaining the clean building elements and reducing the risk of virus.	[92,96,114–118]	✓	✓		✓	✓		✓			✓	✓		✓	
Indoor environmental climate Appropriate air compounds for preventing the transmission of infectious diseases by controlling the quality of the air system.	[8,12,13,51,119,120,125–128]	✓	✓		✓					✓					
Humidity and temperature Supplying comfort temperature, appropriate humidity, air pressure, and airflow for human comfort and health.	[12,120,121,127–129]		✓		✓					✓					
Natural light Supplying the required lighting quantity (illuminance) lighting quality (orientation of natural light; larger window for better direct sunlight; light reflectance, etc.)	[119,120,122,123,128,133–136]				✓					✓					

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Table 3 (*continued*)

Security-Pandemic Variables Terms	Ref	Dynamics						Social Distancing					Living-Working Pattern		
		density	peripheries and spread	interaction	mobility	access-spatial standards and protocols	antivirus building materials	Standard for integrating healthy environment	Relationship - interaction in users' pattern	Environment Design - Nature	Spatial relationship (proxemics)	Place Attachment for architecture	pattern of hybrid activities	new layout for hybrid activities	changing of behavior and culture
Natural Sound Appropriate sound reflectance and absorption for user needs. Not supplying noise and sound disruption that weaken the individual's immune system.	[119–121,128,142]									✓					
Access to nature Quality and quantity of users' ability to engage with the natural environment, natural elements, natural materials within the interior, and access to the landscape.	[73,119,120,128,133,143,144]									✓				✓	✓
Hygienist Natural Building Elements and Materials Selection of building materials and interior surfaces with materials created from nature or look like nature to enhance hygiene and well-being within the space.	[13,84,128,143,145,146]									✓					
UV-C System UV-C system inside the building to increase air quality and reduce virus spread.	[13,126,147–150]				✓										
Hygienist behavior Design in the building that can	[113,119–121,151–157]				✓	✓		✓	✓						✓

(*continued on next page*)

Table 3 (*continued*)

Security-Pandemic Variables Terms	Ref	Dynamics						Social Distancing					Living-Working Pattern		
		density	peripheries and spread	interaction	mobility	access-spatial standards and protocols	antivirus building materials	Standard for integrating healthy environment	Relationship - interaction in users' pattern	Environment Design - Nature	Spatial relationship (proxemics)	Place Attachment for architecture	pattern of hybrid activities	new layout for hybrid activities	changing of behavior and culture
enhance hygiene practices and behavior.															
Hygienic Building Material Surfaces Selection of building and interior surface materials enhances the space's hygiene.	[13,83,113,126,158,159]				✓		✓								
Users' Activity System Users' behavior, motivation, and knowledge systems that affected users' activity within the virtual-physical building elements.	[28,29,46–48,81,85,160]												✓		
Living-Working Flexible Activity Flexible living-working activities within the building that affected users' behavior and activity	[28,46–48,81,85,113,161–163]												✓		✓
Behavior on Zone Isolation – Distance Changes in building elements affected by users' behavior while in isolation and distancing zone.	[113,164–168]														✓
Behavior in Sterilization Zone Changes in building elements that are affected by users' behavior while in sterilization zone.	[105,106,157,166]														✓

(*continued on next page*)

Table 3 (*continued*)

Security-Pandemic Variables Terms	Ref	Dynamics						Social Distancing					Living-Working Pattern		
		density	peripheries and spread	interaction	mobility	access-spatial standards and protocols	antivirus building materials	Standard for integrating healthy environment	Relationship - interaction in users' pattern	Environment Design - Nature	Spatial relationship (proxemics)	Place Attachment for architecture	pattern of hybrid activities	new layout for hybrid activities	changing of behavior and culture
Behavior on Spatial Diversity Changes in building elements that are affected by users' behavior while in spatial diversity zone (such as distancing in elevator).	[50,85,92,96,105,109,169,170]													✓	
Hygienist behavior and ergonomically related architecture element Architectural and interior elements that are designed ergonomically to improve human well-being, comfort, and emotional state	[64,77,112,171–178]							✓							
Digital-virtual space relationship The camera's distance and angle affected the personal and private perspective of the room within the virtual application	[27–29,47,48,179–182]										✓	✓	✓	✓	✓

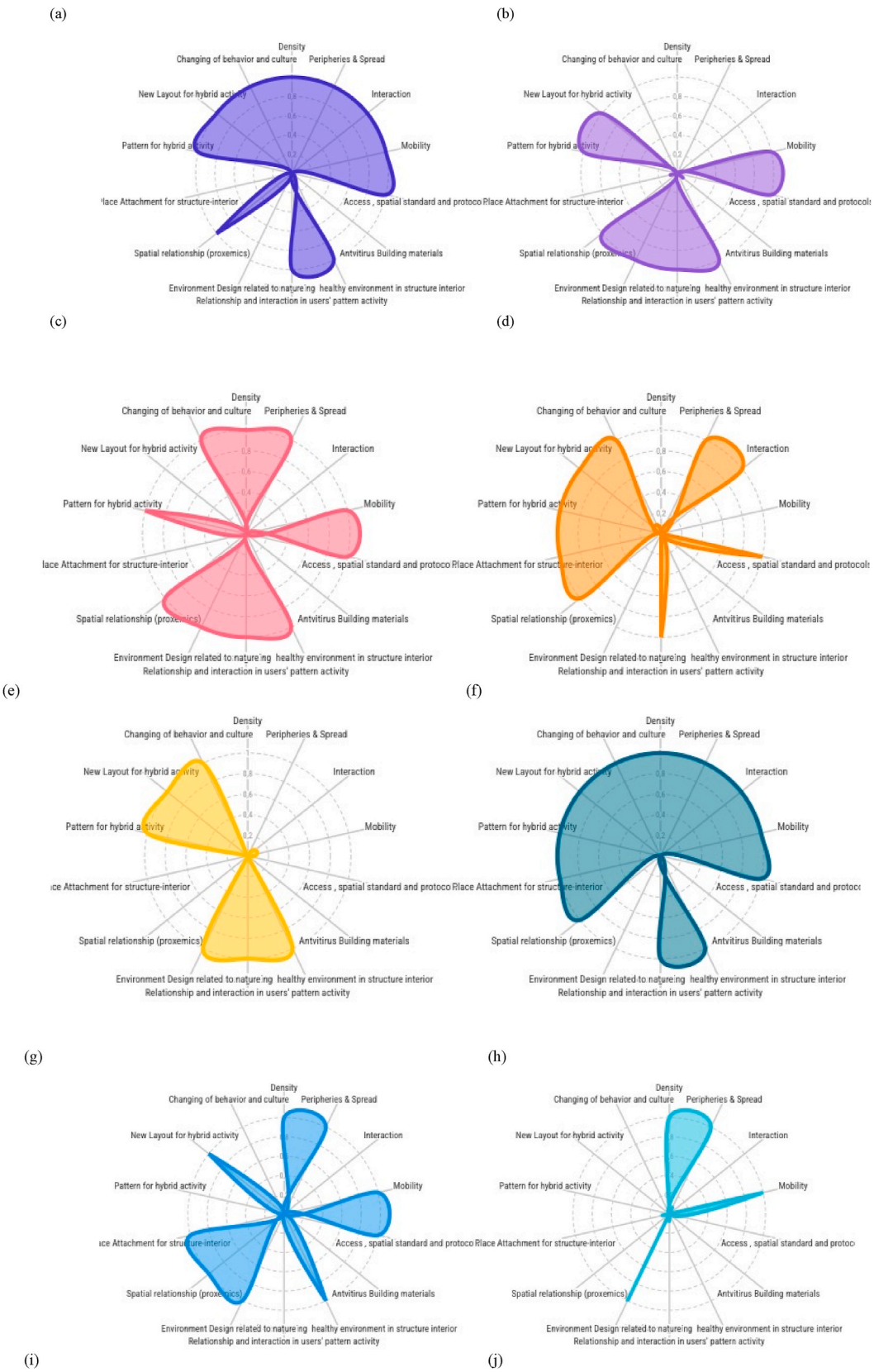


Fig. 2. (a) Access and Movement; (b) Structure; (c) Surveillance; (d) Ownership; (e) Physical Protection; (f) Activity; (g) Management Maintenance; (h) Indoor Environmental Climate; (i) Humidity; (j) Natural Lighting; (k) Natural Sound; (l) Access to Nature; (m) Hygienist Natural Building Elements and Materials; (n) UV-C System; (o) Hygienist behavior; (p) Hygienist Building Material Surfaces; (q) Users' Activity System; (r) Living-Working Flexible Activity; (s) Behavior on Zone Isolation – Distance; (t) Behavior in Sterilization Zone; (u) Behavior on Spatial Diversity; (v) Hygienist behavior and ergonomically related architecture element; (w) Digital-virtual space relationship.

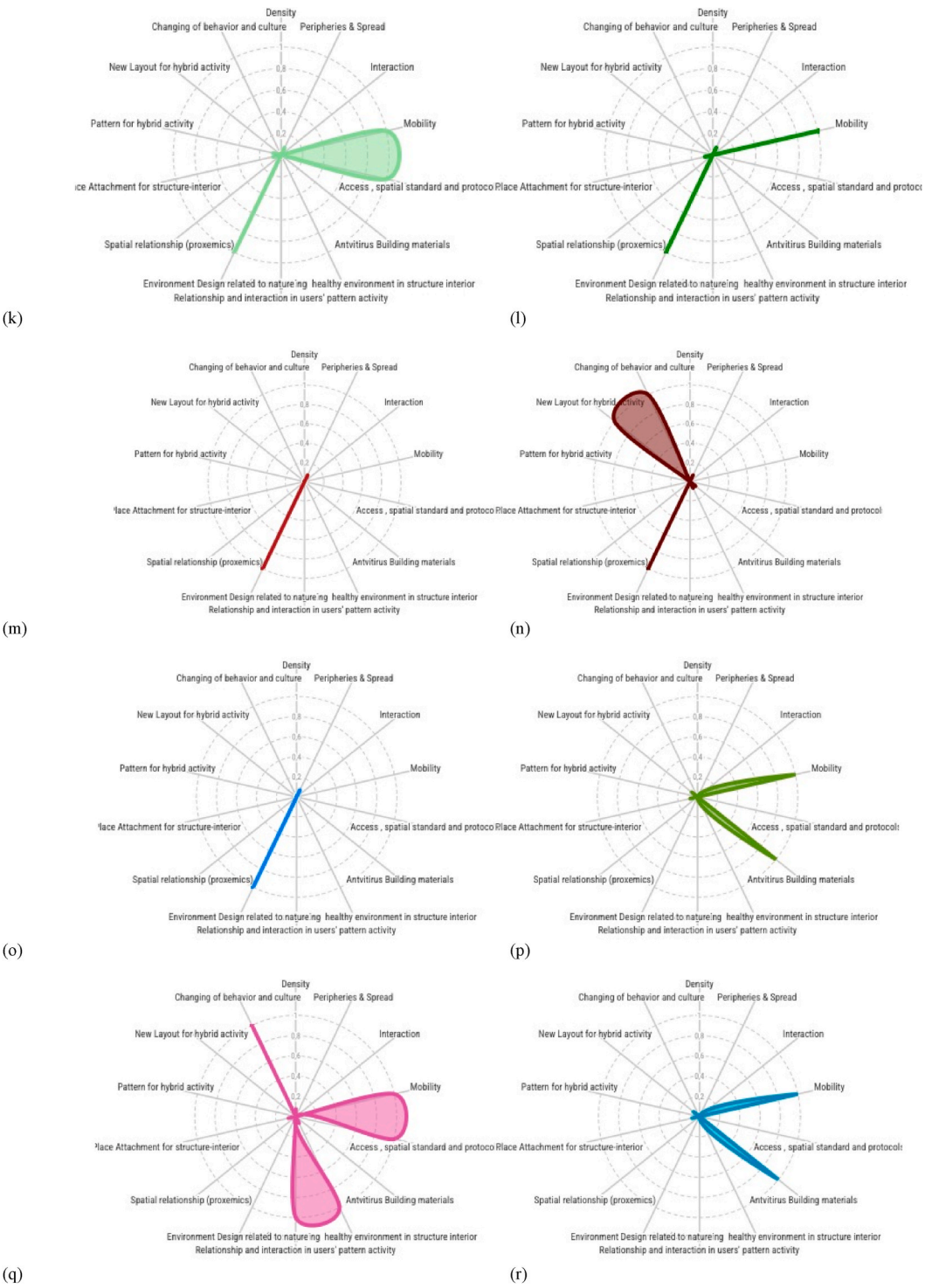


Fig. 2. (*continued*).

human health positively. Natural light, rich in vitamin D, can boost the human body's immunity [85–87,95]. In the context of a security pandemic, the presence of natural lighting-related discussions is used to raise the temperature in the room to reduce the risk of transmission and spread of viruses, increase the intensity of natural illumination in the room, and increase the body's immunity of the user inside the room [85,86,88,89,95,101–104]. One way to increase natural lighting is by increasing the number of openings like windows, light wells, and skylights [85,86,105–107].

3.2.11. Natural Sound

Natural acoustics refers to acoustic comfort associated with sound disturbances or noise pollution from inside and outside that can affect users' health. According to some evidence, sound distortion can cause users discomfort that affects user health (users are more susceptible to virus exposure) [95,101–103,108,109]. In security pandemics, natural acoustical-related speech is used to improve user comfort and health and reduce the risk of transmission due to unhealthy users [85–87,95,110].

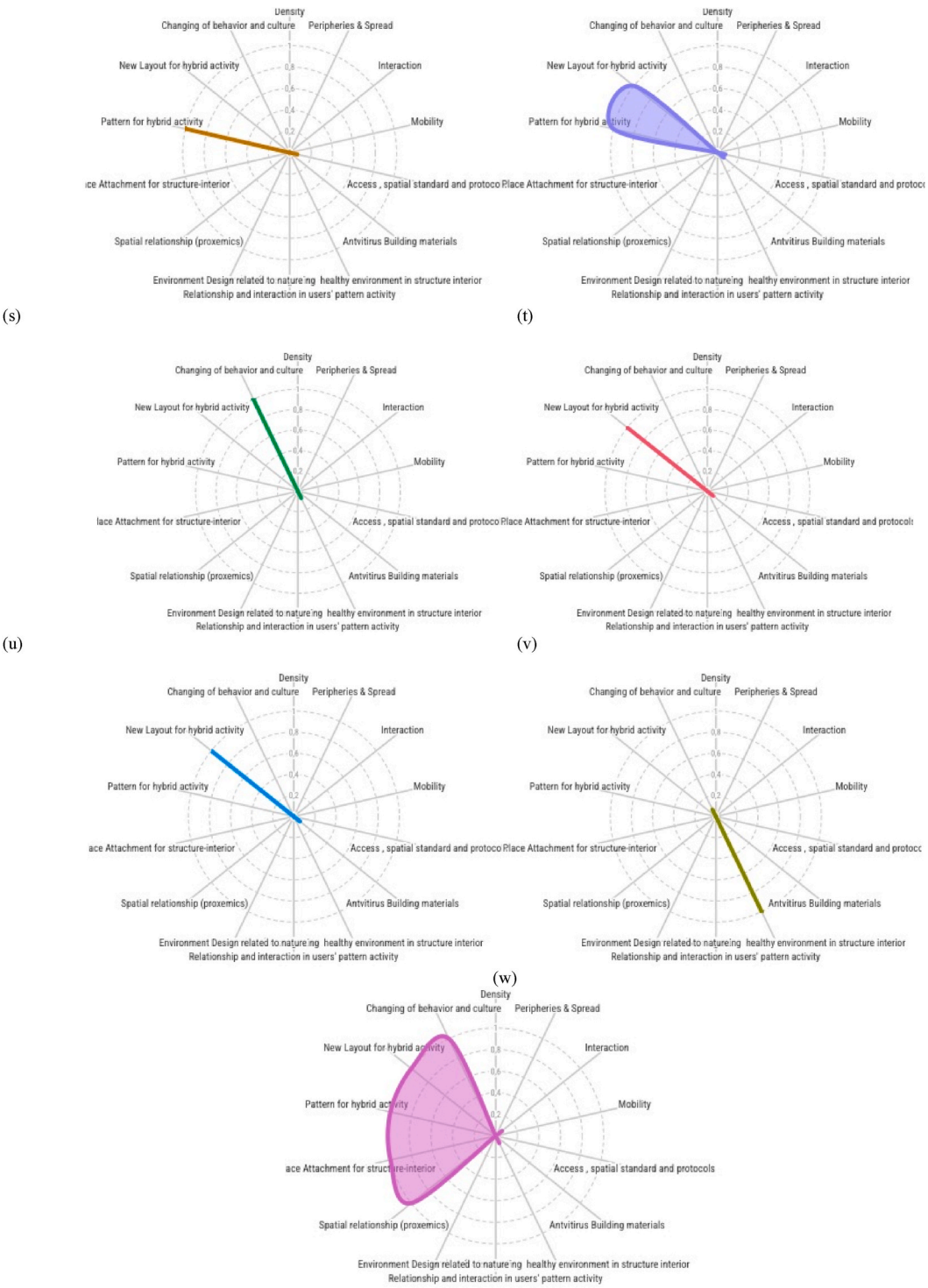


Fig. 2. (*continued*).

3.2.12. Access to nature

Access to nature is the access or connection of inner space to outer space that can improve the user's health. Based on some evidence, access to nature provides several benefits to human health, such as improving the health and endurance of users. If users have better body resistance, they become more resistant to viruses [85,86,95,101,111–113]. In the context of the security pandemic, the existence of access-related discussions about nature is used to improve user health, mental health, and resilience, thereby reducing the risk of viral infection [79,85,86,111].

3.2.13. Hygienist building elements and materials

Materials and natural elements related to interior structures are materials and elements of interiors originating from nature that improve human health and reduce the spread of viruses. According to some evidence, natural materials and natural elements can increase the body resistance of users to viruses [13,95,112,114–116]. In the context of the security pandemic, hygienist building elements and materials are used to improve users' physical and mental health so that users are resistant to viruses and are not infected with viruses through elements and materials inside the room.

3.2.14. Ultraviolet - C system

Ultraviolet-C or UV-C systems are indoor UV-C rays that help improve air quality while reducing the spread of viruses. However, using these UV-C systems requires special surveillance and security so as not to jeopardize the health of indoor users [13,92,117–120]. In the context of a security pandemic, UV-C system-related discussions are used to reduce the risk of transmission and spread of the virus in the air. One way is to optimize the indoor UV-C system as a filter. In interior space, virus spread can be reduced via filtering [79].

3.2.15. Hygienist behavior

Hygienist behavior refers to designs conditioned to support user hygiene behavior through interior design elements, programs, and rules for users to perform hygienic conduct. In a security-pandemic context, hygienic behavior discussions are used to reduce the risk of virus transmission and spread by designing spaces supporting user hygiene behaviors. For example, hand washing, hand sanitation, and touch-free systems in some strategic spaces, such as the elevator area, support user hygienic behavior [79,85–87,121–127]. Good hygienist behavior will protect the users from surface-to-person transmission (fomite) [79].

3.2.16. Hygienic building material surfaces

Using hygienic building materials refers to using hygienic materials and technologies through easy antivirus care on facilities and equipment to keep the building hygienic. In the context of security pandemics, there is discussion regarding using hygienic building materials to reduce the risk of transmission and spread of viruses. These can be done through the materials used in buildings and spaces and the application of touch-free technology that uses sensors, is easy to maintain, and is not easily transmitted by viruses [13,56,79,92,128,129]. A study showed that copper is the most antiviral material (4 h) compared to cardboard (24 h) [79].

3.2.17. Users' activity system

In the context of the security pandemic, there is discussion about the changing system of user activity (especially in the context of motivation, behavior, attitudes, and knowledge) due to hybrid spaces used for activity. This user activity system will help support social cohesion in physical and virtual spaces [79]. A pandemic changes the user activity system, affecting the setting and patterns of elements of physical and virtual space [29,30,48–50,130–132].

3.2.18. Living-Working Flexible Activity

Flexible living-work activities are flexible life-working activities that can be carried out in spaces and elements of space that can adapt to activities and are flexible. In the context of security pandemics, there is a discussion related to the behavior of this flexible living-working activity used for hybrid user activities. For example, when users work in a room but sleep at different hours [29,48–50,79,130,132–135].

3.2.19. Behavior on Zone Isolation - distance

Behavior on Zone Isolation and distance-keeping is the presence of changes in the activity and behavior in the isolated zone and the enforcement of the stance-keeping. In the context of the security pandemic, there is a change in behavior in the isolation zone, and the user is asked to keep a distance from isolated users. This behavioral change is carried out with the restriction of direct communication with the sick user and more optimizing indirect and virtual communication with the user [79,136–140]. Users will protect themselves from person-to-person droplet transmission by distancing [79].

3.2.20. Behavior in the Sterilization Zone

Behavior in a sterilization and distance-keeping area is the presence of changes in activity and behavior in sterilization and the application of distance-keeping located in the areas that access a building. In the context of a security pandemic, there is a change in behavior in the sterilizing area, and the user is asked to keep their distance. These can be done through control of the limitation of the number of users entering the room, standing behaviors based on the stickers below for distance-keeping, or behaviors in the isolation zone through washing hands and checking the body temperature before entering and activity inside [71,72,79,127,138].

3.2.21. Behavior on Spatial Diversity

In the context of the security pandemic, behavioral changes in this area are carried out with control of the number of users entering the room, visitors walking in the direction of the circulation area, distances when climbing escalators and lifts, as well as rules and protocols to be followed when engaging in activities in the room [54,60,71,75,79,132,141–143].

3.2.22. Hygienist behavior and ergonomically related architecture element

The customary culture of ergonomics in interior structures is the habit of using ergonomic designs to optimize the user's health. In the context of the security pandemic, the existence of an ergonomic design culture (related to designs that maximize user health) through the design of furniture, accessories, and space elements will improve the sense of safety and physical health of users [68,78,144–152].

3.2.23. Digital-virtual culture

Digital-virtual culture is the adaptation of digital culture and virtual technology that changes the way and culture human beings live and work. In the context of the security pandemic, there are discussions related to the acceleration and change in digital-virtual culture that affect the change in user habits and changes in the elements of space to support these virtual-digital technologies. There is a pandemic that transforms the digital-virtual culture, and it affects the setting and patterns of aspects of physical and virtual spaces [28–30,49,50,153–156].

Table 3 identifies the explanation of variables' terms and the interconnections between variables of security-pandemic aspects. The discussion of each interconnection within variables and aspects using the network analysis method is summarized in Table 4 and Fig. 3.

3.3. The proposition of security-pandemic theory

Based on the interconnections within sub-aspects and between the aspect diagrams above, the next step is creating propositions and theory systems for the security-pandemic aspects and variables. The propositions of security-pandemic theory in architecture are based on the results of identification of aspects using systematic literature search and review, classification, and interpretation of terms of aspects and sub-aspects, network analysis between variables and three elements of dynamics, keeping distance, and living-working patterns. The synthesis of propositions of security-pandemic theory in architecture is as follows.

1. The dynamic and social distancing aspects are connected in terms of control and prevention of person-to-person (users' activity and interaction), media-to-person (nature, air, light, sound), and surface-to-person (through architecture elements and materials).
2. The dynamic and living-working pattern aspects are connected in terms of control and deter pattern of person-to-person (changes of users' hybrid activity, behavior, and interaction) and media/surface-to-person (changing for healthy behavior and culture by using natural elements such as air, light, and elements).
3. The social distancing and living-working pattern aspects are connected in terms of prevention and deterring patterns of person-to-person and media-to-person by distancing and changing for hybrid culture and behavior using physical and virtual design elements.

This theoretical chart describes the proposition and pattern of interconnection within aspects and sub-aspects of security-pandemic theory. Nevertheless, not all aspects, sub-aspects, and variables in

architecture design must meet the applicable benchmarks. The complexity of architectural and interior design projects also determines how complex elements and variables are needed, discussed, applied, and evaluated later. Therefore, to optimize the proposition between aspects described in this chart, the security-pandemic theory requires the role of the architect as the determinant of the building design, who can prioritize the emergence of aspects and variables in each building design application. The security-pandemic theory in post-pandemic architecture can be optimized through deter, prevention, and control within the built environment with the help of the role of the architect, as well as the support of the owner and the management of the building environment. The proposition of security-pandemic theory between security-pandemic aspects sub-aspects and interconnection context are presented below (see Fig. 4.).

4. Conclusions

The current COVID-19 pandemic is bringing changes to security design architecture. It's our responsibility to prepare plans and take necessary actions for future outbreaks. Health, safety, and security are crucial for humans; therefore, the security-pandemic theory had critical importance during the pandemic and post-pandemic. In conclusion, this section will answer the essential questions from the introduction: "How are the implications and prevention of pandemics in the security design and architecture context (regarding changes in living-working patterns, dynamics, and distancing)? The answer to this question will be as follows: The theory of security in architecture is fundamental for human needs and encompasses human protection. The rapid spread of COVID-19 challenges the existing security theory to transform the architecture to consider transdisciplinary knowledge (transportation, urban planning, environmental science, psychology, health, ethnography, anthropology, technology, and social discipline) and various aspects (the dynamics, social distancing, and living-working pattern). For example, the implications for health-engaged architecture post-pandemic are indicated on prevention through personal hygiene (handwashing, regular cleaning, the use of antiviral materials, and sterilization with UV light); distancing and isolation (increase of safe distance up to 2 m); air control by ventilation, filtering and humidifying (more ventilation in air by 3x, using the HEPA filter and maintaining indoor humidity >40 %); social interaction in public and working spaces (reduce mobility and spontaneous social interaction) [79,157].

After the pandemic, the built environment design variables such as architecture-interior plan, scale, surface, color, opening, users' density, access and shared spaces, air control, barrier between indoor-outdoor, spatial territories, isolating strategies (using partition and cubicles in office) and sense of security have positively affected in preventing the infection and reducing the distress and anxiety. These engagements have led to the changing of people's behaviors and physical-environmental needs compared to before the pandemic [157–160]. Further integration from other disciplines for the security-pandemic theory is the involvement and beneficial impacts on telecommunication, behavior, public health, and environment for post-pandemic architecture. The security-pandemic theory is integrated with the environment, telecommunication, and public health disciplines by reducing the size of the office, creating more controlled access spaces, better-planned ventilation, lowering work-family conflict, and reducing fuel and energy usage in buildings [157]. Another integration of security-pandemic theory is with different geographical and cultural contexts. For example, post-pandemic home design in Egypt uses balconies as hybrid living-working spaces for remote work during and post-pandemic [39,159]. Another example of the global diversity implementation of security-pandemic theory is the connection to natural space (for example, using biophilic design) as one of the solutions to reduce virus spread through architecture. Connection with nature space has proven to be an effective approach to providing better and more secure connections with nature in residential and office projects [40,161].

The next critical question is: "How are the theories of security in architecture evaluated in the presence of pandemics and health issues, and what are the consequences of the change in hybrid activities in the workplace and living space?" The answer to this question will be as follows: The security pandemic in post-pandemic architecture needs to adapt and be flexible as a new change in hybrid activities and technology has impacted the current security and architecture design. The existing security-pandemic theory needs to be elevated, and its existing terms must be interpreted accordingly. The security-pandemic theory in post-pandemic architecture is the development of existing security theory in architecture and post-pandemic in urban design theory by Salama (2020). The theory contributed to new interpretations of aspects and sub-aspects of security-pandemic in post-pandemic architecture. There are 23 security-pandemic variables, including 16 new security-pandemic variables and changes of terms for 7 existing security variables. The security-pandemic theory in post-pandemic architecture can be enhanced by implementing measures of deter, prevention, and control inside the physical structure. The architect plays a crucial role in this process, with assistance from the building owner and administration.

The future implementation of preventive measures in post-pandemic architecture cannot be definitively determined, as the mechanisms of viral transmission and other diseases are still under investigation. One of the implementations in architecture and interior design is accommodating adaptable-flexible-hybrid spaces and touchless-smart technologies to control and eliminate sources of infection. Connecting the interior space with the natural environment and nature can create a more comfortable space, promote physical-mental health, and optimize the users' activity and productivity. Humans should be prepared for the potential occurrence of recurrent outbreaks of other pandemics. Therefore, it is crucial to understand the requirements during pandemics and develop robust solutions. The COVID-19 pandemic is probably not the last, but future pandemics can also be responded using the security-pandemic theory. The security-pandemic theory in this manuscript has analyzed the potential virus spread protection for users and using variables that considered the environmental condition, architectural healthcare, environment, behavior, and cultural context (such as hygienic, distancing, or adapting space) [14,87,162]. New variables of the security-pandemic theory have involved good health, well-being, hygienic behavior, new building strategies, and concern about environmental problems for better future prevention and preparation for future disasters-emergency situations. Future research on security-pandemic theory can focus on creating innovative building codes and green certifications that address post-pandemic preparedness and can be designed as guidelines established by the health authority [39]. These may involve modifying existing codes and certificates to address the issues arising from pandemics specifically.

CRediT authorship contribution statement

Sherly de Yong: Writing – original draft, Visualization, Methodology, Conceptualization. **Murni Rachmawati:** Writing – review & editing, Supervision, Methodology. **Ima Defiana:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

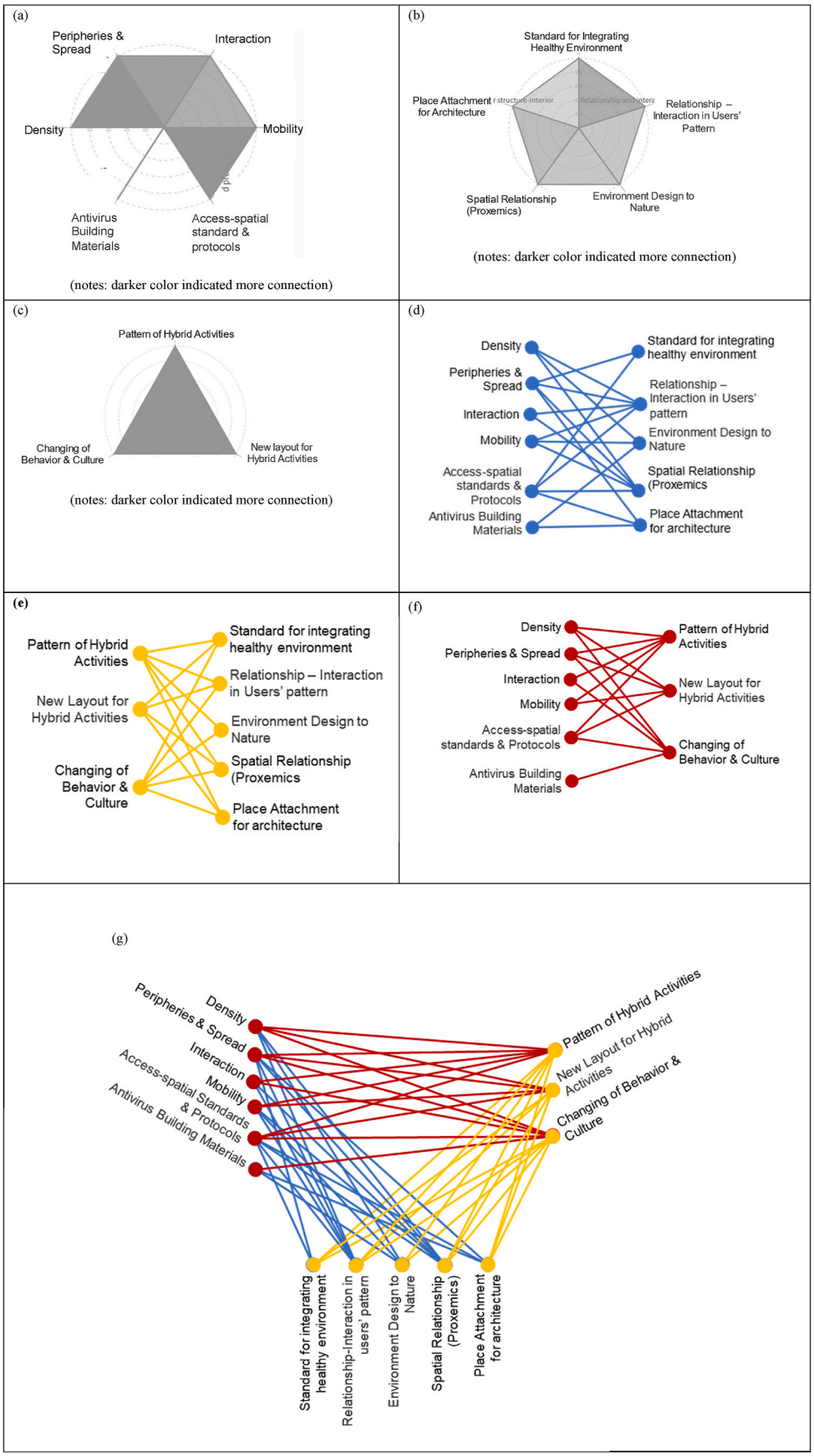
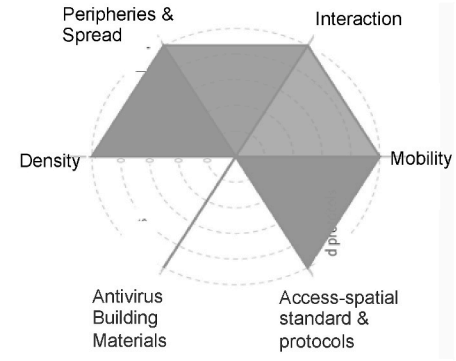
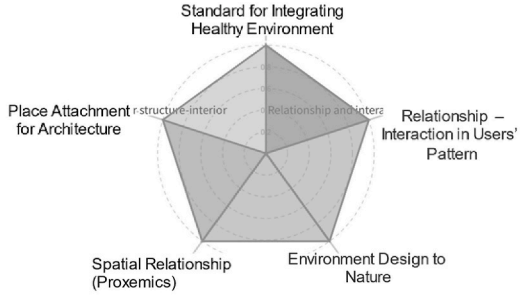


Fig. 3. (a) Interconnection within Dynamics Aspects; (b) Interconnection within Distancing Aspects; (c) Interconnection within Living-working Pattern Aspects; (d) Interconnection Dynamics and Social Distancing Aspects; (e) Interconnection within Social Distancing and Living-working Pattern Aspects; (f) Interconnection Dynamics and Living-working Pattern Aspects; (g) Interconnection Dynamics, social distancing and Living-working Pattern Aspects.

Table 4
Network analysis of security-pandemic aspects and Variables.

Security Post-Pandemic Aspect	Interconnection within sub-aspects	Keywords Interconnection
Dynamics	Sub-aspects that **are directly interconnected** to each other are density, peripheries and spread, interaction, mobility, and access-spatial standards & protocols. These sub-aspects have mutual interaction to control the virus spread through variables: access & movement, structure, surveillance, ownership, activity, management maintenance, indoor environmental climate, humidity and temperature, hygienic behavior, and hygienic building material surfaces. Sub-aspects of antivirus building materials **are not directly interconnected** with sub-aspects of interaction and access-spatial standards & protocols. These sub-aspects did not have mutual interaction to control the virus spread in terms of variables: natural light and UV-C systems. **Conclusion**: The variables that are directly interconnected in these sub-aspects can help control the virus's spread within architecture through the dynamic movement of activity, users' behavior, and nature (air, light, climate).	**Control** of virus spreads: person-to-person: density of people, interaction, activity through building elements air-to-person: indoor air quality & appropriate air compound for users' needs (density of polluted air, airflow, and filtering the air) surface-to-person: through antivirus building materials and cleanliness of surface materials. (a)  (notes: darker color indicated more connection)
Social Distancing	Sub-aspects that **are directly interconnected** to each other are standard for integrating a healthy environment, relationship - interaction in users' patterns, environment design to nature, spatial relationship (proxemics), and place attachment for architecture. These sub-aspects have mutual interaction to prevent the virus spread through variables: access & movement, structure, surveillance, ownership, physical protection, activity, management maintenance, hygienist behavior, and digital-virtual space relationship. Sub-aspects of the standard for integrating a healthy environment **are not directly interconnected** with sub-aspects of place attachment for architecture. Sub-aspects of environment design to nature **are not directly interconnected** with sub-aspects of spatial relationship (proxemics). These sub-aspects did not have mutual interaction to prevent the virus from spreading in terms of variables: indoor environmental climate, humidity and temperature, natural light, natural sound, access to nature, and hygienist natural building elements and materials. **Conclusion**: The variables that are directly interconnected in these sub-aspects can help prevent the virus's spread within architecture through the distancing in design and variables (physical and virtual elements) within architecture.	**Prevention** of virus spreads: Person-to-person: dimension personal and proxemics proportion within building elements Natural elements: increase users' connection with natural elements for a better immune system physical and mental health. Surface-to-person: Maintenance of cleanliness system both in digital and physical space, maintenance of personal hygienist protection through antivirus building materials, and cleanliness of surface materials. (b)  (notes: darker color indicated more connection)
Living-Working Pattern	Sub-aspects that **are directly interconnected** to each other are pattern of hybrid activities, new layout for hybrid activities, and changes in behavior and culture. These sub-aspects have mutual interaction in deterring patterns of virus spread through variables: access &	**Deter Pattern** of virus spreads: Person-to-person: new layout and space elements for interaction in hybrid activity Nature: new healthier behavior and activity by connecting with nature.

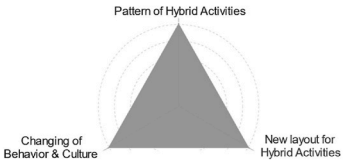
movement, structure, surveillance, ownership, physical protection, activity, access to nature, living-working flexible activity, and digital-virtual space relationship.

These sub-aspects also did not have mutual interaction to deter the pattern of virus spread in terms of variables: maintenance management, hygienist behavior, users' activity system, behavior on zone isolation – distance, behavior on Sterilization zone, and behavior on spatial diversity.

Conclusion: The interconnected variables in these sub-aspects can help deter the hybrid activity pattern through physical and virtual design elements and changes in behavior and hybrid culture.

Media-to-person: new hygienist behavior and culture within the isolation zone, distancing zone, sterilization zone, and spatial diversity zone.

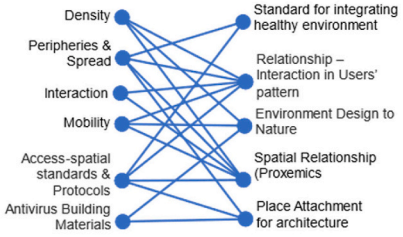
(c)



(notes: darker color indicated more connection)

Network Analysis - Interconnection between two or three aspects

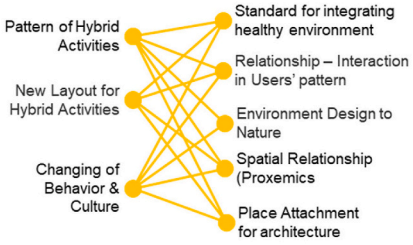
(d)



Sub-aspects in dynamics and distancing **are directly interconnected** and have mutual interaction to control and prevent the virus spread through variables: access & movement, structure, surveillance, ownership, activity, management maintenance, indoor environmental climate, humidity and temperature, natural light, hygienist behavior, and hygienic building material surfaces.

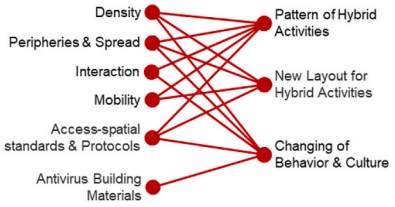
Conclusion: The variables directly interconnected between aspect dynamics and distancing can help control the dynamics of the virus's spread within architecture and prevention through distancing in physical and virtual architecture elements.

(e)



Sub-aspects in distancing and living-working patterns **are directly interconnected** and have mutual interaction to prevent and deter pattern of the virus spread through variables: access & movement, structure, surveillance, ownership, physical protection, activity, management maintenance, access to nature, hygienist behavior, and digital-virtual space relationship.
Conclusion: The variables directly interconnected between aspect distancing and living-working patterns can deter the hybrid activity pattern through physical and virtual design elements, changes of behavior and hybrid culture, and prevention by distancing through physical and virtual design elements.

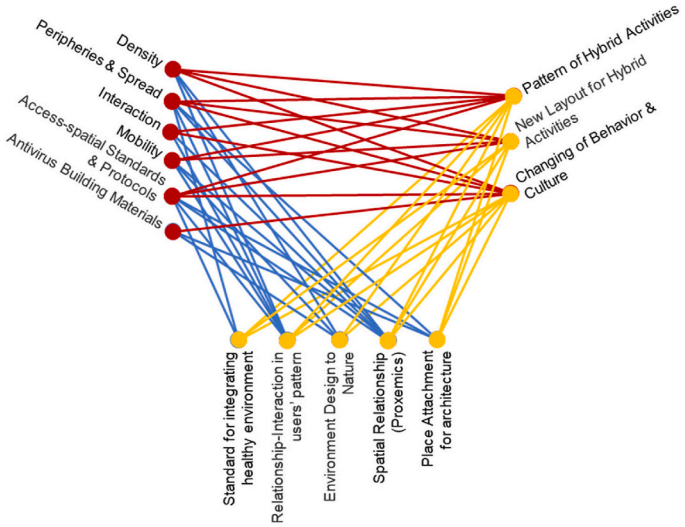
(f)



Sub-aspects in dynamics and living-working patterns **are interconnected** and interact mutually to control and deter the virus spread through variables: access & movement, structure, surveillance, ownership, activity, and hygienist behavior.

Conclusion: The variables directly interconnected between aspect dynamic and living-working patterns can control dynamic movement within architecture and deter the hybrid activity pattern through physical and virtual design elements and changes of behavior and hybrid culture.

(g)



All the sub-aspects **are directly interconnected** and mutually interact in controlling, preventing, and deterring the virus spread through variables: access & movement, structure, surveillance, ownership, activity, management maintenance, and hygienist behavior.
Conclusion: The variables in the three aspects are directly interconnected by control of dynamic movement, prevention through distancing, and deterring the hybrid activity pattern through physical and virtual design elements and changes of behavior and hybrid culture.

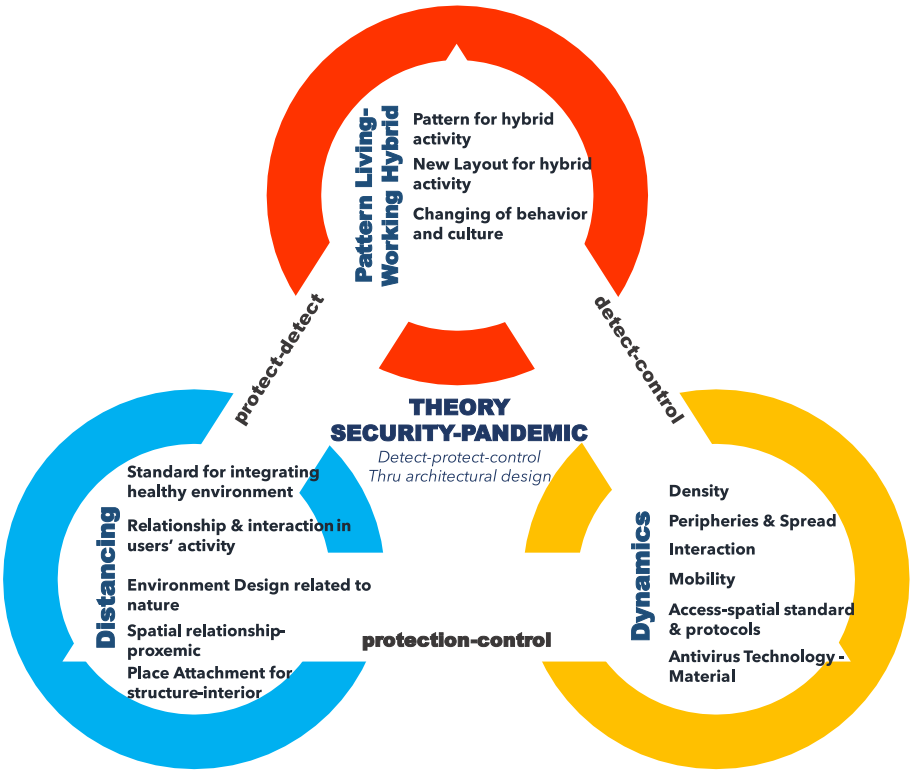


Fig. 4. Proposition security-pandemic theory.

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