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The network of spatial co-awareness

Modelling public and private interfaces in buildings using elderly care facilities as an example

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ABSTRACT

Buildings are argued to play a fundamental role in organising social relations through the construction of socio-spatial interfaces between different categories of people. Understanding how spaces and people are separated or integrated through interfaces is indispensable for the examination of building performance and the identification of building genotypes. Classic space syntax methods characterise spatial interfaces through analysing the configuration of spaces, i.e., the 'empty' part of buildings. What is missed are the 'solid' components of building spaces such as seats, which act as carriers of human behaviours, and their placement inside buildings has the potential to shape socio-spatial interfaces between different people. Taking eight elderly care facilities in China as an example, this study developed a spatial co-awareness network model to disentangle public and private interfaces inside buildings by focusing on the visual relations between behavioural carriers of public seats and nursing beds. An automatic workflow based on functions of DepthmapX and Python code was also proposed for the generation, visualisation and analysis of co-awareness networks. By establishing networks that reflected visual relations among beds, among seats, as well as between beds and seats, varied characteristics and patterns of private interfaces, public interfaces and private-public interfaces in facilities were revealed through network attributes, which were discussed in relation to the stimulation of random interaction, opportunities for passive social participation, and the need for privacy. The paper proposes a method that complements existing space syntax models, thus contributing to the study of complex buildings in which multiple categories of users coexist.

KEYWORDS

Co-awareness network, public and private interfaces, space syntax, isovist, elderly care facility

1 BACKGROUND AND INTRODUCTION

Designed by human beings, buildings have the potential to reproduce or generate social relations. With the separation of rooms by walls, as well as the connection between rooms by doors, corridors and staircases thus forming a network configuration, opportunities for encounter, co-presence and social interactions between people inside buildings are regulated. The spatial relations between different categories of persons that buildings defined were described by Hillier and colleagues (1991, 1984) as interfaces, e.g., the interface between teachers and students in school buildings or the interface between doctors and patients in hospitals. For most buildings, a prominent type of interface is described by Hillier and Penn as the one between inhabitants, who have some degree of control over space, and visitors, who lack control. Interfaces in buildings are regarded to represent the spatial dimension of an organisation. Previous space syntax research illustrated that in some buildings (such as law court buildings or detention centres), interfaces were strictly controlled to ensure certain categories of people were completely separated (Hanson, 1996, Peatross, 1997), while in other buildings (e.g., offices, or research centres), interfaces were weakly controlled and random encounters between users of different categories such as research departments were encouraged (Hillier and Penn, 1991). Understanding how interfaces are constructed through spaces in buildings not only helps recognise socio-spatial identities, but also provides clues for detecting potential incongruences between spatial and social organisations. For example, in some care institutions for the elderly, the aim of creating open and home-like environments can be violated by the architectural design that creates interfaces between users and stuff members which reinforce surveillance and control.

In space syntax research, the concept of interface was normally operationalised by examining the configuration of space in buildings, and how it generates and controls movement, which relates to the probability different social groups encounter each other and interact. A series of analytic techniques were developed to quantitatively describe spatial configuration, such as the convex space model and the axial line model (Hillier and Hanson, 1984), and more recently the visibility graph model (Hillier and Hanson, 1984, Turner et al., 2001). These methods focused on the ‘empty’ part of buildings (i.e., the space), and defined spatial connections based on movement relations (convex spaces and axial lines), or on visual relations (visibility graph) based on isovists (Benedikt, 1979). The focus on space captured the components of buildings that were meaningful for social behaviours, to reveal characteristics of interfaces. However, what is missed by those methods are the ‘solid’ components of buildings embedded in spaces, such as seats and tables, which act as ‘carriers’ or ‘attractors’ of behaviours.

The provision and placement of behavioural carriers and attractors inside buildings were found to be critical factors inducing movement, aggregation or interaction (Sailer, 2010, Gehl, 2011, Wineman et al., 2014). More importantly, the placement of different types of behavioural carriers could define domains belonging to different categories of users and affect the ways in which different users are aware of or interact with each other, such as the placement of seats of different staff members in workplaces (Beck, 2015), the placement of patients' beds and nurse stations in ICUs (Ossmann et al., 2019), the placement of luxury and trendy commodities in department stores (Markhede and Koch, 2007), as well as the placement of private beds, public seats and nurse stations in nursing homes for the elderly (Moore, 2004). In brief, the structure of behavioural carriers, aside from the configuration of spaces, also have the potential to shape socio-spatial interfaces in buildings, through defining visual connections or the physical closeness of different people engaged in stationary behaviours (e.g., sitting) rather than being in moving mode. Koch (2004) described the spatial distribution of entities as distribution in space, which distinguished distribution of space. The former addressed the specific ways entities were placed in spaces which reflected social or organisational structures, while the latter focused on the relations between spaces which were the prominent research topic of classic space syntax studies.

Efforts have been made by researchers to develop methods to describe spatial structures of behavioural carriers or attractors inside buildings, and add them upon spatial configuration in the analysis of movements and interactions inside buildings (Sailer, 2010, Koutsolampros, 2021, Kabo et al., 2015, Markhede and Carranza, 2007). Particularly, Markhede and Carranza (2007) developed a Spatial Positioning Tool (SPOT) to automatically generate the graph of intervisibility among a series of selected positions based on their isovists. Beck (2015) also created intervisibility graphs between seats in offices. Ossmann et al. (2019) modelled visual connections between ICU beds and nurse stations. However, the analysis of spatial structures of behavioural carriers inside buildings is still in its infancy, especially the discussion on how such structures characterise socio-spatial interfaces.

This paper aims to develop a model of spatial co-awareness that characterises socio-spatial interfaces in buildings through the description of the placement of behavioural carriers from a network perspective, which complements classic space syntax methods. Specifically, we choose community-based elderly care facilities (CECF) as an example and model public and private interfaces through the description of visual relations among public seats and private nursing beds in CECFs. The reason we selected CECFs as an example is threefold: firstly, public and private domains coexist in CECFs because they are designed to accommodate both inhabitants (vulnerable elders who live inside facilities) and visitors (healthy elders who visit facilities for social activities) under the same roof to facilitate social integration. Secondly, behavioural carriers including public seats and nursing beds in CECFs play a prominent role in defining public and private domains and their relations, since most of the older people in CECFs spend the majority of their time on the two types of behavioural carriers (seats and beds) due to limits in physical abilities. Thirdly, the spatial arrangement of seats and beds regulates the spatial relations of different users who are in stationary mode. In addition, the complexity of public and private interfaces in CECFs has been addressed by an extensive body of previous studies, as the coexistence of the two types of furniture does not necessarily enhance contact between inhabitants and visitors, but can also lead to conflicts (Wojgani and Hanson, 2007, Wright, 1995, Salari et al., 2006, Moore et al., 2006). For example, inhabitants might feel that their private spaces were intruded by the presence of public seats and visitors. However, the above-mentioned studies have not developed spatial analytic techniques that systematically inspected how public and private interfaces were constructed in CECFs.

In the following sections, we will firstly introduce how the network of spatial co-awareness can be established in CECFs based on visual relations between the behavioural carriers of public seats and nursing beds. In detail, we will explain how the workflow of spatial modelling and visualisation can be automated by using Python code which employs functions from the DepthmapX software and Python packages. Then, with eight cases of CECFs, the paper will demonstrate how various attributes of co-awareness networks can be employed to illustrate the spatial structure of public and private domains in CECFs, as well as the nuanced variance of public and private interfaces. The social implication of characteristics of interfaces will be discussed. We will also point out potential applications of co-awareness networks in other building types and how it might complement classic space syntax models to inspire more comprehensive analytic frameworks for understanding socio-spatial interfaces in buildings.

2 METHODS AND MATERIALS

2.1 Research concepts

The construction of the network of spatial co-awareness in CECFs brings together several key concepts which should be specified first, including 1) behavioural carriers, 2) co-awareness relations and networks, as well as 3) public and private interfaces.

This study focuses on two types of behavioural carriers in CECFs, which are public seats and nursing beds. Public seats refer to all seats in facilities that are used publicly by any users (inhabitants and visitors) for various purposes. CECFs in China – the source of our data – have a large visitor function for people aged 65 and over. Elderly people can use CECFs for a variety of different services including meals, leisure or recreation activities (such as playing cards, reading books, listening to talks, using a computer, attending a sports class or dancing and singing groups), health checks and personal hygiene. To focus on public seats, seats in staff offices and private bedrooms are excluded. Nursing beds in contrast are used by the inhabitants of CECFs who are normally more vulnerable, usually for rest or receiving primary care services. Although nursing beds can be placed inside either private or shared bedrooms, they are not publicly used, i.e., each bed belongs to a specific person. Due to the decreased physical competence of both vulnerable inhabitants and more mobile elderly visitors, the vast majority of older people's behaviours in CECFs occurs on public seats or private beds, i.e., in sitting mode rather than in standing or moving mode. Hence, public seats and nursing beds are elementary carriers of behaviours thus constituting the public and private domains in CECFs.

Co-awareness relations exist between any pair of beds, any pairs of seats or between seats and beds. They are defined by visual relationships, i.e., whether and how occupants of seats and beds could see each other. If we treat seats and beds in a given CECF as 'nodes', and their visual relations as 'ties', a network structure can be established, indicating how occupants of seats and beds can see and be aware of each other's presence and behaviours. The idea of the co-awareness network articulates the visibility graph model (Turner et al., 2001) in space syntax research. The former treats solid components of building space (seats and beds) as the unit of analysis, while the latter focuses on the empty part ('cells' in spaces).

Visual relations between beds and seats are computed based on isovists (Benedikt, 1979). For seats, their isovists are defined by direction of viewing when seated (front-facing direction) and angles of the viewshed pertaining to peripheral vision. In this study, we define viewing angles of all seats at 180 degrees, meaning that spaces behind a seat are not taken into account when constructing isovists (see seats S10 and S20 in Figure 1). As for beds, no direction is specified, and therefore the viewing angle is set to 360 degrees (see bed B2 in Figure 1), because most of the users of nursing beds in CECFs are semi-independent elders, who may sit at any position on their beds to watch or interact with others, which is fundamentally different from patients in ICUs who lie in bed and hardly move.

For both seats and beds, their isovists are generated based on points (cell) of the visibility graph model in DepthmapX. We firstly specify all points within the contour lines of a given seat or bed, then computing isovists for each point, finally aggregating all isovists as the isovist of the seat or bed. A seat or bed is counted as visible to another seat or bed when a target object intersects with or lies completely within the isovist of the root object. Therefore, visual relations between seats and beds have directions, indicating seeing, being seen and being mutually visible. For example, in Figure 1, seat S20 can see seat S10 while S10 cannot see S20; seat S20 and bed B2, as well as seat S10 and bed B2 are mutually visible. In this vein, the co-awareness network of seats and beds is a directed graph.

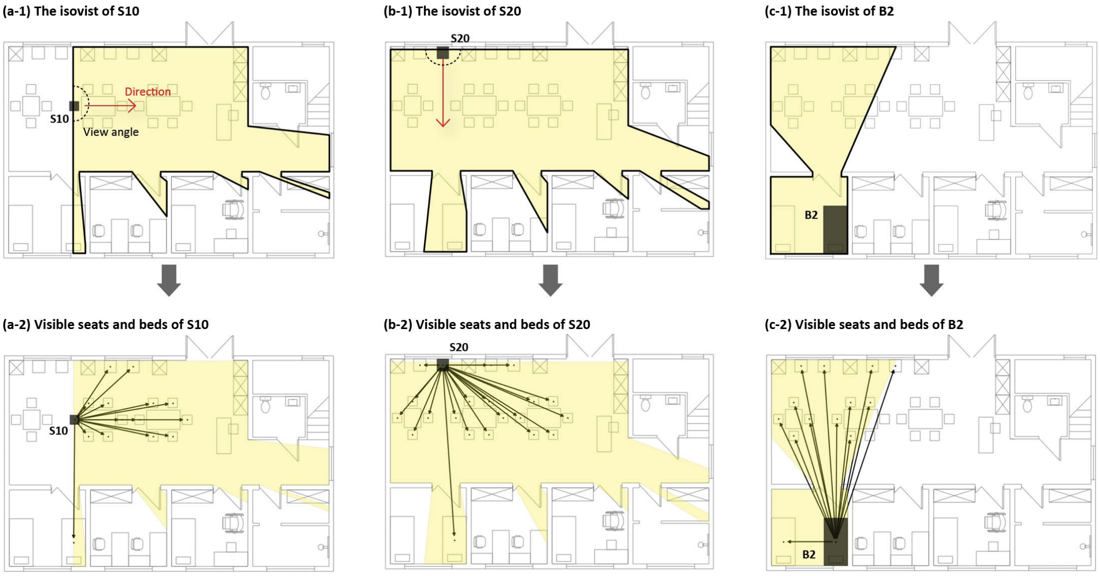

Figure 1. Examples of isovists and visual relations among seats and beds.

2.2 The analytic framework

Co-awareness networks in CECFs reflect the spatial structure of co-presence among users, which according to Hillier (1996), relates to the formation of 'virtual community' that acts as raw material for developing social relations or sense of belonging to the community. Also, the spatially defined co-awareness relations may help elderly people to maintain social resilience as their mobility is decreasing (Sailer and Li, 2022). The opportunity structure offered by space is of great significance for the increasing number of older populations who suffer from loneliness and social isolation. On the other hand, co-awareness among people may also induce disturbance, especially in institutional settings like CECFs where visitors and inhabitants coexist. Therefore, it is necessary to propose a comprehensive framework to analyse co-awareness relations in CECFs.

The analytic framework of this study consists of three dimensions, looking into private interfaces, public interfaces and public-private interfaces in CECFs (Figure 2). The first dimension (Figure 2a) focuses on the private domain in CECFs which is constituted by nursing beds and inhabitants. The study investigates private interfaces by describing how beds relate to other beds, or how inhabitants are aware of other inhabitants with their nursing beds. The third dimension (Figure 2c) focuses on the public domain constituted by public seats and characterises public interfaces by how public seats are spatially arranged. The second dimension (Figure 2b) addresses the intersection of public and private domains. It investigates public-private interfaces by describing how users of public seats are aware of users on nursing beds. Through the spatial analysis of the three dimensions, we aim to develop a comprehensive description of public and private interfaces in CECFs.

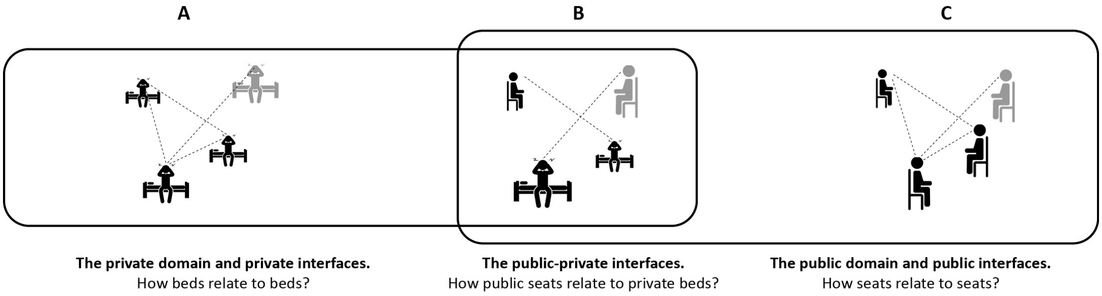

Figure 2. The private, public and public-private interfaces represented by spatial relations between nursing beds and public seats.

2.3 An automatic workflow

Using isovists to describe visual relations between behavioural carriers has been adopted by previous studies in buildings such as hospitals (Ossmann et al., 2019) and offices (Beck, 2015). However, in those studies, only a small number of behavioural carriers (seats in offices or beds in ICUs) were analysed, and the researchers presumably generated isovists and resulting relationships manually. To move this field forward, this paper proposes an automatic workflow to generate, visualise and analyse co-awareness networks of behavioural carriers based on Python codes and functions from DepthmapX's Command Line Interface (CLI)[1], GeoPandas[2] and NetworkX[3].

Major steps of the workflow are demonstrated in Figure 3. The full code of the workflow with exemplar cases can be accessed in the first author's GitHub repository[4]. Before the processing, several materials related to the building should be prepared in advance. The data of the layout plan of the building should be saved as separate .dxf files, containing the location and outlines of beds, seats, walls and annotations. The former two are used for the spatial analysis while the latter two are for visualisation purposes. A file of isovist parameters is needed, containing the data of the IDs, directions and view angles for each bed and seat, which should be saved in a .csv or .xlsx format. The visibility graph file of the building is generated beforehand by DepthmapX. In the workflow, we firstly convert the data (bed, seat and wall) in the .dxf files as polygon geometries and assign isovist parameters to each bed and seat. Then, we loop through all beds and seats to generate geometries of their isovists based on directions and view angles. After that, we loop through all seats and beds to examine whether an object's isovist covers or intersects with other objects, to identify visual links between seats and beds. The results are saved as a link table which contains pairs of source and target objects. The link table is then

[1] https://spacegroupucl.github.io/depthmapX/
[2] https://geopandas.org/en/stable/
[3] https://networkx.org/documentation/latest/reference/index.html
[4] https://github.com/xmli1121/Spatial-Co-awareness-Network

used to generate a directed graph, namely, the co-awareness network. Based on the graph object, we can visualise the network and plot it onto the building layout. We can also calculate various graph properties including global properties which describe structural characteristics of the whole network (e.g., density), as well as local properties that characterise individual nodes (e.g., centrality metrics).

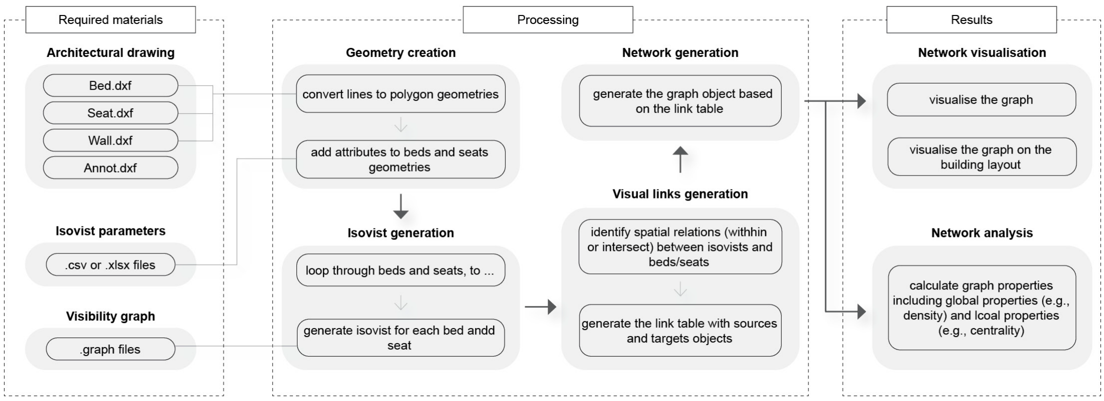

Figure 3. The workflow for the generation, visualisation and analysis of co-awareness networks.

2.4 Sample

Eight cases of CECFs in China are selected as a sample to perform the spatial analysis. The cases are selected to reflect the variety of spatial organisation in CECFs, especially the arrangement of public and private interfaces. The layout plans and basic information are presented in Figure 4 and Table 1. Public seats and nursing beds in facilities are highlighted with green and orange colours respectively. Among the eight cases, the layout plans of FH, FG and FF are collected by the author in the Chinese city of Nanjing. The layouts of the other cases were redrawn by the first author based on published research papers. FD is a facility from the city of Hangzhou (Zhang and Zhao, 2017), and FC, FA, FB and FE are from Beijing (Bu et al., 2018, Hu et al., 2018, Lin et al., 2018).

Table 1. Basic information of the eight CECF cases.

Facility ID	Area (m^2)	Location	No. of public seats	No. of nursing beds	Proportion of seats to beds
FA	230	Beijing	17	16	1.06
FB	270	Beijing	30	19	1.58
FC	440	Beijing	16	11	1.45
FD	450	Hangzhou	26	22	1.18
FE	310	Beijing	26	19	1.37
FF	380	Nanjing	44	4	11
FG	250	Nanjing	46	5	9.2
FH	430	Nanjing	28	9	3.11

Figure 4. Layout plans of the eight CECF cases.

3 RESULTS

The co-awareness networks describing public and private interfaces in the eight facilities are generated and visualised in Figure 5, Figure 6 and Figure 7. In the figures, nursing beds are marked as orange and public seats as green. The different size of nodes indicates different levels of degree centrality, and the width of links indicates physical closeness (the inverse of metric distance) between nodes. Networks between beds and seats (public-private interfaces) are bipartite networks (also called two-mode) in which links only exist between beds and seats.

Also, all these networks are directed graphs, and the directions of links indicate seeing, being seen or mutually visible. In Figure 7, the bed-seat network of FH is left blank because visibility does not exist between any beds and seats in the facility. Descriptive statistics on the attributes of co-awareness networks were summarised in Table 2.

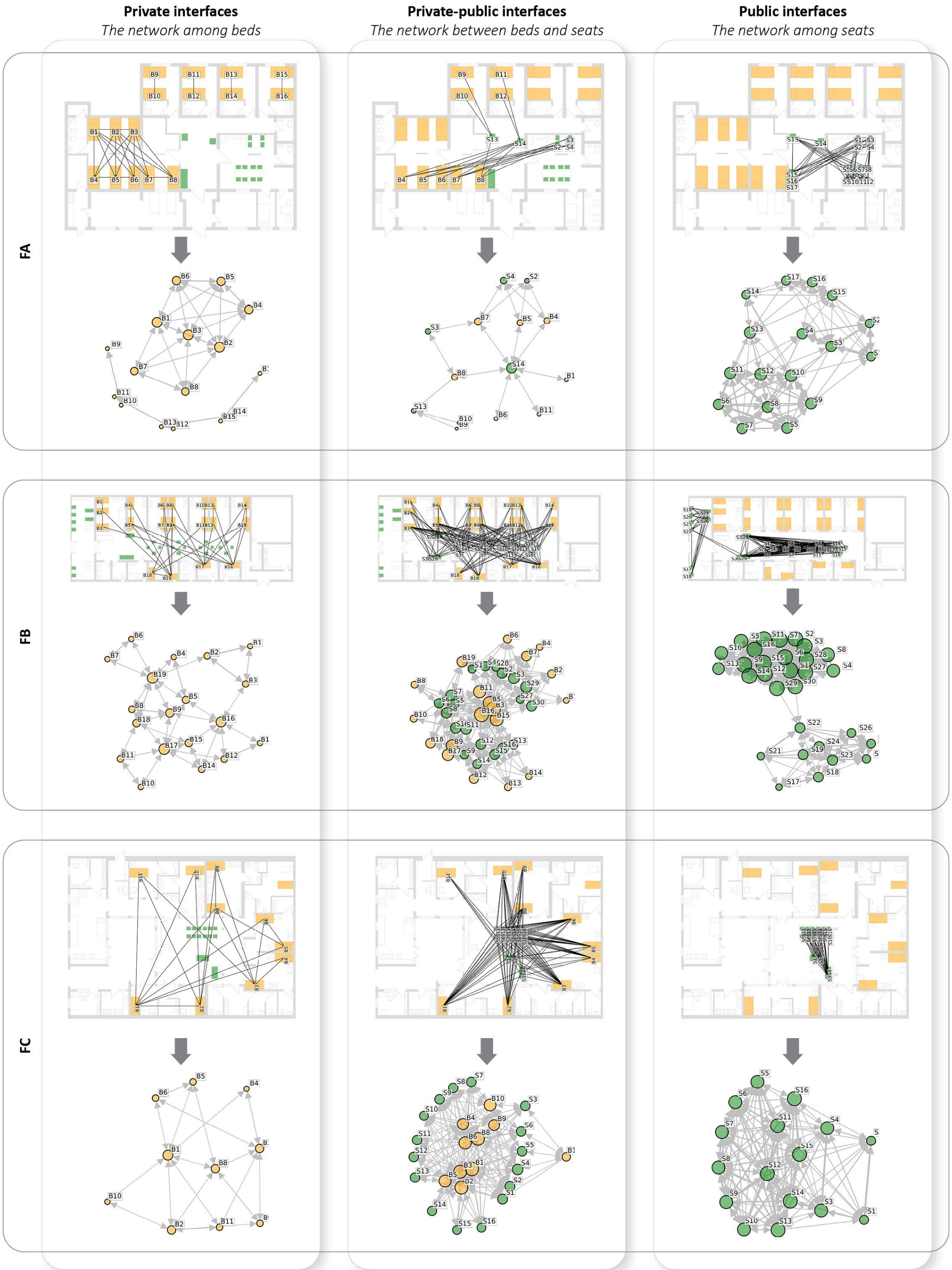

Figure 5. Co-awareness networks describing public and private interfaces in facility FA, FB and FC.

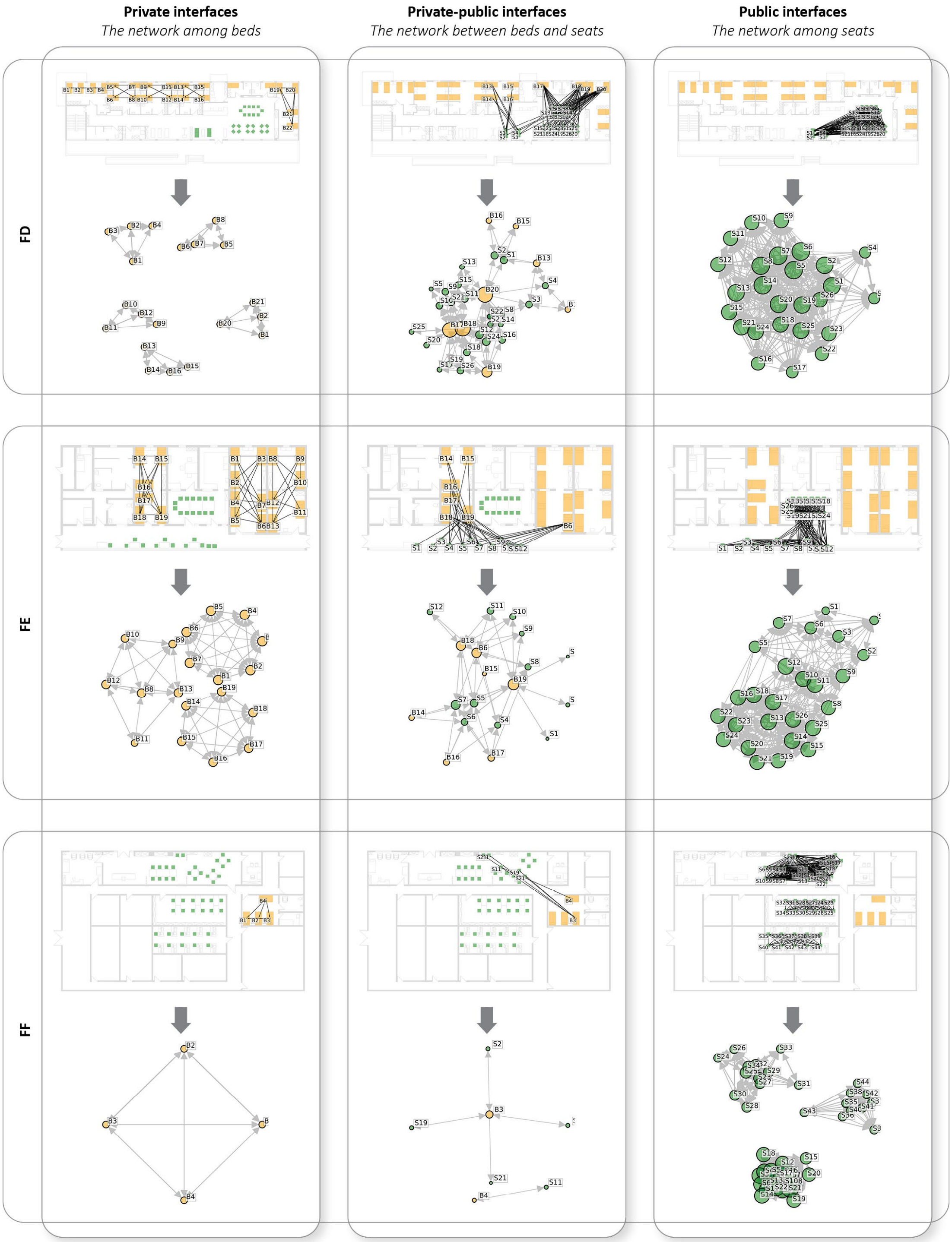

Figure 6. Co-awareness networks describing public and private interfaces in facility FD, FE and FF.

Figure 7. Co-awareness networks describing public and private interfaces in facility FG and FH.

Table 2. Descriptive statistics on the attributes of co-awareness networks.

Network types	Facility ID	No. of nodes	No. of ties	No. of Components	Density	Avr. Degree
Beds and beds (private interfaces)	FA	16	52	5	0.22	6.50
	FB	19	70	1	0.20	7.37
	FC	11	38	2	0.35	6.91
	FD	22	60	7	0.13	5.45
	FE	19	98	3	0.29	10.32
	FF	4	12	1	1.00	6.00
	FG	5	4	3	0.20	1.60
	FH	9	8	5	0.11	1.78
Beds and seats (private-public interfaces)	FA	33	30	20	0.06	1.82
	FB	49	273	11	0.24	11.14
	FC	27	206	2	0.59	15.26
	FD	48	126	15	0.11	5.25
	FE	45	57	27	0.06	2.53
	FF	48	9	43	0.03	0.38
	FG	51	43	30	0.09	1.69
	FH	37	0	37	0.00	0.00
Seats and seats (public interfaces)	FA	17	129	1	0.47	15.18
	FB	30	360	1	0.41	24.00
	FC	16	192	1	0.80	24.00
	FD	26	425	1	0.65	32.69
	FE	26	352	1	0.54	27.08
	FF	44	492	3	0.26	22.36
	FG	46	573	3	0.28	24.91
	FH	28	228	2	0.30	16.29

3.1 Public interfaces

Public interfaces refer to the spatial relations between people using the public domain of CECFs, which in this study, are represented by visual relations between public seats. It can be seen from seat networks in Figure 5, Figure 6 and Figure 7 as well as Table 2 that, at the global level, a prominent feature distinguishing those networks is the emergence of components. In some cases (e.g., FC and FD), seat networks only have one component, while in others (e.g., FF and FG), several components exist, among which seats are totally invisible to each other. Further nuanced differences among components also exist, such as their size (number of seats included) and density, which are summarised in Figure 8.

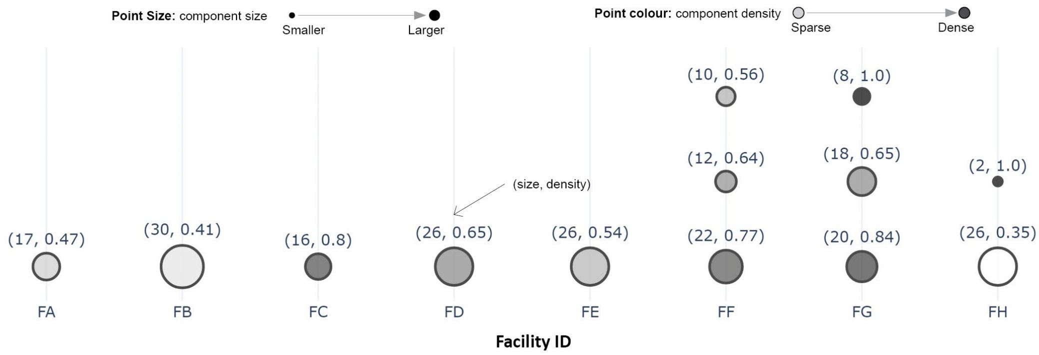

Figure 8. The constitution, size and density of visual components in co-awareness networks of public seats across facilities (components in each facility are stacked vertically with the largest ones at the bottom).

Public interfaces in FF and FG can be described as *globally separated*, because public seats in the two facilities were separated into several subgroups that are totally invisible to each other, while relatively high levels of intervisibility exist between seats within the same component as shown by relatively high values of network density. The advantage of this type of organisation of seats is that it enables different types of social activities in facilities to occur in parallel thus avoiding or at least minimising potential usage conflicts. However, the total absence of visual connections between groups of seats also has disadvantages. Visually segregated seat components are usually located inside enclosed rooms (e.g., the ones distant from entrances in FF and FG), which are less likely to be noticed and used, making the activity space less public and friendly, especially for visitors who are new and unfamiliar about the facility.

In contrast to FF and FG, the public interface in FC could be described as *globally integrated*. The value of network density (0.8) indicates that almost every person in the public domain of the facilities could easily be aware of the ongoing activities among others. The setting may help increase the probability of random encounters and interactions among users. However, the cost is that users are all under the surveillance of most others, which may not satisfy the needs for intimate social activities such as conversations between families or close friends. Characteristics of public interfaces in FE and FD could be described as *partially integrated*. Although all public seats in those facilities are within one component, their densities are lower than that of FC. As shown in Figure 6, a small number of seats in FE and FD are placed away from the core of the dense and mutually visible seats, creating settings with a slightly lower degree of seeing and being seen exposure.

As for the public interfaces in FH, FA and FB, we describe them as *partially segregated*. The overall density of these networks is lower (0.54, 0.47 and 0.41). As shown in Figure 5 and Figure 7, seats in the networks of FA, FB and FH are grouped into clusters, and different clusters are either unconnected (S6 and S22 in FH) or only connected by a few pivotal seats (e.g., S30 in FB). In most of these three cases, users on seats can only see or be seen by a limited number of others. The settings engender the advantage of the globally separated type in the way that they can also support the concurrence of multiple social activities, yet they also avoid the disadvantage of the globally separated type because visual links still exist between different clusters. In other words, clusters are separated but not totally segregated from other parts of the public domain. This could help avoid users being completely unaware of other people and opportunities for encounter and engagement, as well as the associated potential underutilisation of public spaces that are enclosed and segregated.

3.2 Private interfaces

Private interfaces refer to the spatial relations between users of CECFs in the private domain, i.e., the inhabitants of CECFs on their nursing beds. We illustrate private interfaces by visual relations between nursing beds. As shown in Figure 5, Figure 6 and Figure 7 and summarised in Figure 9, facilities of FE, FD, FH, FA and FG have co-awareness networks of beds that are constituted by multiple components with a density equal or close to one, reflecting multiple shared bedrooms within which inhabitants are mutually visible while inhabitants in different rooms are invisible to each other. This type of private interface could be described as *globally separated*. The difference is that FA and FD offer private domains with a varied degree of privacy, containing bedrooms being either private or shared by only two inhabitants, as well as those shared by four or eight inhabitants. This could satisfy either inhabitants who demand more privacy, or more vulnerable inhabitants who need more care and surveillance.

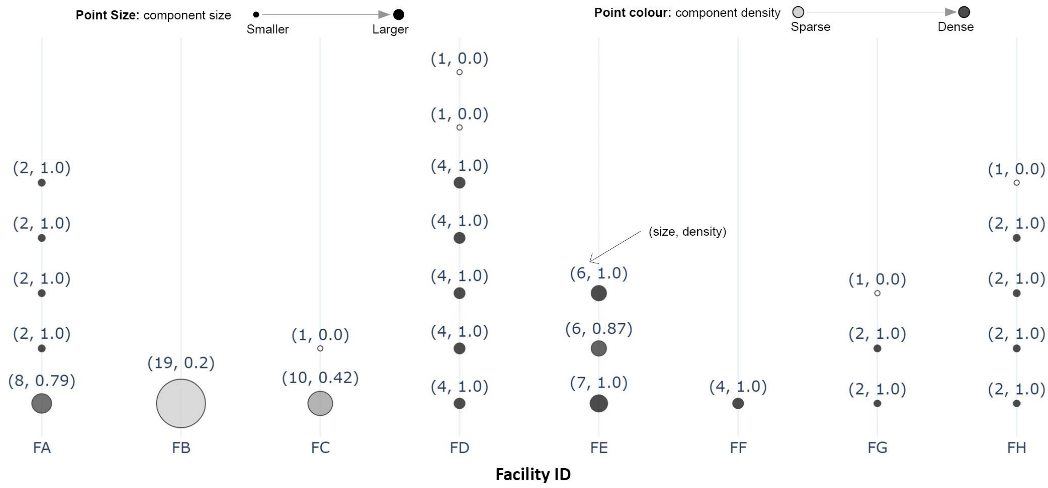

Figure 9. The constitution, size and density of visual components in co-awareness networks of nursing beds across facilities (components in each facility are stacked vertically with the largest ones at the bottom).

The only exceptions are FB, FC and FF. Although beds in the three facilities are also placed in multiple private bedrooms, most beds are integrated into one visual component, because the bedrooms are placed surrounding central lounge spaces, and inhabitants on nursing beds in different rooms can see other nursing beds through windows and doors facing the lounge spaces. This type of private interface could be described as *globally integrated*. Compared to the globally separated interfaces, globally integrated interfaces of the private domain could enhance the feeling of communal living among inhabitants, which run counter privacy and autonomy. In FB and FC, even with private rooms, inhabitants' private spaces are still exposed to others unless they close the doors or pull the curtains on the windows.

3.3 Public-private interfaces

Public-private interfaces refer to the spatial relations between users in the public and private domains in CECFs, represented by the structural characteristics of visual connections between public seats and nursing beds. It is shown in Figure 10 that a considerable portion of nodes in the networks does not connect with any other nodes at all, resulting in components containing only one node.

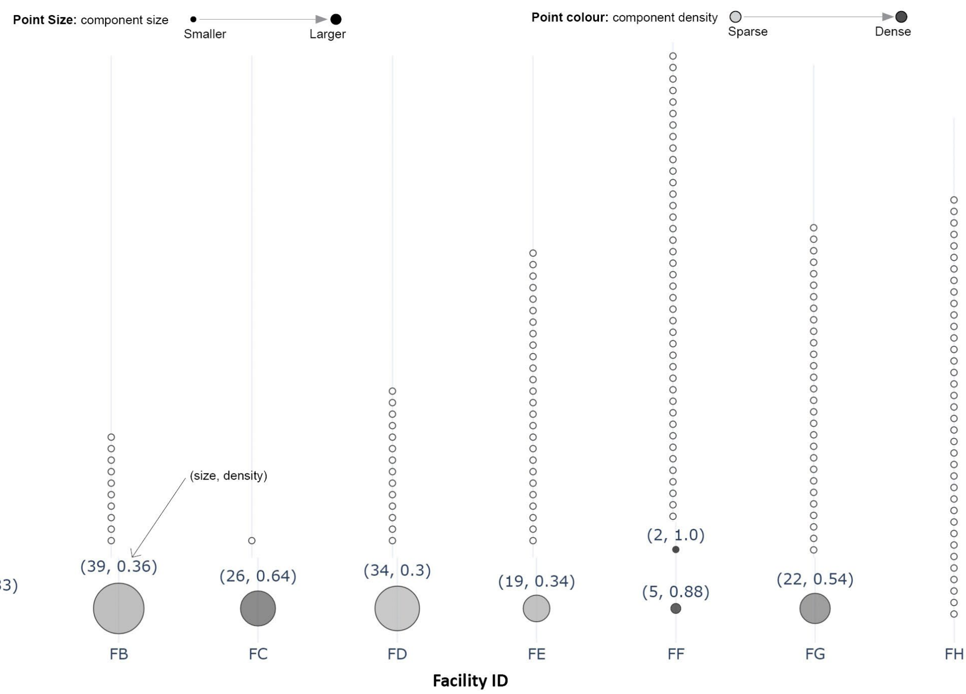

Figure 10. The constitution, size and density of visual components in co-awareness networks of nursing beds and public seats across facilities (components in each facility are stacked vertically with the largest ones at the bottom).

As suggested in Table 2, in general the density of seat-bed connections in FB (0.24) and FC (0.59) are much greater than those of other facilities. It means that inhabitants on most beds in FB and FC could see or be seen by a considerable number of public seats. Their public-private interfaces could be described as *globally integrated*. In contrast, no visual connections exist between seats and beds in FH, meaning that visually for users of the facility, public and private domains are *totally separated* while being seated. For the other facilities, relations between beds and seats lie in-between globally integrated and totally separated. The overall densities are rather low (see Table 2), and intense bed-seat connections only emerge between a small number of seats and beds. For example, in FG, only beds B1 and B2 connect to large numbers of public seats; in FD, intense connections to public seats are mainly observed for beds B17, B18 and B20. This type of public-private interface could be described as *partially* or *locally integrated*.

Intensively integrated public and private domains, such as those seen in FC and FB, are obviously not ideal to satisfy inhabitants' needs for privacy. However, one of the potential benefits of such interfaces is that it might facilitate 'passive' social participation of vulnerable elders. For example, in FC and FB, when inhabitants have to stay on nursing beds due to physical incompetence, they could easily watch the ongoing social activities in public spaces, which is widely argued as an important approach for vulnerable elders to maintain social participation (Pinet, 1996, Moore, 2002, Lawton et al., 1984). For facilities in which no visual connections exist between beds and seats, inhabitants' privacy can be well preserved. However, it also means when inhabitants are in lack of mobility, they are likely to be 'trapped' on their nursing beds, being incapable of contacting others in public spaces unless they are visited purposefully. In this vein, facilities with partially integrated public-private interfaces offer opportunities for inhabitants to be allocated to nursing beds that are either more open or more segregated from public spaces depending on their needs and vulnerability.

The characterisation of public-private interfaces based on the co-awareness networks also sheds new light on the understanding of living spaces meeting older people's needs for privacy. Normally, nursing rooms with single beds are regarded as more private than those shared by multiple beds. However, in this study, we reveal that single bedrooms are not necessarily private when they have intensive visual connections with the public domain, such as beds B17 and B18 in FD, beds B16 and B17 in FB, as well as beds B2 and B10 in FC. A more comprehensive perspective taking multiple behavioural carriers into account is necessary when determining the spatial placement of beds and seats in CECFs.

4 DISCUSSION

Using CECFs as an example, this study developed the spatial co-awareness model and elaborated how the model could help disentangle public and private interfaces inside buildings.

Specifically, we found varied patterns of visual connections among public seats that characterised public interfaces in CECFs, described as the globally separated type, globally integrated type, partially separated type and partially integrated type. These patterns were interpreted as relevant to social processes such as the stimulation of random contact, space access and use, as well as inclusiveness for the concurrence of multiple social activities running in parallel. As for private interfaces, although in most cases nursing beds were visually separated by rooms, several cases existed where beds in single rooms were visually connected as an integrated whole, which might go against the original intention of preserving privacy by small bedrooms but actually enhanced the feeling of communal living. Public-private interfaces were described by visual connections between public seats and nursing beds. It was found that in most cases, public and private domains were partially connected, with a few beds intensively exposed to public seats. Besides, there were also cases with globally integrated interfaces in which almost all beds and seats were mutually visible, as well as cases with no visual connections between the private and public domains. Varied attributes of public-private interfaces were discussed in relation to inhabitants' need for privacy and opportunities for passive social participation.

This study contributed to the discourse of the social and spatial organisation in CECFs. Compared to the previous studies (Moore et al., 2006, Salari et al., 2006) which qualitatively described spaces inside CECFs as more or less 'separated', 'divided' or 'diverse', this study quantifies those spatial attributes with properties of co-awareness networks. In particular, we demonstrated the diversity and complexity of public and private interfaces inside CECFs, echoing the arguments of previous researchers (Salari et al., 2006, Wright, 1995) and making it more explicit with techniques of spatial visualisation. The model can serve as an effective tool to evaluate the interior design of care facilities for the elderly, regarding the balance between privacy and participation, as well as the spatial relations between visitors and inhabitants.

By constructing the spatial model focusing on behaviour carriers, this study further developed the concept of 'interface' proposed by Hillier and colleagues (1991, 1984). Instead of addressing how different categories of people might encounter and interact when moving inside buildings, this study put emphasis on how different persons were aware of each other when sitting inside buildings. In this vein, the model of co-awareness networks complements classic space syntax methods in characterising socio-spatial interfaces. Moreover, based on the work of previous researchers that addressed visual relations of behaviour carriers and attractors inside buildings (Beck, 2015, Ossmann et al., 2019, Markhede and Carranza, 2007), we developed an automatic workflow for the generation and visualisation of networks, making the method more effective when applying to research studies dealing with large samples. Hence, the spatial co-awareness network model could also be used in the study of other types of buildings in which the roles of certain behavioural carriers are vital, e.g., the relations between patients' beds and nurse stations in hospitals, or the relations between teachers and pupils in secondary schools via their desks and seats in classrooms but also the relationship between staff offices, classrooms and breaktime spaces such as found in playgrounds but also school canteens for example, where seats as behavioural carries overlap with spaces for movement.

The limitation of this study is also worth noting. On the one hand, the size of the sample is relatively small, and the selected cases of CECFs are all from China. On the other hand, we did not incorporate empirical behaviour data to attest the effectiveness of the model in predicting social outcomes. Future research might take more samples from diverse cultural contexts into consideration, and link the outcomes of spatial analysis with data relating to human behaviour or perceptions. Also, we hope to develop more systematic frameworks to integrate spatial co-awareness models with classic space syntax models such as the visibility graph model, to model socio-spatial relations of people inside buildings in both static and dynamic modes.

5 CONCLUSIONS

Taking community-based elderly care facilities as an example, this study developed a spatial co-awareness network model to disentangle public and private interfaces inside buildings by focusing on the spatial relations between behavioural carriers of public seats and nursing beds. An automatic workflow based on functions of DepthmapX and Python codes was proposed for the generation, visualisation and analysis of co-awareness networks. Through establishing networks that reflected visual relations among beds, among seats, as well as between beds and seats, characteristics of private interfaces, public interfaces and private-public interfaces in CECFs were revealed. The study not only furthered the discourse of the relation between public and private domains in elderly care facilities, but also added knowledge to space syntax research, regarding the understanding of the concept of interface, as well as the method to disentangle characteristics of interfaces inside buildings.

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