HOW TO SHARE A HOME
Towards Predictive Analysis for Innovative Housing Solutions

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Abstract. Renewed interest in cohousing solutions is driven by the rapid population growth and a lack of affordable housing in many cities across the world. The home share has become more prevalent in recent years due to the cost benefits and social gains it provides. While it involves challenges primarily concerned with the usage of communal areas, the viability of this housing model increases with the advancement of technology enabling new tools for analysis and optimisation of spatial usage. This paper introduces a method of sensor application in the occupancy analysis to provide grounding for future studies and the implementation of advanced computational methods. The study focuses on the underexplored potential of the communal spaces and provides a method for the measuring of specific aspects of their usage. The study applies principles of mathematical set theory, to give a more conclusive understanding of how communal areas are used, and therefore contributes to the improvement of housing design. Presented outcomes include an algorithmic chart and a blueprint of a behavioural model.

Keywords. Cohousing; Housing share; Post Occupancy Evaluation; Machine Learning; Predictive Analysis.

1. Introduction
Cohousing is a housing model, where private dwellings and communal facilities are combined (McCaman and Durett 1988). The close-knit relationship between private and communal spaces is a vital characteristic of this housing typology. However, there is a stark defence between these two kinds of space. Private space is of a standard dwelling typology, whereas communal space can be anything and with many different roles. Private dwelling space is designed according to tested typologies, normative and regulations such as Apartment Design Guidelines for Victoria published by the Department for Environment, Land, Water and Planning (2017) in Australia. Communal space, on the other hand, is not so clearly defined. Its potential is not fully recognized in strategies, such as Housing Design
Guidelines (2018) published by the Department of Health and Human Services of Victorian Government concerned with public housing. In shared housing schemes, the communal space serves as an extension of the private domain and its use is subject to more dynamic occupancy patterns. Therefore, the role of communal space is open to interpretation. The focus of this study is on the usage of communal housing spaces, and the aim is to find ways to understand complex occupancy patterns arising from space-sharing to benefit both designers and occupants.

Conventional architectural analysis of three international and well-known housing precedents allows an initial insight into different roles of communal housing space (Figure 1). In Japan, four artists share communal space on the ground floor of a house, while their private studios are on the first floor (Ondesign Partners 2009). In Denmark, 54 families share a large communal dining room and an outdoor courtyard surrounded by individual units (Dorte Mandrup 2009). In the US, 55 micro homes share access to recreational facilities on the ground floor and a communal terrace of a multistorey building (nArchitects 2016). These three recently built projects offer themselves as testing grounds for the development of a methodology which can be applied across different scales and different time frames for in-depth occupancy evaluation.

2. Objective

The complexity surrounding the concept of communal space in housing is related to ownership, maintenance and social aspects, amongst other things. Typically, in a co-living arrangement, private units are owned individually, while communal spaces are owned jointly. The maintenance of the communal zones is delivered cooperatively by all residents. The regime of maintenance is agreed between occupants. It is not only based on a financial contribution toward corporate
fees but the active participation of occupants. Social aspects involve a sense of the community, which exceeds a single household. In addition to family bonds relevant to the design of individual housing units, housing share residents form both short and long-term bonds with other residents relevant to the design of communal areas. Therefore, this study establishes a way to measure specific aspects to expand understanding of how communal areas of housing share are being used.

In response to the topic of the conference RE: Anthropocene - Design in The Age of Humans, this paper introduces a novel method for design analysis of communal areas belonging to cohousing communities, relying on machine learning techniques. The research reported on is based on the interaction between architectural design, computation and mechatronics and contributes to the design methodology of cohousing solutions. The approach is based on data collection for through evidence-based understanding of shared usage of spaces and things.

The study aims to maximise opportunities arising from technological advances and utilise innovative ways of data collection to give more insight into occupants’ behaviour. Post occupancy evaluations are demanding tasks and therefore infrequently conducted. Detailed research is rarely conducted after buildings are complete, and designers often remain uninformed of true implications of their decisions. The presented approach focuses on data collection and introduces temporal dimensions into the analysis process to help understanding how buildings are used. This study opens up the possibility to apply machine learning techniques in the design of communal housing spaces.

3. Previous research

Numerous research efforts have identified the role of data mining in the understanding of the built environment. For example, data produced through occupancy scheduling has been valuable to the analysis of shared office space via machine learning techniques (Davis 2016). Similarly, machine learning algorithms are frequently used for the analysis of the built environment on a different scale. For example, Aschwanden (2016) has shown an application of learning algorithms to identify changing boundaries of the city’s neighbourhoods based on geospatial and transportation data. Likewise, Panagoulia (2017) has identified the role of open data in identifying and evaluating the liveability of urban space. At the same time, data harvesting for housing analysis is challenging in its own right, and studies concerned with living spaces are still rare.

The departing point of the study is to establish what can be measured and what data is both available and relevant to better undersetting of how communal housing areas are used. A wide array of techniques to measure specific aspects of space use has been tested, based on energy consumption, CO2 emission, and movement detection, radio-frequency identification (RFID) and many more. Occupancy analysis of office buildings, most commonly focus on data obtained through energy consumption to make conclusions on workplace optimisation. For example, Chang, W. K., and Hong, T. (2013) use lighting-switch data in statistical analysis and modelling of occupancy patterns in open-plan offices. In
the study by Cali et al. (2015), CO2 level recordings were used to detect occupancy relevant to the validation of use in office and residential buildings. Other ways of collecting data for usage analysis include infra-red sensor application such as the one developed by Hashimoto et al. (1998) for detecting the number of people passing a wide door and their movement directions. A related application of sensors to capture "dynamic visuo-locomotive narrative experience" of building users is described in a study by Bhatt et al. (2016).

Reviewed techniques and technologies for measuring different aspects of space use are equally applicable to data gathering for occupancy analysis of communal housing spaces. The method described in the following chapters shows how data gathered by sensors can be turned into design intelligence for housing share solutions of different scales. Methodology for measuring and acquiring information on the usage of communal housing areas has not been described before. Moreover, the proposed method aims to provide a way to apprehend overall and qualitative aspects of space through usage, rather than to concentrate on specific and technical aspects of building performance.

The following chapter gives a more detailed description of the method for acquiring specific data sets and their overlapping to enable informed decision making in the design and use of communal housing areas. It gives an account of the network of sensors needed to harvest data and a blueprint of a behavioural model, including an algorithmic chart which demonstrates a specific information flow. The method identifies input data, way of data processing, and output information.

4. Method

The input data is divided into four categories, each representing a distinct initial entry point to feed the system with information. These categories are named: presence and identification of occupants, time and duration of activities, type of activity, and environmental conditions. The first group gives information on WHO is using communal space. It detects the presence of users in the specific areas of communal space and recognises their unique identification so that system knows not only where a resident is at any given time, but more importantly which resident is where. This will show if certain zones of communal areas are used more than others, but also if particular residents frequently populate them. The second group is concerned with WHEN is communal space occupied. It records the time of arrival and measures the amount of time spent by each user in an area. This is useful to establish peak usage times for certain areas, and to look for recurring instances in occupancy scheduling. The third group of entry data provides information on HOW is the space used. It establishes the type of activity performed by occupants through tracking the use of key furniture and appliances in an area. The fourth group monitors environmental conditions such as noise levels, air quality and temperature in an area. This category of entry information also helps to understand how space is used by measuring the environmental effects of the use in the area observed.
5. Structured data collection

The diagram (Figure 2) presents the flow of the information gathered by the network of sensory devices distributed in the communal space of housing share. For this study, it is assumed that this is a communal garden surrounded by individual housing units. The information provided by sensors is then processed according to the pre-defined algorithm to generate the output. There are two groups of sensors. The first group produces a general layer of information which is used to establish outcome categories. Presence, movement, interaction and time spent are measured using radio-frequency identification (RFID), camera, voice recorders and timers. There are four categories of the expected outcome, and they are named WORK, REST, PLAY and PARTY. Each category signifies the prevalent use of an area within the communal space of housing share. Also, the system defines the footprint of an area defined by the dominant use. The diagram contains a feedback loop which allows continual correction of the output based on the change of input data. The expected result is, therefore, a dynamic map which describes the actual change of areas defined by a dominant usage. In other words, the map changes according to the behaviour of occupants tracked through time. The information feedback enables reconfiguration of the initial map according to changes in the input, resulting in the dynamic occupancy mapping. The second group of sensors provides more detailed information on activities within established zones. This information is focused on the appliances/devices used (IOT), levels of noise (soundmeter) and quality of air (air quality sensor). For designers, this is a tool to understand spatial change through use over time, and for users, this is a way to plan the occupancy and use communal areas more efficiently.
6. The algorithm

The algorithm (Figure 3) gives a detailed description of the information flow based on the decision-making logic adjusted to one or more users. The system is, therefore, occupant centred. The movement and actions of occupants are tracked, and data sets gathered by different sensors are overlapped to establish activity zones. The zone is established when specific criteria are met, based on the proximity of users and correspondence between their actions. The size of the zone is directly proportional to the number of occupants.

The system is redundant, using both camera and RFID to detect people presence. The algorithm distinguishes individuals from groups based on their proximity. If the distance between two individuals is greater than two meters, they are not considered as a group. After this decision, the algorithm branches into two sections, making a differentiation between individual and group activities which form distinct but changeable spatial zones within the communal space. The individual zone is the area of the circle with a radius measuring two meters and its centre at the place where the occupant is. The group zone is defined as an area equivalent to the area of the circle. The radius of that circle is the number of occupants multiplied by the distance measured between them. In other words, the
more occupants there are in a group, the bigger the zone is. Once the boundaries of the zone are established, its type is defined according to variables related to the movement of occupants, their interaction, noise levels and age identification. The algorithm then relies on the set of defined conditions to differentiate between four zonal categories, named WORK, PLAY, REST, and PARTY. For instance, REST category is characterised with little movement and interaction, while PLAY or PARTY have plenty, and WORK zone is characterised with no movement and low noise levels. The naming of categories responds to the character of activities quickly establish through observation, but the algorithm also captures dynamics between zones and intensities of activities within each zone. The data is gathered every two minutes and the algorithm updates the map. Timestamps and RFID data are gathered and stored for further analysis. The diagram presents the first step in introducing the computer-supported analysis of communal housing spaces by providing replicable and easily automated steps for data processing.

Figure 3. The algorithm showing data gathered by the network of sensors is overlapped to establish activity zones.
The algorithm is based on the principles of mathematical set theory, whereby objects are being grouped into sets. The system recognises occupants as objects while areas established within the communal space are understood as sets. The type of the object is established according to the action performed by the user. When the activity and location of the user change, the output, which is the size of the thematic area, changes accordingly. The output is, therefore, a dynamic map representing sets which are exchanging objects and thus growing and shrinking over time.

7. Discussion

The conceptual framework presented in this study demonstrate a way to collect data by electronic sensing in order to develop a better understanding of communal areas within collective housing. The proposed method enables designers to understand the usage of communal space across time, by tracking who is using communal areas, measuring when and establishing how is the space used.

The main advantage of the proposed occupancy analysis method is the ability to capture a large amount of information about the usage of communal areas over time. Computational techniques are employed to make sense of raw data. Instead of a static image, the expected result is a dynamic map showing fluctuations in occupants’ behaviour over time. The presented time-based method enables designers to investigate and establish behavioural patterns and lends itself as a tool for predictive analysis in the design process.

The implications of joint ownership, cooperative maintenance, and changing social dynamics result with complexity, which is difficult to understand, to predict and to design for. The innovation in housing typology involving different forms of space share is, therefore, supported by the presented method for occupancy analysis. The method is applicable as a new tool for both the design and management of communal housing spaces. The presented occupancy analysis method will show if a specific area is underused, or if it is in high demand. The designer will then be able to make informed decisions if that area should be omitted, amended or expanded with architectural means. More importantly, the designer will be able to look comprehensively at the relationship between private units and communal spaces and take educated prediction on how to make this relationship more purposeful in future designs. At the same time, presented analysis method and a resulting visual map, could help occupants to predict if using a specific communal area at a specified interval would likely be a social occasion or a solitary opportunity. Children playing together would be an example when social interaction would be desired while reading a book in the garden would be the case when solitude is preferred.

The dynamic map is the very first layer of the information offered by the proposed system. It gives a visual overview of measured information. The system provides a tool for extracting precise information on how people use communal housing spaces and sets grounding for generating datasets for further research. For example, acquired information could give evidence if particular areas are used more often, if specific activities unfold at certain times and if owners of
individual units tend to use particular areas of communal space more often. Spatial components of activities intersect with temporal so that in the next phase of this research, information harvested over time and through the method described will form a database. Such a database provides training data for the model able to predict spatial implications of change in occupancy behaviour.

8. Conclusions

The development of housing typology involving different forms of space share is driven by the rapid population growth and a lack of affordable housing in many cities across the world. While housing share may be viewed as an affordable solution and an answer to the shortage of living space, it also involves challenges primarily concerned with ownership, maintenance and social aspects. These challenges have a significant impact on the overall quality of housing and the comfort of its residents, and more conclusive understanding of such complex behavioural patterns demands innovative analysis supported by computer science.

This paper gives an account of a post-occupancy evaluation method, based on the evidence obtained from the monitoring of shared use of thing and spaces in the communal areas within collective housing. The presented research outcome includes an algorithmic chart which demonstrates a specific information flow based on who, when and how is using communal space. The presented result is a blueprint of a behavioural model, comprehended as a dynamic map showing occupancy changes over time.

The computational methods have become essential in architecture, through construction innovation, but also through analysis and optimisation of spatial usage. This paper shows how computational techniques can improve methods of post-occupancy evaluation and therefore contribute to better design and use of communal housing space. The number of recent cohousing projects has been developed for uniform social groups such as students, young professionals or senior citizens. A more conclusive understanding of behavioural patterns through computer-aided processes may help create new models centred on more profound ways of space sharing, so that they may become simultaneously attractive to occupants form different groups.

This paper provides grounding for future studies and the implementation of advanced computational techniques to understand how people use space. Further research will focus on the methodology for overlapping of acquired data sets to establish a framework for predictive and evidence-based architectural design

References


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Author/s:
Stojanovic, D; Vujovic, M

Title:
How to share a home: Towards predictive analysis for innovative housing solutions

Date:
2020-01-01

Citation:

Persistent Link:
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