KOALA

Developing a generative house design system with agent-based modelling of social spatial processes

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Abstract. The paper presents the development of an agent-based approach to modelling the interaction of human emotion and behaviour with built spaces. The study addresses how human behaviour and social relation can be represented and modelled to interact with a virtual built environment composed in parametric architectural geometry. KOALA, a prototype of agent-based modelling of social spatial dynamics at the core of a parametric architectural design environment is proposed. In building KOALA’s system architecture, we adapted the PECS (Physical, Emotional, Cognitive, Social) reference model of human behaviour (Schmidt 2002) and introduced the concept of Social Spatial Comfort as a measurement of three key factors influencing human spatial experiences. KOALA was evaluated by a comparative modelling of two contrasting Vietnamese dwellings known to us. As expected, KOALA returns very different temporal characteristics of spatial modifications of the two dwellings over a simulated timeframe of one year. We discuss the lessons learned and further research required.

Keywords. Parametricism; generative house design system; architectural parametric geometry; human behaviour; social-spatial dynamics.

1. Research aims and questions

The aim of this research is to connect existing knowledge from cross-disciplinary fields into a systematic applicable parametric platform whose purpose is to simulate humans’ adaption to a specific built environment and generate adaptive architectural proposal. The computational method is agent-based modelling. In this paper, our study addresses the following three questions:

1. What parameters can we define to represent and characterise the social and spatial processes towards dwelling comfort and satisfaction?
2. Can an agent-based modelling system be developed as a parametric design environment facilitating participatory design comparable to social production of culturally lived architecture?
3. How can we evaluate the performance of parametric architectural geometry resultant from supposed interaction with episodes of social dynamics?

The conceptual framework we propose in this study is developed into a system design and implementation of a prototype (nicknamed KOALA) based on the popular Rhino-Grasshopper parametric modelling platform for modelling social-psychological interaction with a virtual environment. In evaluating how the system performs, we applied KOALA to comparative modelling of two real houses in Vietnam - one is a well-known historical vernacular house (Hue Garden House) and the other a contemporary house (House For Trees) designed by VTN Architects in Ho Chi Minh City. The input datasets for evaluating KOALA were intended as an initial ’sanity check’ not to represent the social characteristics of real Vietnamese households. Therefore, the result from the comparative modelling of the agents’ social-psychological states and the spatial modifications over the simulation timeframe should be seen as an initial verification of our prototype development.

2. Previous studies in agent-based modelling of human behaviours and social spatial processes

There are existing applications of human behaviour simulation in computational design literature. Recent studies such as the MASSIS (Multi-agent System Simulation of Indoor Scenarios) (Pax & Pavon, 2016) and Event-based model (Schaumann et. al, 2016) have developed proposals for indoor crowd simulation by simplifying human behaviour into two categories: high-level (decision-making process) and low-level (environmental perception and communication) behaviours. Although the agent structure is different, their approach is similar in using agents’ behaviours, which includes expected behaviours (scheduled or user-defined) and unexpected (random) behaviours to evaluate the simulation environment, in this case, the architectural space.

Hong and Lee (2018) developed a process using game engine and Revit toolkits to bring designers and students into the human-computer interaction through agents’ behaviour 3D visualisation. By exploring combination of behavioural data modelling with rule based systems from architectural social science, Jorn and Shin (2013) showed that the social psychology of spatial modification behaviours can be modelled and simulated. These studies indicate the prospect of how architectural parametricism may be redefined and enriched with inclusion and synthesis of spatial-social dynamics in computational design process, whose results can be applied in user-focused architectural design process such as collective design and evidence-based design.

Overall, despite the differences, the three studies have provided valuable methods and experiences in designing the simulation system, including: The conceptual structure of each agent, comprised of two components: memory storage for individual psychological and social traits, and environmental perception for dynamic reaction modelling; The construction of agents’ behaviour dataset, including predefined scheduled activities, and unscheduled activities which require calculation; The human - computer interaction, or how the
simulation system can inform architects or architecture students in their design process.

3. The PECS reference model

Because of the simplification in agent behaviour calculation, existing agent-based modelling systems tend to treat architectural users as similar entities with binary decision ability, e.g. to move or to stand, violent or non-violent behaviour, while in real life, human behaviour decision process is much more complicated and strongly affected by individual personality (Ratti & Claudel, 2015). Proposed by Bernd Schmidt in his book titled “The Modelling of Human Behaviour” (2000), the PECS (Physical, Emotional, Cognitive, Social) reference model has been applied in a number of studies, in which researchers tried to model some aspects of human behaviour in connection with the built environment. One example is the simulation system used for security force training (Kvassay et al., 2017) under project EUSAS (European Urban Simulation for Asymmetric Scenarios), dealing with threats in urban context, such as rioting crowds, insurgents, or terrorists. Sibbel and Urban (2002) applied the model into a hospital management project, by evaluating the architectural performance based on users’ behaviour and decision-making. Another application of the framework is in public transportation safety (Briano et al., 2011), which looks into crowd modelling in motorway tunnel emergency evacuation.

It should be noted that the PECS reference model is based on 'causal partition' (Kvassay et al., 2017), in which the output decision is quantified from the contribution of various numerical inputs. This approach allows the model to dynamically modify the relative importance of agents’ motive values during the simulation process, thus it can predict human behaviour by collecting their psychological data. However, at the same time, it requires an understanding and documentation of the product of emergent behaviours in order to successfully model them into the PECS framework (Heppenstall et al., 2016).

4. KOALA system development

4.1. KOALA SYSTEM ARCHITECTURE

Conceptually, the KOALA system consists of three layers. The centre layer or the most inner layer, namely the Virtual World of agent, is where all the simulation results are stored in interaction between three main components: The Agents, the Behaviours and the Environment. The second layer, the Controller, provides all mathematical calculations that links three main components’ dataset together inside the simulation loop. The most outer layer, the User Input, plays the role of interaction with user, creating the setup for all input data used during the simulation. The calculation process is a sequence of exchanges of data and methods between three layers. By repeating this sequence continuously, each entity in three main entities (Agents, Behaviours, Environment) can affect others, and at the same time, can be effected by others during the simulation period, creating a conceptual imitation of time. The result is a so called culturally lived architecture space, which simulates the dynamic relationship between human, space and behaviours.
Table 1. Relationship between agent behaviours and parametric system.

<table>
<thead>
<tr>
<th>Layer 1: Entity</th>
<th>Layer 2: Calculation methods</th>
<th>Layer 3: User input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent behavioural</td>
<td>(a) Behaviour calculation process</td>
<td>Set of agent's psychological and physical values</td>
</tr>
<tr>
<td>Motives</td>
<td>- Choosing behaviour based on the comparison of agents' societal motives.</td>
<td>Set of agents' societal motives, analysis and schedules</td>
</tr>
<tr>
<td>Output behaviour dataset</td>
<td>(b) Output analysis and social spatial context (SSC) evaluation process</td>
<td>Set of behavioural spatial requirements set of assets preferences</td>
</tr>
<tr>
<td>Environment</td>
<td>- Evaluation of the environment based on behaviour's expectation and assets preferences</td>
<td>Set of parametric architectural input</td>
</tr>
</tbody>
</table>

4.2. BEHAVIOUR CALCULATION MECHANISM

According to the PECS framework, human behaviour can be computable if it is simplified and modelled as a combination of several mathematical functions. Within this ‘causal partition’ model, behaviour motives are translated into numeric value, before being compared and selected (Figure 1). Parameters in this model include constant values, which are defined by user before the simulation, and dynamic values, which are continuously calculated and updated by the system.

Constant (input) values: Motive (representing human’s psychological drives (e.g. the need to socialise)); Motive weight (representing individual’s personality by combining a set of motive); and Input behaviour dataset (predefined behaviour set that the agent will select from). Dynamic values: Intensity (representing the urge, or motivation to do a behaviour link to a motive at a specific time); Time (representing a real time line (24 hours a day) in the agents’ world); Output behaviour dataset (the selected set of behaviours based on motives and intensities that the agent will further select from).

In KOALA, an agent’s personality is built with five motive values, or psychological parameters including: Sociable value - Sp (an agent’s inclination to interact with other agents, which is linked to social behaviours); Carefulness value - Cp (the extent an agent attends to get immediate surroundings organised, which is linked to behaviours such as cleaning, washing, and organising); Life enjoyment value - Ep (an agent’s desire to be stimulated, pursue interests, have fun, and is linked to relaxing, or entertaining behaviours); Self-perception value - SP (an agent’s ability to identify and perceive her/his own emotion and motives, and is linked to emotion perception); and EQ (an agent’s self-awareness level, or the ability to carry on behaviours without being highly influenced by other internal values such as emotion and physical state, and is linked to emotional restraint).
As an agent can have a large set of behaviours that link to a smaller set of motives, the causal partition model may generate a set of expected behaviours with equal motive intensity. This set is then filtered and chosen based on three other factors (Figure 2), including: (1) The relationship of an agent and other agents (an agent will tend to choose the behaviour, which can help her/him to be in the same place with her/his favourite agent, and avoid interaction with the least favourite one); (2) The locations of behaviours (the agent will tend to choose behaviours that have less travel distance from her/his current location); and (3) The emotional state (if an agent is happy, he/she will tend to choose behaviours, which are driven by certain motives such as the Life Enjoyment and Sociable Value motives. If it is sad, behaviours, which are driven by Life Enjoyment and Sociable Value motives, will be temporarily suspended from the behaviour set to prevent the agent to choose those behaviours).

Figure 2. Calculation of an agent’s behaviour.

Agents’ emotional states not only affect their decision-making processes, but they can also change their psychological motive values. For example, an agent in a happy state will automatically increases her/his Sociable and Life enjoyment values, while a ‘sad’ agent will decrease those motive values. This combination of these factors is expected to better reflect the complexity of the agent’s behavioural decision process, or in other words, being perhaps more ‘human like’.

4.3. SPATIAL EVALUATION AND MODIFICATION MECHANISM

To evaluate the social comfort of an architectural space according to an agent-based framework, we define Social Spatial Comfort (SSC) value as a behaviour-led measurement. The SSC value is developed from three main factors influencing human spatial experience (Sussman & Hollander, 2014; Bittencourt et al., 2015): The convenience of traveling between functional spaces, in term of distance and accessibility; The dimension of space and how it supports users’ activities that happen inside the space; The openness of space which provides views and connections to the outside of the space.

Since each behaviour of an agent is integrated with a unique set of spatial requirements, these three values represent the agent’s behavioural comfort by
evaluating the set of spatial requirements with the actual architectural geometry in terms of the following:

- **Moving Distance (MD)** = The distance from agent’s current location to the location of chosen behaviour (metre)
- **Dimensional Comfort (R1)** = (Location dimension / Chosen behaviour required dimension) %
- **Openness Comfort (R2)** = (Location openness / Chosen behaviour required openness) %

After the simulation, those values and recalculated to evaluate the social comfort of each architectural space or location, by four values, each ranging from 0% to 100%, which is then used to calculate the SSC value:

- **Li (Importance level)** = (Time spent at location / Total simulation time)
- **Lf (Moving distance comfort)** = 100% - (Total distance to move to location (HM) / Total moving distance) %
- **R1A (Dimensional comfort)** = Average all Behaviour’s dimensional comfort (R1) at location, weighted by behaviour’s time proportion
- **R2A (Openness comfort)** = Average all Behaviour’s openness comfort (R2) at location, weighted by behaviour’s time proportion

\[
SSC = \sum_{i=0}^{n} \frac{L_f + R1A_i + R2A_i}{3}
\]

The fact that people change their buildings over time suggests the necessity of a system to perform a spatial modification process, as though agents inhabit to modify the virtual architecture in order to maximise the SSC value. In Koala, we propose to start with a general spatial modification process involving only four functions as specified below: (1) Modifying interior spaces’ areas to reach their R1A% expectation values, by increasing their dimensions towards the exterior spaces; (2) Modifying interior spaces’ opening levels to reach the R2A% expectation value, by increasing their window sizes; (3) Modifying spaces’ locations by switching them with more suitable functions that share similar areas and higher Lf% values; and (4) Creating canopy on top of exterior space if they are frequently used as transportation space (the space used to go from one destination to another) more than 20% of simulation time.

Specifically, the rule set for executing geometrical and constructional modifications was specified as follows:

**Step 1 - Area modification:** (1) Checking the current space’s boundary lines (poly-surface outlines) and find its adjacency to other spaces. (2) Categorising those boundaries into two types: (a) adjacency to interior space; and (b) adjacency to exterior space. (3) If the R1A% is smaller than expectation value, scale the current space’s geometry in one direction towards each boundary line in type (b).

**Step 2 - Window modification:** (1) Categorising the space’s walls/surfaces into two types: (a) with windows; and (b) without windows. (2) If the R2A% is smaller than expectation value, scale up each window in type (b) surfaces until R2A% reaches expectation value or the window area is equal 90% of the wall/surface area. (3) If the R2A% is still smaller than expectation value, create window in type
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(a) surfaces by offsetting each wall/surface boundary (polyline) towards its centre point. The offset distance is calculated based on the window area needed.

The above set of rules allows a system to modify the input parametric geometries towards agents’ satisfactory psychosomatic state, individually as well as collectively.

5. Case study

To evaluate the current version of the KOALA prototype, we conduct two case studies to examine the differences of the simulation outcome using two typical residential building in Vietnam. The first one is the House for trees by Vo Trong Nghia Architects, winner of AR House Award 2014. Despite its success in architectural competition, this house is highly criticised inside the country. Drawing from Vietnam National Architecture magazine, March 2016: ‘Buildings of Vo Trong Nghia Architects are hardly suitable to Vietnamese people’s psychology, preferences and also aesthetic notion’. In contrast to this house, the other example is an applauded traditional prototype of Vietnamese heritage architecture. Based in Hue, the old capital of the country, this village of garden houses is famous for its combination of outside and inside spaces, as well as shared and private spaces (Nguyen & Kobayashi, 2015).

Given that real-world vernacular architecture can be seen as the outcome from the working of Social-Spatial Dynamics as a reference, this case study will test if the simulation result of spatial-social evaluation and modification is radical, and if it matches with the actual social evaluation of these two buildings.

5.1. AGENT CONSTRUCTION

The psychological construction of agents is shown in Table 1, and the input dataset of Agent Relationship and its interpretation is shown in Table 2. When choosing the behaviour, an agent chooses the one that it can take place in the same place with its favourite agent, and will avoid its least favourite one. We used a common set of inputs to test KOALA modelling of the two houses. The input psychological data were prepared for hypothetical persons as agents, thus they do not represent any of real Vietnamese people’s characteristics. Similarly, the agents’ relationship links were set to simulate a hypothetic social scenario of dwelling. However, some public references of the two houses known to us were taken on board when interpreting KOALA’s outputs.

<table>
<thead>
<tr>
<th>Agent, Age, Gender</th>
<th>Father, Male, 35</th>
<th>Mother, Female, 30</th>
<th>Son, Male, 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carefulness Value (Cp)</td>
<td>0.8</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Sociable Value (Sp)</td>
<td>0.6</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Life Enjoyment (Ep)</td>
<td>0.4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Self-Perception (SP)</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>EQ</td>
<td>0.9</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The input data also specified individual personality profiles of the agents (Table 2). With his high values of Cp and EQ, the ‘Father’ agent was built as a careful, thorough man who mostly took care of the housework. In contrast, the ‘Mother’ agent was more likely to be relaxing (high Ep value) and easily
to be affected by emotion (SP > EQ). The ‘Son’ agent, on the other hand, was sociable (high Sp value) liking to spend most of his time outdoors. Since the behaviour selection was driven from these agent input data, KOALA could be set up to model diverse individuality and social relations as virtual inhabitants of a household dwelling in a virtual built environment over a timeframe.

5.2. RESULT OF SOCIAL SPATIAL COMFORT (SSC) VALUES

The simulation was set to run for 360 days (1 year), in which KOALA continuously evaluated and modified the architectural data to increase the SSC value. The output data showed a clear differences between two case studies, in which the Hue Garden house SSC value (from 89.7% to 97.7%) exceeded the House for Trees value (from 77.9% to 94.3%). This can be explained by three points below: (1) The functional network of HGH provides more efficient movement between spaces, thus increasing the distance comfort (Lf) value; (2) The spaces of HGH are interlinked together, thus creating more dimensional (R1) and openness (R2) comfort; and (3) The exterior spaces of HGH are more defined, providing more room for spatial modification and SSC value increase.

In addition, agents’ individual SSC values also show the difference between agents’ spatial perceptions and comfort preferences. For example, overall, Mother and Son have higher SSC values, suggesting that they enjoy the spaces for relaxation since most of their behaviours are driven by Sociable and Life Enjoyment values. Meanwhile, because agent Father has lower SSC value, it can be assumed that spaces for Carefulness-driven behaviours are less social comfortable.
5.3. SPATIAL MODIFICATION OUTPUT

Figure 4 illustrates how KOALA modified the architecture of two case studies throughout the simulation process. The changes are categorised into four groups: dimensional change, openness change, canopy generation and function swapping. It can be seen that there was no functional changes in the HGH case, and it has less dimensional changes. Both case studies have canopies generated, i.e., the Central Yard of H4T and the Pond Garden of HGH. Since the goal of modification is to maximise SSC value, the case with less changes (HGH) reaches the highest value of SSC faster (Day 30).

![Figure 4. Spatial modification process of Hue Garden House and House for Trees.](image)

6. DISCUSSION AND FURTHER DEVELOPMENT

Overall, the result shows that the Hue garden house, a typical heritage building which has been lived in and adapted to users’ needs for more than 150 years, has much better results than the House for trees, a criticised contemporary architecture. This can be considered a radical outcome of the social spatial comfort evaluation, based on the architectural convenience, adaptation and also their ability to support users’ activities and social interaction, matching with their generally social evaluation in Vietnam.

However, the link between agents’ psychological motives and real life human psychology is to be further studied including (1) to gather real psychological data from social research; and (2) to test the system on different architectural types / sizes, in order to show how those motive values could be extended to represent a social, or geographical group of human inhabitants. Further work is required to
improve the current behaviour selection process which presents uncertainties in the calculation. For instance, the assumption that human prefers behaviours required of less travel distances; the dynamic links between agents’ scheduled activities and their relationship with other agents (relationships change overtime); the effects of group behaviour on an agent’s individual decisions. Therefore, suggestions for further development of the KOALA system can be categorised into two groups: (1) Development of the behaviour decision process in relation with spatial data; and (2) Development of the applicability of the KOALA system.

The KOALA system can also be applied into the collective design / participatory design framework, since it provides a computational platform for architects to easily use and analyse the users’ social and psychological preferences during the design process. With further development, KOALA is expected to be an open tool for a broader use scenario, in which users can provide their life experiences as references for modelling social-spatial processes of inhabitation in the built environment.

References


