#29

A WEB-BASED PROTOTYPE SURVEY METHOD EXEMPLARILY APPLIED ON ACTIVITY ALLOCATIONS IN APARTMENT FLOOR PLANS AND THEIR SPATIAL PROPERTIES

MICHEL TRIEMER
Bauhaus-Universität Weimar, Weimar, Germany
Michel.Triemer@uni-weimar.de

SVEN SCHNEIDER
Bauhaus-Universität Weimar, Weimar, Germany
Sven.Schneider@uni-weimar.de

SASKIA KULIGA
Bauhaus-Universität Weimar, Weimar, Germany
saskia.kuliga@uni-weimar.de

REINHARD KÖNIG
Eidgenössische Technische Hochschule Zürich, Zurich, Switzerland
reinhard.koenig@arch.ethz.ch

DIRK DONATH
Bauhaus-Universität Weimar, Weimar, Germany
dirk.donath@uni-weimar.de

ABSTRACT

Floor plan retrieval for supporting design by suppliance of reference objects requires comparable information in understandable categories. Spatial properties of floor plans are objectively comparable, but hard to relate to subjectively perceived verbal demands toward a searched-for spatial configuration in a digital reference repository. In this paper, we will sketch a comprehensive methodological approach on filling this gap by presenting a prototype framework, which combines databases, responsive web interfaces, analysis measures and aggregation methods of all kinds, in order to conduct online surveys about icon allocations in floor plans. Participants allocate these icons, which are adjustable to any examined verbally stated meaning in floor plans. We aim at supporting previous studies like, e.g., Güney (2007), Hanson (1999), Seo (2004) and Monteiro (1997), by using a floor plan database that contains information about multiple local (e.g. 'daylight factor', 'isovist properties', 'visibility graph', 'exterior view') and relational ('euclidian distance', 'walking distance', 'visual step depth') spatial properties grid cell-wise for the usable interior area of floor plans. We developed this prototype framework in order to gain knowledge about (1) the behaviour, while participants operate on allocating icons in floor plans using the framework, (2) approaches towards the exploration of relationships between the assumed allocations and their spatial properties and (3) the method itself regarding its applicability and enhancements for future studies. As a use case, we exemplarily study how people allocate activities ('Cooking', 'Eating', 'Hygiene', 'Leisure', 'Sleeping', 'Working') in single-floored apartment units and whether certain patterns can be detected, in order to show potential for the database application framework that we seek to develop. We asked 154 participants online to allocate expected user activities (represented by icons) in floor plan drawings of apartments (without furniture) via drag and drop, in order to determine afterwards, by which degree which kinds of spatial configurations meet the participants' expectations towards the cultural code transported by the icon. Participants were advised to mark exactly the location where in their opinion the user would be situated 'best' while acting on an activity. Each participant saw three floor plans that were a priori categorized as (1) closed structured, (2) open structured, and (3) not supplying a separated space for each activity. In addition to the final allocations of the activity placements, the drag events done on the icons were stored and analysed. We concluded that the framework meets the expectations well, yet enhancements can be identified. The gathered data reflects on the expectations towards its characteristics well; and thus there is strong potential in implementing 'fuzzy' matching algorithms based on comparable studies in anticipation of the future environment of a case-based reasoning approach. Our long term objective is to fill a floor plan database containing geometries and analysis measures of floor plans, in order to supply a reference repository with 'fuzzy' retrieval approaches based on participants' input data regarding allocations. Additional use cases can be found for design automatisation, support and decision making.

KEYWORDS

Activity Patterns, Space Usage, Spatial Properties, Online Research Tool, Floor Plan Retrieval

1. INTRODUCTION

The steadily increasing availability of web-technologies (such as databases and responsive interfaces in browser clients) provides numerous possibilities for the automatisation and support of research and spatial planning tasks (such as online surveys, design tools and floor plan repositories) and reaches many people worldwide. This article describes a prototypic framework that brings together database technology, web applications and spatial analysis methods in order to conduct web surveys on user allocations in floor plans.

The context of our former work on web technologies and their potential in the field of architecture (Triemer,2014;Schneider,2014) was the motivation for the work at hand. We previously aimed on the retrieval of reference objects from digital floor plan repositories, considering precalculated spatial properties of a floor plan's geometry as 'performance-based search criteria'. An often occurring demand towards a searched-for floor plan is to supply a specific room schedule like 'small flat having two individual rooms, kitchen, two bathrooms ...' or similar. However, not even an experienced user of such a design tool could manage to state such demands towards a searched-for reference object's floor plan using spatial property measures as criterion intuitively. Thus we needed to offer additional criteria, which could help to translate these verbal demands to spatial property specifications. These specifications could be compared to the ones of spaces in the repository's database and give back a fitness value for a 'fuzzy' search/matching or ranking algorithm. For this heuristic approach on floor plan retrieval we first need to understand, how a human confronted with a floor plan solves the same problem to think about where in a spatial configuration certain human activities are how likely to be carried out. Thereby, local (properties of the location where an activity is assumed) as well as relational spatial properties (physical and visual distance between the activity's allocations) have to be taken into account.

Previous comparable studies that investigated relationships between spatial properties and user activities were often based on manually compiled large data collections about apartment units including time-consuming semi-automatic and thus non comprehensive spatial analysis (e.g. Monteiro, 1997; Hanson, 1998; Seo, 2004; Güney, 2007).

Monteiro (1997) gained data from 101 apartments that represented three types of homes (favela, public housing estate and middle class neighbourhood). The authors identified activities that happen in these flats and compared the former by examining the mean integration and depth measures of activity allocations in the floor plans. A justified graph for every apartment had to be elaborated as the basis for further calculations. Justified graphs arrange functional spaces along a tree-like structure with the exterior as the root and thus visualize the permeability of floor plans (page 4). These functional spaces do not necessarily need to be equal to the physical closed spaces (rooms): Monteiro used convex space break-ups, which are defined in an ambiguous way, because their layout might vary by researchers' judgement. Thus, a possible way to extend this study is to use a grid-based approach, calculate spatial and relational properties for each of these grid cells and relate them to as many different coexistent break-up layouts as are available.

Hanson (1998) aimed to "illustrate the complexity of human habitation and to suggest ways in which houses can carry cultural information in their material form and space configuration" (page 1). Consequences for the historic and contemporary lifestyle, popular taste and thus the relevance of spatial properties are worked out by discussing three different examples of ancient habitations as an introduction and afterwards showing recent work done on spatial analysis methods (page 49). Most approaches were dedicated to the justified graph method spectrum and visibility analysis, by means of the isovist (see figure 2) - here only for selected locations. Floor plan collections were managed partly by database technology.

Seo (2004) studied the evolution of habitation in Seoul by describing its emergence from the traditional Korean courtyard houses to contemporary serialized detached apartments. 75 examples from different periods were analyzed by utilizing the justified graph to compare integration. A special feature of Korean building culture is to differentiate between two ground levels: Seo (2004) identified clusters and the permanence of this separation principle dividing in "elevated clean space" and "earthen-floored dirty space" (80.1). This separation principle could also be handled as an allocation in a floor plan as supported by our framework.

Güney (2007) enhanced the concept of integration with measures for each grid cell and visibility analysis. By investigating 108 houses in Turkey, correlations between visual depth and integration were shown. Conclusively visual measurements were found to be more sensitive than permeability (page 1). She describes how depth and integration measures characterize the evolution of the apartments in subgroups per decade.

These four exemplary research projects have in common that they required sophisticated data collections about the spatial characteristics of apartments. Their analysis was time-consuming. User allocations in floor plans like the room usage were gathered by surveys. In some cases they were conducted in field, visiting investigated apartments and their users. This approach could have profited from using a mobile device for ascertainment. Furthermore, subgroupings in statistical operations on the compiled data were necessary in order to discover influences by comparing data sets. In other words: much effort was invested to obtain a limited spectrum of methods at once and data acquisition required complex management. We argue that we can use similar study concepts like the previous as basis for the implementation of an algorithm that is able to predict how likely a particular user activity will happen at a specific place in a floor plan. A derived algorithm from the gained knowledge could not only be applied for a matching factor for the retrieval of floor plans from reference repositories, but also for design validation and automatisation, decision-making and other improvements of the computer-aided design process, where heuristics are needed. The prototypic framework will be applicable to various comparable research tasks - not just on activities, but on anything, that could be marked by allocating an icon (from furniture, building technology and day time to proceedings or scents).

Hence, the main objectives of this article are to gather knowledge about

1. the way participants operate on allocating icons at a certain location (2d-space),
2. the possible approaches towards heuristics regarding the assumed allocations and spatial properties of the floor plans' geometry,
3. the study concept itself regarding its practicability and flexibility for future studies and the extension of our framework found.

For these objectives, we developed a prototype framework that supports publishing similar surveys as in the outlined previous research, but makes the technical requirements more accessible for researchers by combining database technology, responsive web interfaces and spatial analysis. On this basis we will conduct an economical exemplary survey on activity allocations in single-floored dwelling units with the icons 'Cooking', 'Eating', 'Hygiene', 'Leisure', 'Sleeping' and 'Working'.

Our paper focuses on the methodological approach rather than the results (which still were not gathered in in the intended environment and do not have ecological validity). We will describe strategies to increase meaningfulness and quality of derived knowledge and thus algorithms.

2. METHODS

2.1 MATERIALS

To explore our proposed framework and to predict where in spatial configurations specific allocations are how likely to be assumed, the use case considers precalculated spatial properties of the floor plan's geometry as 'performance-based search criteria' for a reference repository. Furthermore, the prototype framework should meet the aspirations to

1. be able to flexibly manage bulk floor plan collections including their analysis measurements,
2. collect various user input from a huge number of user devices (icon allocations, drag events and form input) online and
3. provide efficient interfaces for advanced analysis that facilitate sub grouping, derivating data and generating automated visualisations.

The software is based on a server-sided script, concatenating HTML and JavaScript documents to render a graphic user interface in the participant's browser/client (figure 1). The underlying database application is derived from the software 'floorplandb' (Triemer 2014) where floor plan's analysis data – the so called 'performance values of reference objects' – and their geometry are stored together into a relational database.

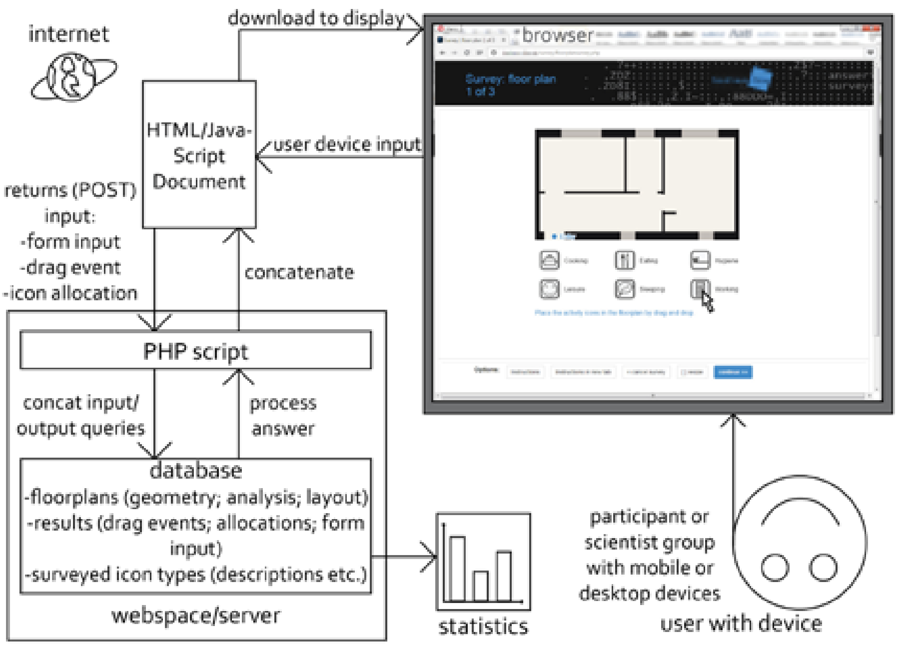

Figure 1 - screenshot of the online survey interface including the frameworks technical infrastructure

2.2 FLOOR PLAN ANALYSIS

In preparation of a study by means of our framework, floor plans need to be drawn in a CAD system and be comprehensively analysed by the toolbox presented by Schneider (2014). This analysis algorithm subdivides the interior area of a single-floored apartment unit in quadratic grid cells of an edge length of 20cm and calculates several measures for each of them. Afterwards, the calculation results are stored into the database and can get visualised (figure 2). Among other data, the measures of spatial properties were precalculated and stored. The grid cells can correspond to various layouts of spatial break-up and could be aggregated for each space unit of it. For the purposes of the prototype we implemented the in figure 2 explained analysis methods on local spatial properties for each grid cell and relational properties for each pair of them. Additionally general measures like sizes of the physical closed space (room) the grid cell is situated in are available.

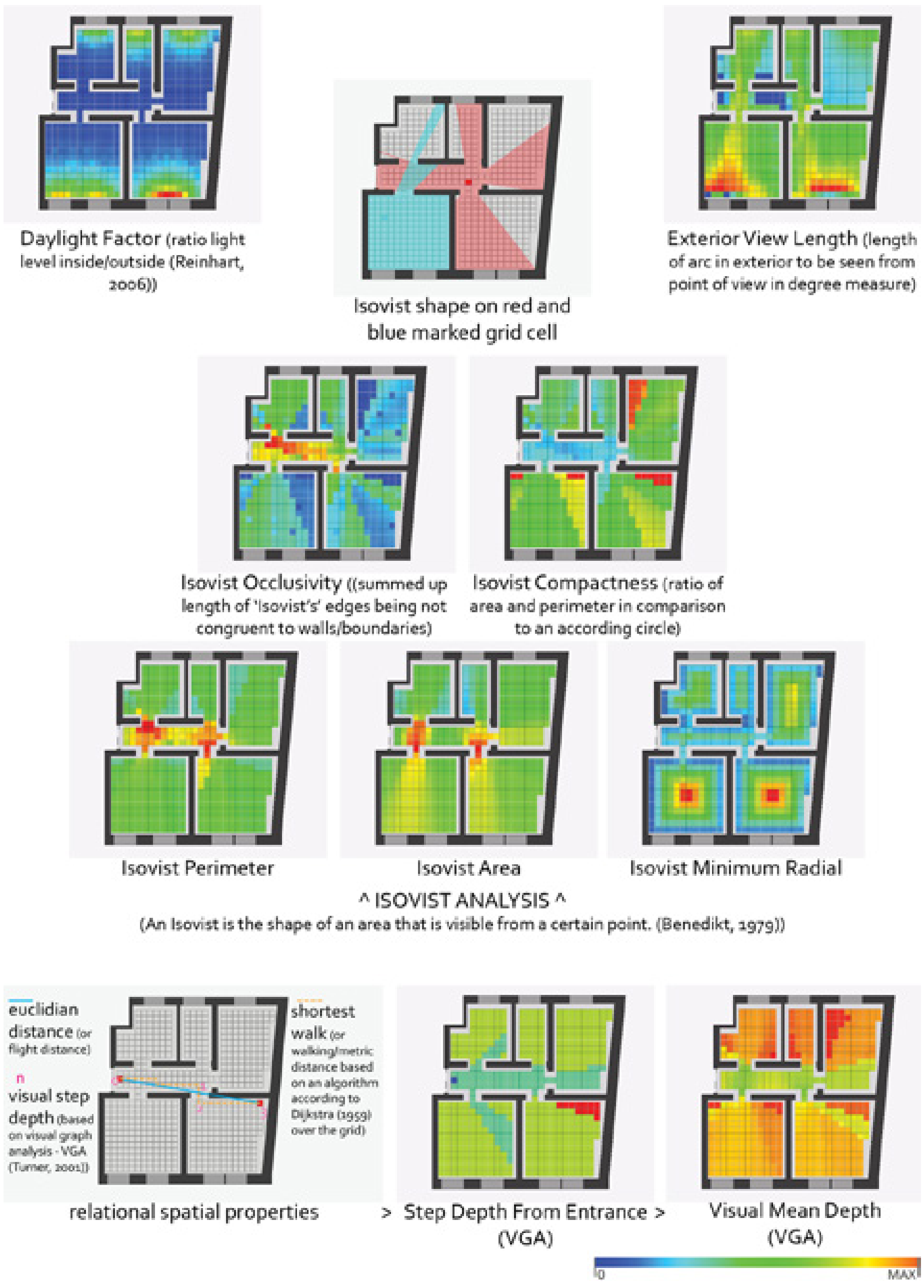

Figure 2 - spatial properties - explanation and heat map display

2.3 USER INTERFACE

Three types of user interface templates are available in the framework: (1) info pages, (2) forms and (3) floor plan stages. On the latter, participants see a floor plan of an apartment and are asked to allocate icons by drag and drop (figure 1). The icons represent a configurable meaning by a pictogram (figure 3 left). By default the placement sequence is up to the participants. An icon cannot be dropped upon another one. The icons snap to the grid when they are dragged/dropped by the intention that the mapping between grid cells and icon allocations is always unambiguous. The participants can manipulate the icons' position as often as they want. Every drag and drop event gets listed including its start time, drop time and drop target. All icons have to be placed inside the floor plan before the final placements and task duration get ascertained and participants can continue. This set of rules is easy to adapt in the framework.

The icon allocations and drag event targets correspond to grid cell '22' in the centre of an icon, having three times the edge length of a grid cell (figure 3 right). In case they exist, the eight neighbours surrounding the grid cell '22' get stored for the final allocations in order to affine results by compensating analysis outliers.

Activities

activity icon	Name	Description
	Cooking	Where you usually prepare meals and drinks: E.g. chopping, braising, washing vegetables etc.
	Eating	Where you eat.
	Hygiene	Where you take care for your personal hygiene: E.g. brushing teeth, combing, blow drying etc.
	Leisure	Where you engage in your hobbies or simply relax: E.g. reading a novel, doing exercises, playing games
	Sleeping	Where you usually sleep at night.
	Working	Where you get required tasks done: E.g. filling out your tax declaration, repairing the toaster, writing down ideas for tomorrow etc.

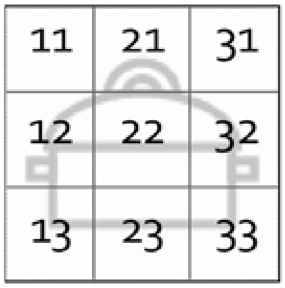

Figure 3 - left: activity icons with explanation; right: grid cells in icon

2.4 USE CASE

To test on a use case, we asked participants to allocate 'common' user activities in the floor plans and supposed to create an algorithm miming this ability. We assigned six categories of activity as meanings to icons (see figure 3 left): 'Cooking', 'Eating', personal 'Hygiene', spending 'Leisure' time, 'Sleeping' and 'Working'. These cultural codes/meanings were chosen to be applicable for as many people as possible and leave space for interpretation or a translation to the own culture, because we suspect these to be intuitive labels on searched-for spaces that shall be found in performance-based reference repositories (see introduction) matching the code's underlying spatial definition to a certain degree. For every icon/label a strong iconic pictogram was chosen and a brief description and examples were supplied.

For our exploratory study we used nine different floor plans (see figure 4). These correspond to three variations of three different floor plan categories. The floor plan categories were chosen to depict different structural typologies. They were designed to check, if the cultural code of the spatial configurations can be read by the participants and thus manifests in easy to expect allocating behaviour. Their variations should provoke participants to behave differently by only small modifications of the spatial configurations. We worked with three categories/scenarios (details: appendix):

1. 'enforced overlap of activities' (four spaces; 1-3)
2. 'closed structured' (five spaces, 4-6)
3. 'open structured' (one space, 7-9)

These nine floor plans can be understood as a minimum test database, being open to further millions of examples, which are not available yet and would result in few answers per single floor plan, because of the limited media penetration of the exemplary survey website. For our test survey we aimed at an economic placeholder with simple and small floor plans to validate the reasonableness of huger effort by stating expectations that can have reflections in the aggregations of the derived data.

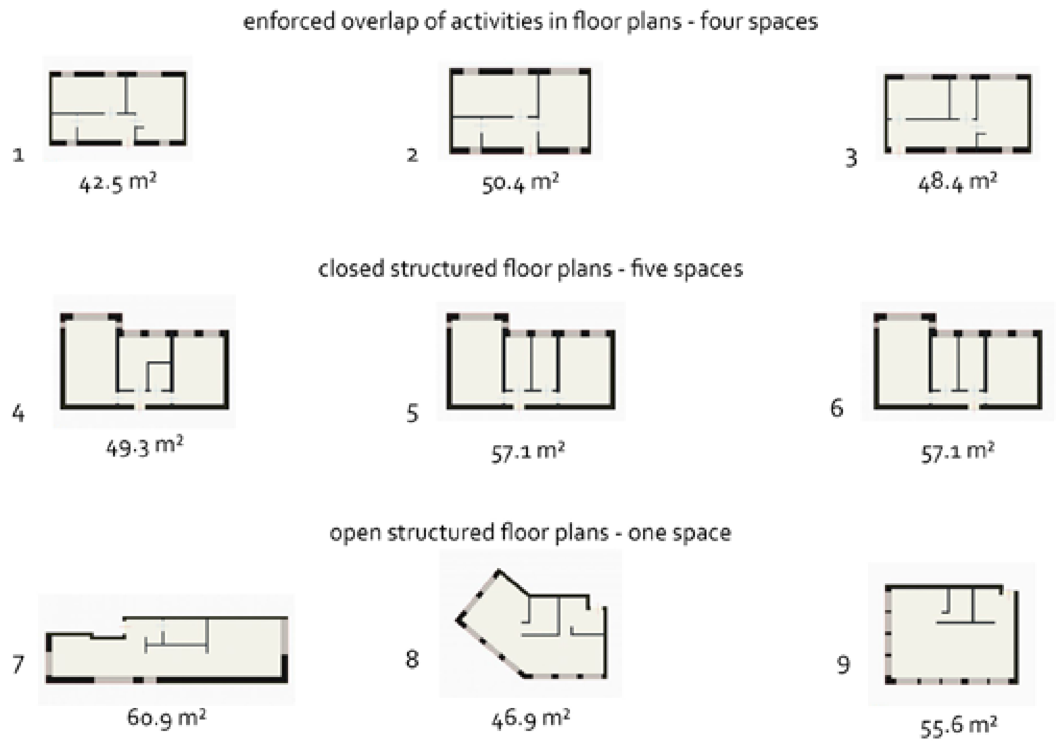

Figure 4 - the nine floor plans

For gaining the test data, a survey website generated by means of the framework was put online and promoted via different channels: design and architecture related and not related fora.

Here, as first step, participants filled-in their year of birth, gender, country they grew up in, highest educational degree, profession, and the experience level in designing apartment units (scale 1: lowest to 5: highest). On the subsequent info page, the operation of the interface of the floor plan stage (figure 1) was described in a tutorial. Participants were told to exactly mark the location where the activity (figure 2 left) would be located best in an apartment floor plan. It was stated that they should not think about their own circumstances, but rather of a scenario of a single person between 20-40 years (because we suspected different forms of residential community). Furthermore, technical issues, such as pipes and wires, should also not be considered to be of priority. Afterwards the icon allocation procedure started. Every participant had to solve three floor plan stages with one out of the three variations randomly chosen for each of the three floor plan typologies (figure 4). Additionally, the floor plans were randomly either displayed in their original layout, or rotated north to south, in order to find whether there was an impact of cardinal direction on the placement behaviour. After finishing these three tasks, participants were asked to comment on their strategy.

3. RESULTS OF USE CASE DATA

Among the 154 participants were 67 men and 83 women; age ranged between 17 to 77 (M= 31.2 years; SD=10.1) and their field of study was mainly related to architectural design (50%).

In the following, we will provide an analysis on the gathered data in order to better understand the placing behaviour. Additionally, considering participants who stated they studied more than four years, worked in architectural, interior or urban design, were older than 21 years and had an experience level of three of five or more, we differentiated in a group of 62 experts and another of 92 laymen.

3.1 PLACEMENT DECISION-MAKING

Individuals intuitively have an idea where to conduct certain activities best and, how these relate to each other. These opinions might be diverse due to personal preferences. Thus the validity of such studies is limited, if we try to only elaborate results testing our own way of thinking. Consequently, the participants' comments on their strategy are an immediate source for further hypotheses. We were interested in understanding, how participants would describe the researched cultural patterns (see appendix for a summary and interpretation of the participants statements).

3.2 SEQUENCE OF PLACEMENT DECISIONS

Box plots were used to examine the drag and drop handling during the task (to examine whether we could identify clues to the solving strategy). The plot (figure 5 A) about the number of drag events done with the icons of each activity suggests that the participants did not iterate the icons' positions a lot. Interestingly the sum of seconds every activity icon was dragged (figure 5 B) is lowest, where also the fewest drag events occurred: for 'Hygiene' and 'Sleeping', which thus are considered to be least demanding. After the implementation of the survey interface, we watched beta testers: some held the mouse button down and dragged icons around and others were repeatedly dragging and dropping when concentrating on finding a solution.

On the interface the icons were displayed in alphabetical order (see figure 1). Assuming the placement decision was done when the participant dropped an icon to the position where it was confirmed later (final position), it appears that the ranking of decisions equals the enumerated sequence of the latest available drag events for every activity ordered by their timestamps increasingly.

The aggregation of these rank numbers shows that there is a tendency to place the icons in the order they were displayed for all participants (figure 5 C). In a few cases more than other activities, 'Hygiene' was preferred to be in a fixed position first. Thus it is very unlikely to find clues on priorities or operational strategies when allocating icons.

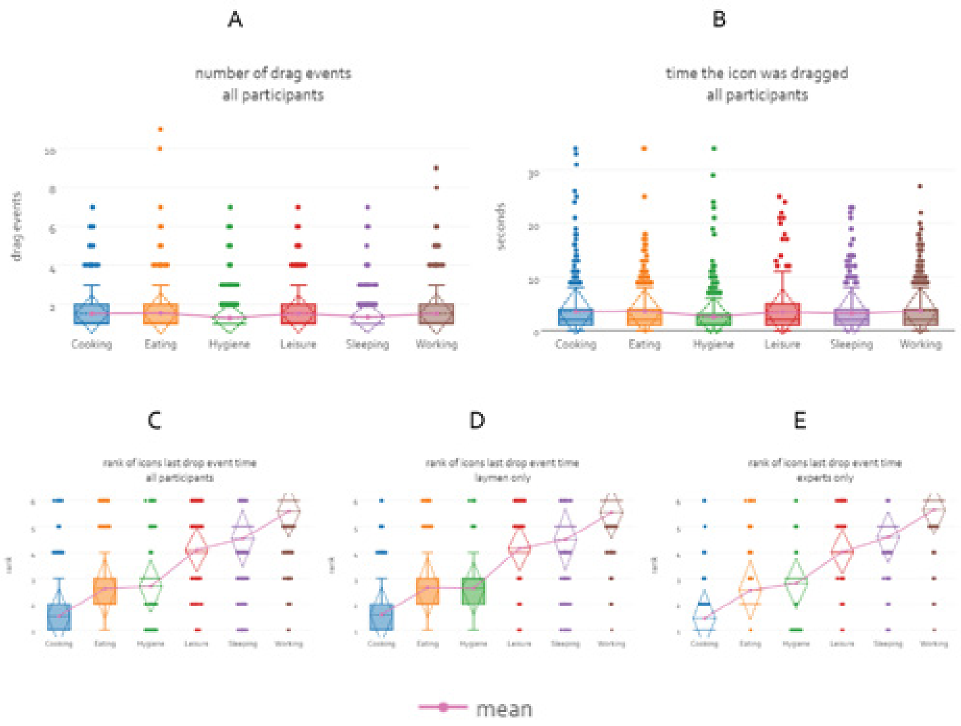

Figure 5 - upside: A: drag events per test; B: sum of time elapsed dragging the icon; downside: Preferred order of placement decision: C: all; D: laymen only; E: experts only

3.3 FREQUENCY OF PLACEMENT DECISIONS

Heat map analysis of the frequency of participants choosing the grid cells for the six activities in the nine floor plans will be taken into account to evaluate how these grid cells are distributed and whether there are patterns to find (figure 6).

Obviously, the least varying activity was 'Hygiene' - it was in almost every test allocated in the same room, while other activities almost never occurred here.

'Cooking' seemed to occur pretty close to the entrance and participants tended to place this activity in alcoves. 'Leisure' was more likely placed in one of the largest rooms available. The heat maps also suggested that 'Sleeping' was influenced by the entrance location.

The floor plans '4', '5', and '6' represent the 'closed space' typology (figure 4). In floor plan '4' we expected the smallest room without windows to be in use for 'Hygiene', which turned out to be always the case. Floor plans '5' and '6' were geometrically identical. Only the position of the flat entrance varied to be aligned to either one of the small rooms' doors. One was neighbouring the larger room and one the smaller room among the bigger rooms available. Surprisingly, no differences could be observed in the allocating behaviour when the entrance's position was altered: 'Hygiene' was placed more often neighbouring the smaller room and 'Cooking' equally more often neighbouring the larger in both variations. Participants also tended to allocate 'Leisure' in the larger room, neighbouring the small room, which was often used for 'Cooking'. The latter condition's impact seems predominant.

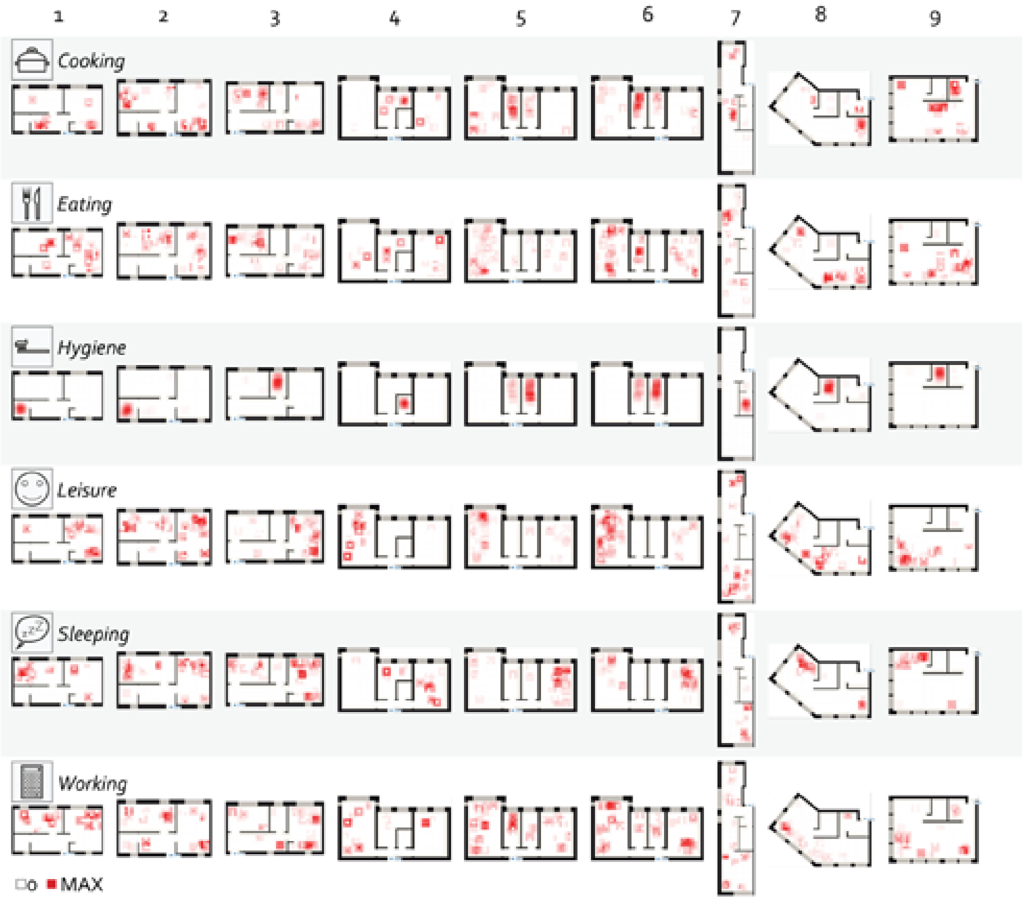

Figure 6 - heat map on the frequency of allocation

3.4 CHARACTERISTIC LOCAL SPATIAL PROPERTIES

The next question was how spatial properties were distributed for the places of activity allocations (figure 6). To plot figures 7 and 9, these spatial properties p_{loc} of all grid cells including their neighbours (according to figure 2 right) were normed to the percentage of range p' between flat's/ floor plan's minimum $min\ (p_{flat})' = 0\%$ and maximum $max(p_{flat})' = 100\%$.

$$p \in R,\ \ min(p_{flat}) < max(p_{flat}),\ \ p' = f(p_{loc}) = \frac{p_{loc} - min(p_{flat})}{max(p_{flat}) - min(p_{flat})} \cdot 100\%$$

The results p' were aggregated in a box plot, showing one box with given mean and standard deviation for each spatial property and activity. Thus, we deal with a proportion among all possible choices inside a specific flat. Otherwise, a high maximum of only one apartment would turn placements at the maximum in other ones into medium values for the aggregation, despite they are preferably extreme.

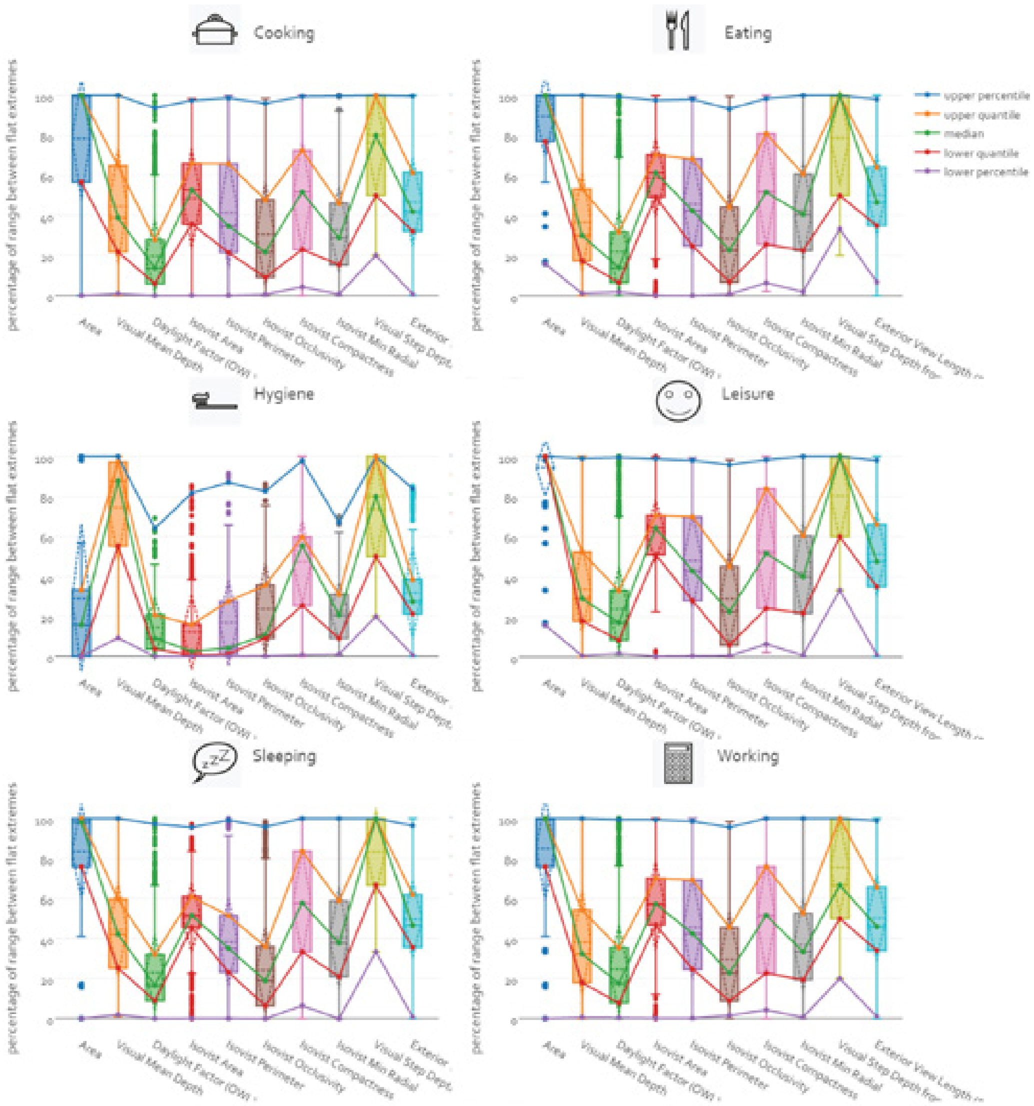

Figure 7 - local spatial property patterns for each activity

To keep it short, we will only comment on the most striking findings. We state for the 'area of room', that 'Hygiene' is likely to be allocated in the smallest available room, while 'Sleeping', 'Eating', and especially 'Leisure' cumulate in the hugest rooms.

'Visual Mean Depth' is significantly high for 'Hygiene', and shows a strong tendency to be lowest for 'Leisure' and secondly for 'Eating'. Thus 'Hygiene' appears to be most integrated and 'Leisure' to have the best accessibility from the entrance.

Even no outlier of 'daylight factor' occurred for p'69%. Participants seem to avoid placing any activity but seldomly 'Working' and 'Leisure' at the grid cells with maximum 'daylight factor'.

'Visual step depth from entrance' has the lowest median for 'Leisure' and the highest for 'Sleeping' and activities never occur right at the flat's entrance.

Participants appear to avoid allocating 'Sleeping' in extremely large and also small isovists and have a remarkably unambiguous optimum around medium values here.

75% of all placements for all activities had 'isovist occlusivity' p'< 56%, which suggests that highly occlusive places correlate with left free circulation space.

All in all, this data shows the expected heuristics (which in this case is desired); and gives strong input for informing an algorithm.

3.5 SUBGROUPING

We plotted groups of boxes combining the aggregations of *p'* for all participants with the influence of displaying floor plans in altering cardinal direction (figure 9; appendix). One could argue that the cardinal presentation of the floor plans had an impact. This is only partially the case. Analysis via median subtraction shows that there were slight differences for 'area of room', 'daylight' etc.. Furthermore, individuals with more experience react stronger. Additional groups could be defined based on these kinds of data sets and could be compared in the same way.

3.6 RELATIONAL SPATIAL PROPERTIES OF ALLOCATIONS

In order to summarize about patterns to find in the spatial relations between all activities (and additionally between the entrance and these activities), we analysed the heat maps (figure 8) displaying measures for each pair of allocations. Three heat maps display the percentage of participants' placing activities together in the same closed space (room); considering different subgroups of floor plans. Another three heat maps display *p'* for the distance measures/relational properties (figure 2).

Considering; if activities are in the same room and if it is getting more or less likely if one space more is supplied to combine them, the most striking finding was that 'Hygiene' has been placed solitarily. A majority of participants grouped 'Eating' with 'Cooking', which indeed gets less likely when an additional space is supplied. Only 37% thought 'Leisure' would fit 'Cooking' and still less (16%) in case a fifth space is available. We found that 'Sleeping' is combined with 'Working' or 'Leisure' much more unlikely when there is an extra space (65% to 33%). In general 'Sleeping' seems to be favoured to be in a room separated from other activities. Regarding distance measures in all three plots it is interesting that there are high minima to find, thus there seems to be a strategy to keep a moderate distance between all allocations. We could identify the group of 'Eating' and 'Cooking' to be close to 'Leisure', but as far away as possible from 'Sleeping'. The 'euclidian distance' between 'Sleeping' and 'Hygiene' is surprisingly low, while 'shortest walk' tends to be comparably long.

The following sequence of activities from entrance is apparent according to:

-euclidian distance:

'Cooking' < 'Hygiene' < 'Eating' < 'Working' < 'Sleeping' < 'Leisure'

-shortest walk:

'Cooking' < 'Eating' < 'Working' < 'Hygiene' < 'Leisure' < 'Sleeping'

-visual step depth:

'Cooking' < 'Eating' < 'Working' < 'Leisure' < 'Sleeping' < 'Hygiene'

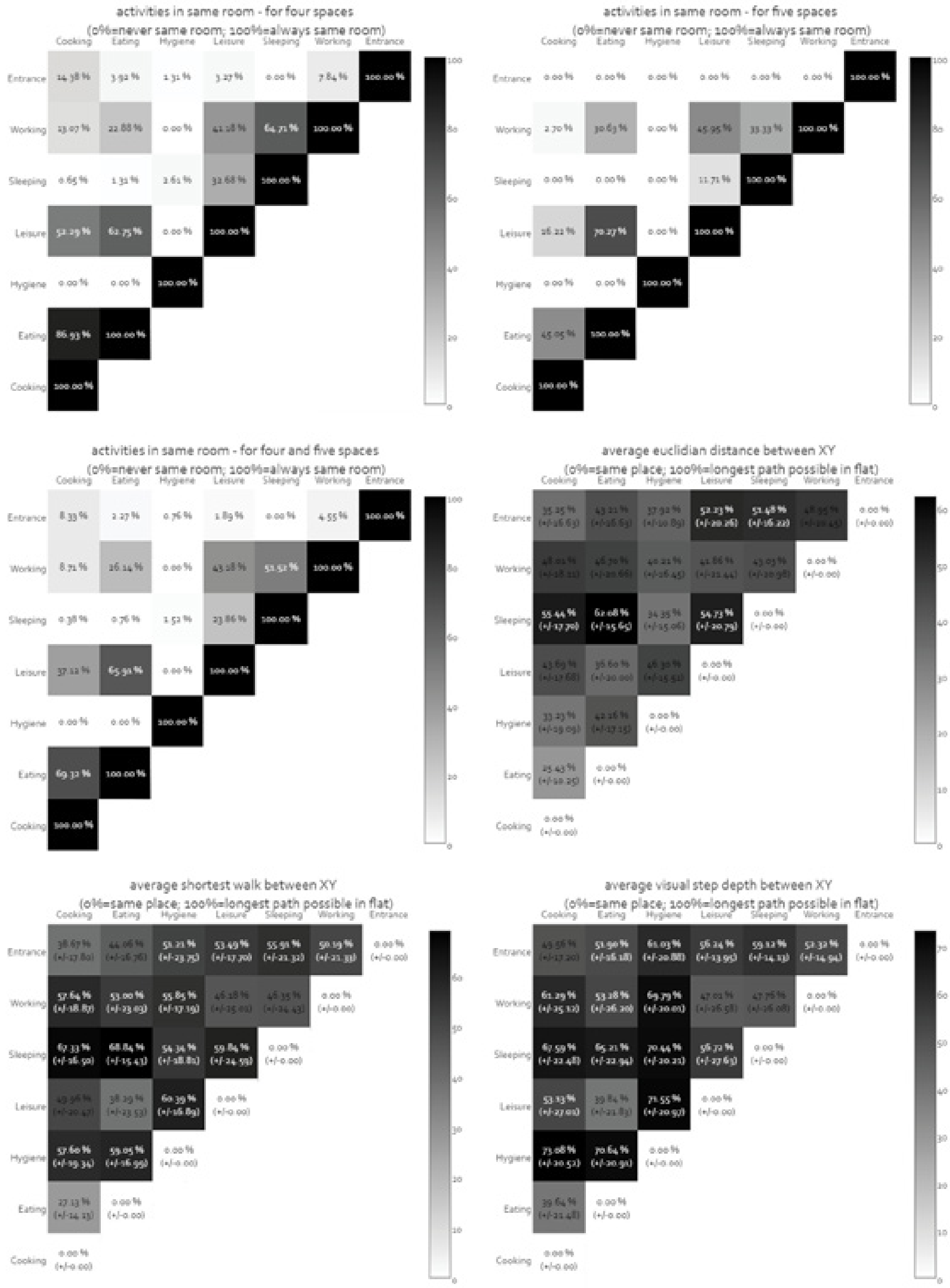

Figure 8 - distance analysis between activities and relation to entrance

4. DISCUSSION AND OUTLOOK

The result of our work is a prototype framework smoothing the path to a future method for bringing together verbally stated cultural codes and measurable properties of spatial configurations by online surveys. We tested the method by conducting a test survey on activity allocations in apartment floor plans. We found potentials and concrete indications on strengthening synergies by achievable enhancements. The framework improves the analysis depth for researchers of previous similar surveys.

For instance, Kim (2005) conducted a study with 426 participants and found several 'behavioural patterns' in serialized uniform apartments. The work presented in this paper is valuable in terms of comparability and detailing; and is based on data collected directly from in-use apartments. The uniform approach would make a finer categorization of allocations possible. The implemented prototype framework is tested on conventional environments; including mobile/touch devices. This approach could not only be used to conduct an online survey, but also for data acquisition by a researcher. Thus, it would support Kim's work by low technical requirements towards the equipment of the data collector. Several points of connection to further applications of the presented framework could be found on the field of design support; e.g. enabling a CAD system to recognise when a user draws a bathroom and thus suggest associated options like adding a sink. A further use case could be validation methods for automated designs by means of optimisation. A generated floor plan could be automatically tested to fit the features of a usable flat and in case it does not, the generating algorithm could abolish and continue generating.

In addition, the framework needs only moderate adjustments and extensions to fit the requirements of the study concepts by Monteiro (1997), Hanson (1998), Seo (2004) and Güney (2007) and numerous other research tasks. Hanson (1998 p. 8) showed that some activities in some cultures are not allocated inside the private housing. Hence, the configuration of the set of rules for the operation of the floor plan stages could be adjusted to allow to leave icons unconsidered. Güney (2007) suggested emphasising two alternative concepts to the convex break-up: end point spaces and movement spaces (according to Peponis 1997, 1998), which measures from grid cells could also be related to by means of the framework's database. Hence, these additional spatial break-up classes to the implemented 'room' and 'convex' concept are easy to supplement, because they can be unified to the database structure via the entirely grid-based relational approach. Enhancing additional analysis methods to the framework's infrastructure is possible with little effort. The named researchers always address only a part of what would be available, the framework enhances all their work by supplying all their advances to the state of the art at once. By means of a highly normalized database structure the framework additionally provides the intended efficient interfaces for advanced analysis that facilitate subgrouping, derivating data and generating automated visualisations for flexible and iterable statistics.

We modelled and conducted an exemplary test study utilizing the framework prototype. We asked participants online where certain activities would be located 'best' - and to mark these places with an activity icon. So far, we have omitted, what 'best' actually means in the context of the vague categories of activity like 'Hygiene', 'Working', 'Leisure' etc. (figure 3). We indeed intended that an intuitive image comes to the participants' minds, because, using the work at hand, we wanted to prepare an algorithm that evaluates the degree to which a subjectively stated category eventuates from objective spatial properties. If an algorithm was implemented based on the test survey results, placing the activities could be controlled by rules like the following: 'Hygiene' is easy to identify - it is always segregated, needs no natural light and is situated in the smallest room. 'Cooking' is acceptable to be in a small room and is strongly related with 'Eating', while the latter is also closely associated to 'Leisure'. 'Leisure' and 'Sleeping' are preferably situated inside the largest available rooms etc. However, at the current stage, this algorithm development needs more steps:

Until so far, we have neglected progressing the algorithm's implementation in anticipation of a technical context (described later) that results in more reliable knowledge discovered in databases. The aim of such an algorithm applied in a matching algorithm for “fuzzy search” in a digital floor plan reference repository (see introduction) is to fit ‘best’. That meets users’ expectations from being shown a specific verbal description and a pictogram. One could argue that it is not clear what is measured by surveys by means of the framework and the use cases of a derived algorithm would be very limited. However, we argue that it is possible to increase knowledge quality in comparison to the current prototype, which rather geared towards validation of larger effort that is given. Utilizing the test survey results would enable at least a majority of the survey’s participants to retrieve satisfiable search results from the repository. It is not surprising that the aggregations on local and relational spatial properties of the test study show direct reflections on the cultural codes beyond the floor plan categories and variations. It is a simple task for a human, but a hard one for a computer to meet human expectations towards allocating subjectively coded verbally stated meanings. Simply manually labelling spaces by their current usage for the repository is a priori ineligible - not only because of the huge effort for judging a comprehensive repository and deficient comparability of the applied labelling criteria, but also because another inhabitant could find, e.g., a former sleeping room to be suitable as living room or a former kitchen as bathroom and so forth. Thus we need to automatise such tasks, involve users or participants efficiently and enable an algorithm to make judgements on the suitability of a space/location to be occupied by any meaning that could be represented by an allocated icon.

We see a strong potential in offering surveys conducted by means of the framework together with the above described reference repository as a mixture of a design tool and social network data collection for planners and students. Besides, the search function, public and private communication and coworking in cloud engineering, they could upload their designs, analyse them and hereby progress in acquisition of reference objects to the public repository on the side. On the basis of this higher-quality data set, a self-revising algorithm could be implemented using ‘big data’. Therefore, the next step the envisioned algorithm would be checking its validity using a different data set. Since online services are available to everyone, the test survey examined the input quality of non-specialist participants. In our study, as a side note of our results, we found that laymen seemed to add only little noise to the data and just need a little more time and drag events for reflection. Besides, laymen are not out of focus, because a retrieval tool could also be used for an online real estate market. Nevertheless: one would know more about the participants’ personal data, because it is related to a user account. On that basis one could give participants a sophisticated weighting in statistics according to their background, optimize search results by user geolocation or setting and calculate models of populations in order to make knowledge more representative.

In conclusion, one could accelerate acquisition, increase data quality and make users and researchers profit from each other. This is the synergy effect we intend for the future. More bridges from abstract objective properties of spatial configurations towards understandable categories of cultural meanings will be established by the derivation of matching algorithms and decent case-based reasoning approaches will be within reach.

REFERENCES

Benedikt, M. (1979) 'Take hold of space: isovists and isovist field', In *Environment and Planning B* Volume 6, Austin: University of Texas at Austin, p. 47-65

Dijkstra, E. W. (1959) 'A Note on Two Problems in Connexion with Graphs', In *Numerische Mathematik*, Vol. 1, No. 1, p. 269-271. Available at: < http://www-m3.ma.tum.de/foswiki/pub/MN0506/WebHome/dijkstra.pdf >

Güney, Y. I. (2007) 'Analyzing Visibility Structures In Turkish Domestic Spaces', In *Proceedings of the 6th International Space Syntax Symposium*, Istanbul: ITU Faculty Of Architecture, p. 3801-3812.

Hanson, J. (1998), 'Decoding Homes and Houses', Cambridge University Press.

Peponis, J., Wineman, J., Rashid, M., Kim, H., Bafna, S. (1997), 'On the Description of Shape and Spatial Configuration Inside Buildings: Convex Partitions and Their Local Properties', *Environment and Planning B*, 24, p. 761-781.

Peponis, J., Wineman, J., Bafna, S., Rashid, M., Kim, H. (1998), 'On the Generation of Linear Representations of Spatial Configuration', *Environment and Planning B*, 25, p. 559-576.

Reinhart, C., Petinelli, G. (2006) *Advanced Daylight Simulations Using ECOTECT // RADIANCE // DAYSIM*, Ottawa, Ontario: National Research Council Canada

Schneider, S., Bielik M., Donath, D., Triemer, M., Tschetwertak, J., Hollberg, A. (2014) 'Rapid Data Collection using Automated Model Generation and Performance Evaluation - A workflow for morphological studies of apartment floor plans', In *Proceedings of the 32nd Conference on Education and research in Computer Aided Architecture (eCAADe)*, Newcastle upon Tyne, UK: Northumbria University, p. 303-311.

Seo, K. W. (2003) 'Topological Paths in Housing Evolution', In *Proceedings of the 4th International Space Syntax Symposium*, London: University College London, p. 8001-8014.

Triemer, M. (2014) *Entwurf und prototypisches Implementieren einer Datenbank zur performancebasierten Suche nach eingeschossigen Wohnungsgrundrissen (unpublished thesis)*, Weimar: Bauhaus-Universität Weimar/Informatik in der Architektur

Turner, A. (2001) 'Depthmap: A program to perform visibility graph analysis'. In: Peponis, J., Wineman, J. and Bafna, S. (eds.) *Proceedings of the 3rd International Space Syntax Symposium*, Atlanta, U.S.A: Georgia Institute of Technology, p. 31.1-31.9.

Kim, M. H., Lee, Y. L. 'The Behavioral Patterns on Residential Spaces among Middle-size Apartment Residents - with special reference to 30s pyong apartment with 3 bed rooms', *Journal of the Korean Housing Association*, Volume 16, Number 6, p. 21-27., Available at: < http://www.koreascience.or.kr/article/ArticleFullRecord.jsp?cn=JAKO200508824075719 >

Monteiro, C. (1997), 'Activity Analysis in Houses of Recife, Brazil', *Proceedings of the First Space Syntax Symposium,* London: University College London, Available at: < http://www.spacesyntax.net/symposia-archive/SSS1/SpSx%201st%20Symposium%2097%20-2003%20pdf/1st%20Symposium%20Vol%20II%20pdf/2%20-%20Domestic%20space/20%20Monteiro%20300.pdf >

APPENDIX

The participants of the survey were asked for:

- their year of birth - range of age: 18-78 years, average: 32(+/-10) years,
- Gender:
- 'male' ~44%;
- 'female' ~54%;
- 'I don't feel represented by these categories' ~3%,
- Country they grew up in (question: 'What is the country you spent most of the time in between your 1st und your 16th year of age?' ~81% from European countries),
- highest educational degree:
  1. 'school of general education' ~11%;
  2. 'completed job training' ~4% ;
  3. 'completed job training with additional qualifications' ~1%;
  4. 'University/College - study less than 4 years standard period' ~19%;
  5. 'University/College - study more than 4 years standard period' 50%;
  6. 'Doctor or comparable' ~11%;
  7. 'Professor or comparable' ~6%;
  8. 'not applicable' ~1%,
- profession:
  1. 'architectural design' 50%;
  2. 'interior design' ~1%;
  3. 'urban design' ~14%;
  4. 'design student' ~6%;
  5. 'no design related profession' ~28%,
- and their experience (question: 'How would you judge your experience in designing apartment/apartment houses/units?', range: 1-5, level 3 and above ~55%).

The original task description participants got displayed was:

'We will show you floor plans of apartments. Mark the distinct location (not just the room), where - in your opinion - typical activities (cooking, sleeping etc.) are located best.

The activities are represented by the icons from the table.

The icons do NOT represent the dimensions of a physical object (such as sofa, table), but the position of the inhabitant's head while carrying out the activity.

Assume, that the flat is inhabited by only one person (age: between 20-40 years).

Don't take care about technical questions like pipes and wires.

3 floor plans will be displayed on the following pages.'

The question after the survey was:

'Please describe, how you came to your decision concerning the placements of the activity icons. What was on your mind? Languages: English, German'

Details on the floor plan categories:

1. 'enforced overlap of activities' (four spaces; 1-3)

   Floor plans with a smaller number of rooms than available activity icons, forcing one to combine more than one activity per room. The position of the smallest room and suppliance of an alcove was varied to find whether room proportion and geometry impacts the allocating behaviour.

2. 'closed structured' (five spaces, 4-6)

   Floor plans with closed spaces supplying one space more than category '1' and one less than the number of available activities. The position of the entrance was varied to find whether a specific activity is preferred to be seen from the entrance or not. The area of one room was varied to find whether a small room with no windows is always predicting a 'Hygiene' space.

3. 'open structured' (one space, 7-9)

   Floor plans with one huge room for all activities and a segregated space for a private activity. This category was taken into account to guarantee a predominant impact of the local spatial properties over individual room properties.

Summary and interpretation of participants' comments

Participants were widely consent in their following statements among each other:

- a spatial separation of the 'hygiene' space from the rest of the apartment to be a must-have for the -purpose of intimacy and for this effect compromising it to be the smallest room with fewer demands on quality aspects such as view to the exterior or daylight
- high segregation/ isolation between entrance and 'sleeping' also for the purpose of intimacy
- immediate proximity between 'eating' and 'cooking' for practical reasons, often paired with 'leisure'
- 'leisure', 'eating', and 'working' needing more natural light and view to exterior than other activities
- 'cooking' to be close to the entrance for bringing in shoppings and getting rid of garbage easily
- long distance between 'sleeping' and 'cooking' to avoid odour nuisance
- 'sleeping' needing more space than 'cooking', if separated
- three participants named cardinal orientation as criterion

Some participants gave hints that no other participant disagreed with:

no activity directly in the entrance zone

- 'leisure' is closest activity to the entrance (least segregated)
- 'eating' bridges 'cooking' to 'leisure'
- 'leisure' is seen as something that could be combined with 'sleeping'
- noise disturbance should be considered
- cultural aspects might lead to different results
- 'working' should be well lit

For some statements there was a contradiction between different demands

- 'hygiene' close to 'sleeping' but also 'hygiene' should be accessible from the entrance, yet 'sleeping' should be most segregated
- there are several preferences for 'working': some want to avoid to have it too close to 'sleeping' because it conflicts with the idea of a relaxation zone, some others see an advantage in double using the 'sleeping' space because it needs a comparable silence and privacy and one never sleeps and works at the same time, a separate 'working' space is a nice-to-have.

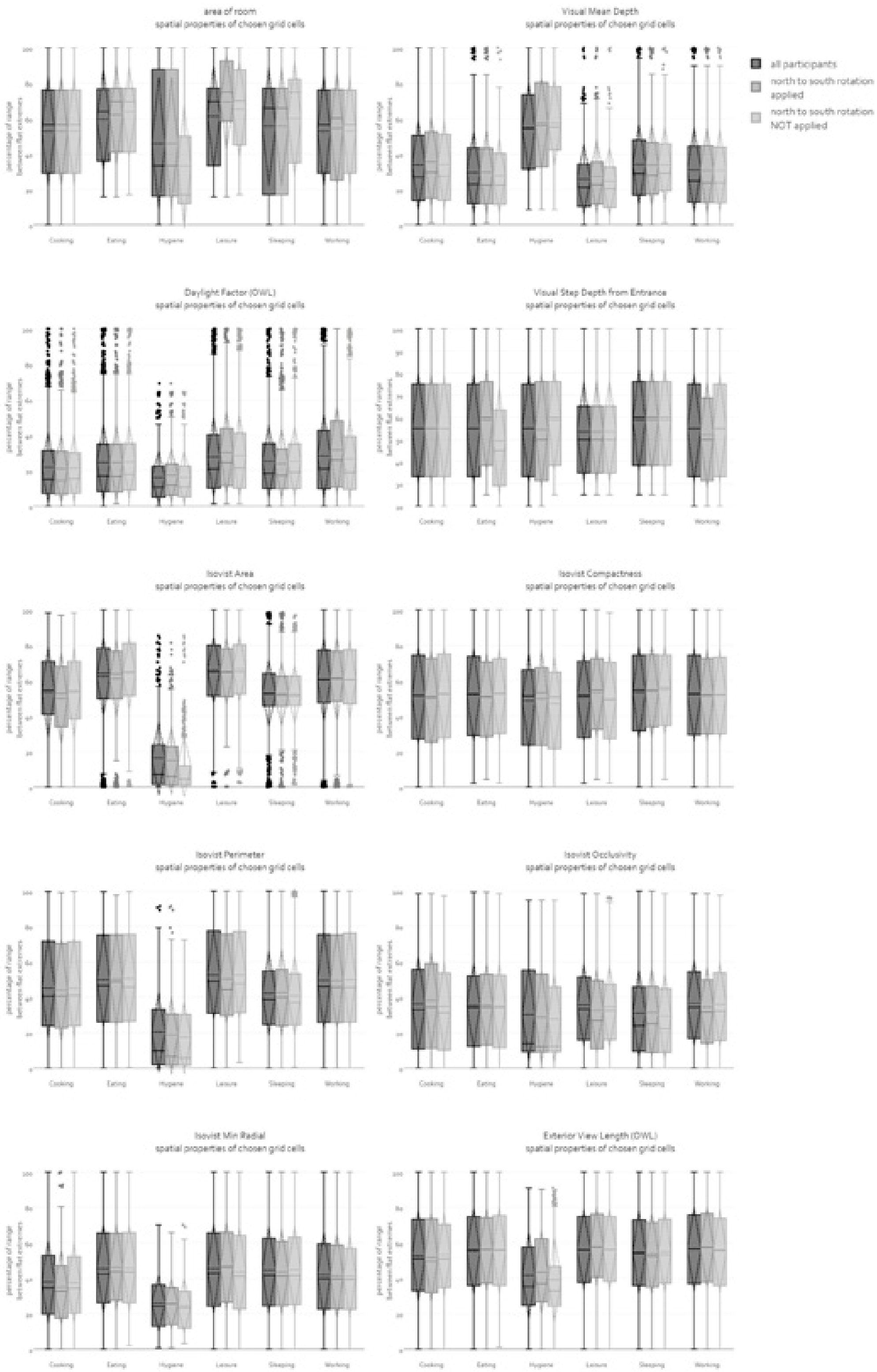

Figure 9 - local spatial properties of chosen grid cells - for all participants and comparison between applied and not applied north to south rotation