Crowdsourced Clustering of Computer Generated Floor Plans

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Abstract. This paper identifies the main criteria used by architecture specialists in the task of clustering alternative floor plan designs. It shows how collective actions of respondents lead to their clustering by carrying out an online exercise. The designs were randomly pre-generated by a hybrid evolutionary algorithm and a questionnaire was posed in the end for the respondents to indicate which similarity criteria they have used. A network of designs was then obtained and it was partitioned into clusters using a modularity optimization algorithm. The results show that the main criterion used was the internal arrangement of spaces, followed by overall shape and by external openings orientation. This work allows the future development of novel algorithms for automatic classification, clustering, and database retrieval of architectural floor plans.

Keywords: Architecture · Network theory · Crowdsourcing · Clustering · Floor plan design · Online survey

1 Introduction

With the advent of computer-aided design, the computer has become more than a mere drawing tool or structural properties calculator. It also takes part in assisting building practitioners during the creative process, by allowing the exploration of potential solutions in the daily architectural practice. In Sect. 2 a brief review of how the field is engaging with these new tools is presented, namely how algorithms are used to generate designs, to classify, and may be used to retrieve architectural documents from databases. The development of such algorithms requires a profound knowledge of the way human practitioners of architecture perceive, understand, group and classify those same documents. The aim of this

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study is to understand what are the collective actions of architecture practitioners when grouping floor plan designs. To this effect an online survey was conducted in which participants were asked to select similar floor plan designs and to answer a questionnaire indicating the similarity criteria used. The resulting answers were mapped to a network of floor plan designs co-selection and were clustered by a modularity optimization algorithm (Sect. 3). The findings of this study (Sect. 4) can help in the development of query mechanisms for database retrieval of floor plans and the implementation of clustering mechanisms to aggregate results from generative design methods. Besides these applications, the understanding of how architecture practitioners solve this complex problem may help to develop specific programs for the teaching of architecture. The limitation and implications of this work are broad and range from the pedagogic level to the development of new algorithms and databases (Sect. 5).

2 Related Work

One of the early architectural tasks in the building design process is space planning. Architects seek to accommodate all requirements and preferences into architectural floor plans during the synthesis phase, which are determined during the analytical phase. This is a time-consuming trial-and-error process with its associated costs. The resulting design is much dependent on the past experience of the architect and often based on already built examples. As the rooms' configuration is essentially a combinatorial problem, medium to large design programs—list of functional spaces, topological relations, and geometric constraints—can easily reach a number of alternative design solutions that are impossible to be drafted by humans in the traditional way. For this reason, since 1960 s researchers have been developing computer-based approaches to help practitioners [1,2]. These approaches have tried to resolve specific design problems such as area assignment [3], partitioning of a boundary [4–6], allocation of rooms [6–10], design adaptation [11], or the hierarchical construction of different elements [12]. If the earlier approaches looked to enumerate all possible configurations, which led researchers to face the cumbersome problem of the exponential growth of possible solutions for design programs with more than 8 spaces, recent studies tried to find only the most promising solutions. To achieve this, evolutionary computation techniques were used, as these have shown capabilities to deal with ill-defined and complex problems, and demonstrated to produce surprisingly novel solutions applied to the generation of architectural floor plans [13].

Online surveys have been used in several applications and are a method of data collection that conveys several advantages, namely they provide access to many individuals who share specific interests and professions that would otherwise be difficult to contact. Surveys also save time as they do automated collection of responses and allow researchers to work on other tasks while data is being collected [14]. When properly developed and implemented, a survey portrays the characteristics of large groups of respondents on a specific topic and allows assessing representativeness [15]. Several types of surveys are available; e.g. questionnaire and interview formats, phone survey, and online surveys, which can be coupled with inference engines that act and direct the survey according to respondents' answers [16,17].

The use of surveys in architectural environments has been conducted in many aspects of the discipline. They have been used in the establishing ground truths in perceptual understanding of floor plans for the characterization of shapes, lines and texture [18,19]. Feedback to architects is being given by surveys of architecture virtual immersive experiments that aim to understand physiological signals of emotions, namely fear, in space perception [20,21]. Several studies have been proposed that include the participation of the crowd and are bottom-up learning processes, e.g. peer assessment [22] where students mark each other' work. In this study the process of grouping floor plans is investigated to understand the criteria used by the students and other practitioners during the grouping process.

3 Methods and Materials

3.1 The Online Survey

An online survey was setup as an exercise to collect information on how the respondents perform the clustering task. There are many online tools for conducting surveys [14,15], but none can handle the special problem posed by using architectural documents. Therefore, it was decided to develop a web application for the experiment (Fig. 1). To understand the perception and criteria of the target population, a post experiment questionnaire was presented to participants. Individuals whose daily activities are related to building design were chosen as the target group; i.e. architects, architecture students, civil engineers, and urban planners. As the target group is well delimited, the selection of participants was conducted through University communities of architecture students and former students, and also through the professional affiliation contact lists. This ensured that the majority of the participants in this study were related to the subject or if their present professional occupation is not related to architecture, at least they received training in architecture.

From a total of 72 generated floor plans, twelve were randomly selected and displayed in a web interface. The user was asked to drag-and-drop to a specific area in the screen the floor plans that he considered similar. Each respondent repeated this iteration ten times. The 72 floor plans were generated using the Evolutionary Program for the Space Allocation Problem (EPSAP algorithm) [7–9]. This algorithm is capable of producing alternative floor plans according to the user's preferences and requirements set as the building functional program. The solutions generated were for a single-family house with three bedrooms, one hall, one kitchen, a living room, one corridor and two bathrooms. One bathroom and all bedrooms are connected to the corridor. The remaining spaces are connected to the hall. The kitchen presents an internal door connecting it to the living room. One of the bathrooms serves the public areas of the house, while the

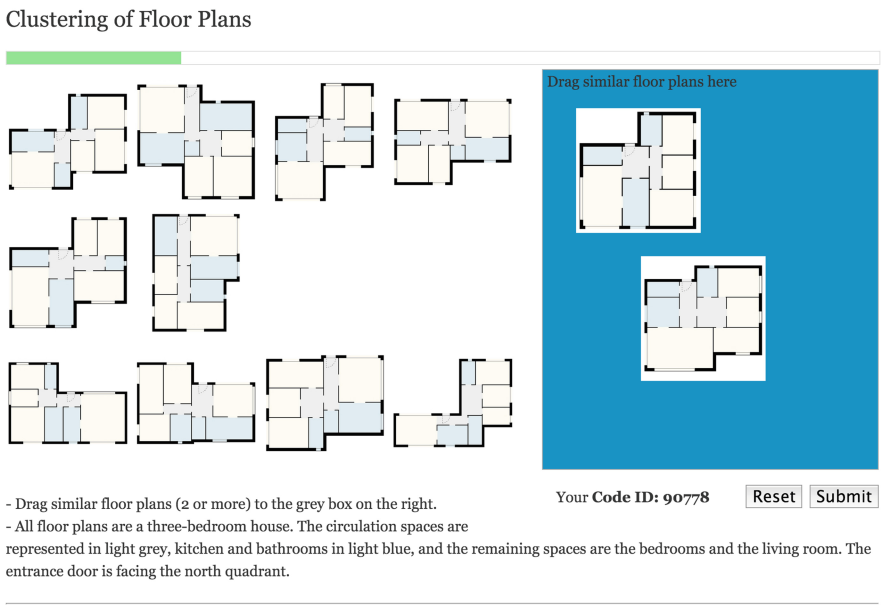

Fig. 1. Users drag-and-drop floor plans into the shaded area according to similarity

other connects to the corridor of the private area of the house. All inner rooms have doors of 90 cm width, the exception being the living room doors that are 140 cm. Except for the circulation areas and one of the bathrooms; all areas have at least one window. The hall has an exterior door facing north. No other restrictions were imposed. At the end of the online survey, a final questionnaire was presented with a list of possible criteria and the user could chose which he used or to provide written alternatives. After submission the exercise ended and the user was redirected to the home page.

3.2 Network Science Analysis of the Collected Data

A normalized matrix depicting the fraction to times each pair of floor plans was co-selected is constructed. This matrix is understood as an adjacency matrix where the entries represent the weights of the connections between two designs. The results present some background uncertainty and it is necessary to define a minimum threshold for the entries of the matrix. The threshold value was tested to identify the structure of the selection process, which represented the floor plan's network. This network—undirected and weighted—is partitioned with the edge betweenness community detection algorithm [23]. This is a divisive hierarchical mechanism that aims to find communities by maximizing the value of modularity—networks with high modularity have dense intra cluster connections but sparse connections between vertices of different clusters. The algorithm for creating the dendrogram proceeds in the following manner [23]:

1. Calculate the edge betweenness in the network.
2. Remove the edge with highest value of betweenness.
3. Recalculate betweenness for all edges affected by the removal.
4. Repeat from step 2 until all nodes are isolated (no edges remain).

The betweenness centrality of an edge is the sum of the fraction of all-pairs shortest paths that pass through that edge [24–26]. The graph and the resulting partition are characterized according to diverse properties—average path length, density, and clustering coefficient.

4 Results

A total of 609 invitations to participate in the online survey were submitted. The survey was available for the respondents during two weeks. Of those invitations, 202 persons answered the survey by reading the informed consent, filling the optional demographic information form and initiated the experiment. Of those 202 only 110 carried out the 10 iterations asked and filled the final criteria questionnaire. In total, the respondents performed 1257 iterations. Of the participants that registered, 92 did not conclude the exercise. The average number of iterations made by those 92 persons was 1,7. The pool of participants inhabits mainly in Portugal and the ages range between 18 and 50 years old.

By varying the threshold of the fraction of co-selections of floor plan designs, it is possible to verify that the initial dense network presents low modularity, high density of edges, and small average path length (Fig. 2). It also presents a high clustering coefficient, which is indicative of many triangles in the network. The

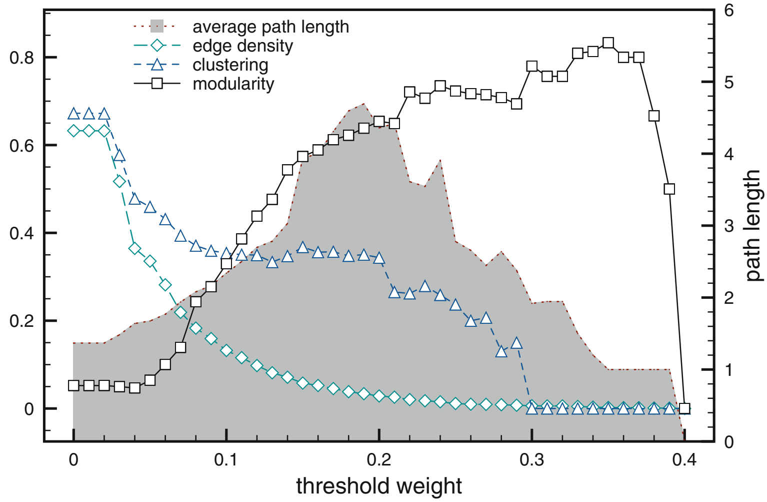

Fig. 2. Floor Plan Design Network properties: clustering, density, modularity (left axis) and average path length (right axis).

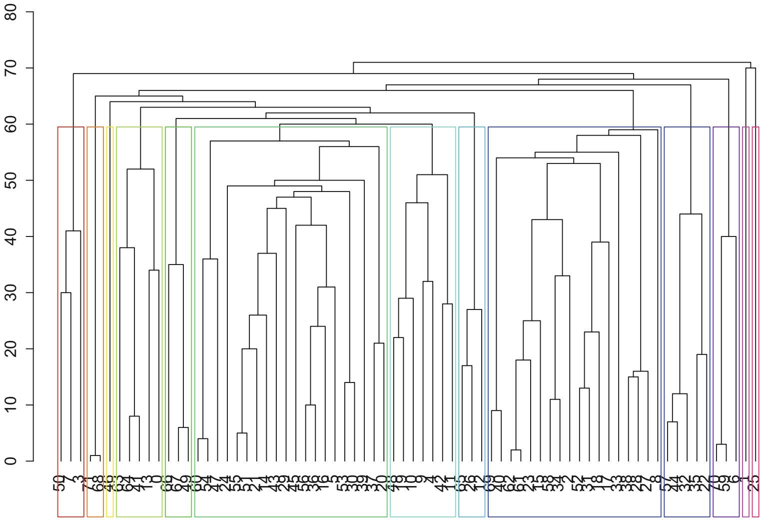

Fig. 3. Dendrogram of the clustering identifying the resulting clusters.

increase of the threshold leads to higher average path length, lower edge density, and lower clustering coefficient. Modularity starts rising until a threshold of 0,36. The average path length peaks around a threshold of 0,19 and a value of 4,6 and after starts decreasing again as a result of the fragmentation of the resulting network were many isolated nodes emerge.

Due to this fragmentation, a threshold of 12 % was chosen. This still ensured a modularity value of 0,44 and an average path length of 2,7. The clustering resulted in 13 clusters (Fig. 3). It is clear from the dendrogram that this clustering present some isolated nodes, namely $\{1, 25, 46\}$. The distribution of the floor plan design clusters was $\{20, 18, 7, 5, 5, 3, 3, 3, 3, 2, 1, 1, 1\}$.

The clusters present good internal consistency, meaning that upon inspection they are coherent with the criteria reported by the users. This can be seen in the three examples of the clusters obtained from the clustering process in Figs. 4, 5, and 6.

The survey co-criteria analysis indicates that two criteria are often selected together by participants, *by interior spaces* and *by circulation spaces* (Table 1). On a second level, the participants considered criteria related to the overall *shape*

Fig. 4. Cluster of plans $\{0, 13, 41, 63, 64\}$

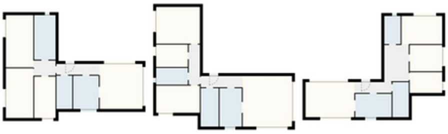

Fig. 5. Cluster of plans $\{3, 7, 50\}$

Fig. 6. Cluster of plans $\{4, 9, 10, 11, 19, 42, 48\}$

Table 1. Criteria co-selection. Diagonal entries represent frequency of each criterion. Intersections of the lower triangle indicate frequency of co-selection of two criteria.

75	by interior spaces					
22	41	by shape general				
20	18	36	by shape mirrored			
17	18	18	29	by shape rotated		
47	19	20	12	63	circulation spaces	
13	7	7	3	12	18	exterior openings

(either considering cases where mirroring or rotations occurred) and in a third tier respondents considered the existence of *external openings*. This clearly shows that users favor the interior space organization as the most important feature in defining similarity of floor plans.

5 Conclusion

The results, as shown in Table 1, indicate that architecture practitioners give higher importance to the interior configurations of spaces than the overall building shape. This information is important for future development of ICT-mediated strategies for architecture education and professional practitioners. They will also impact other applications such as floor plan design database retrieval—by identifying the encoding features used by human practitioners that can then be implemented in the encoding of database records—and aggregation of similar solutions that result from generative design methods—releasing humans from the tedious and repetitive task of grouping similar floor plans, and allowing for concise typological presentation of floor plans in automated ways.

The execution of online surveys is not free of problems. Sampling issues might be present, as the respondents are not monitored and some misbehavior can happen; e.g. double answering [14]. The minimization of these problems was achieved by assigning a unique five-digit code to each participant that matches the answers in the dataset with the IP address. The problem "lurkers" was minimized by contacting each participant directly, that is people who do not participate but have access to the survey [14].

The response rate was around 30 %. Although many online surveys have low response rates, they try to increase by some incentive mechanisms, e.g. financial incentives, prizes, coupons, or books. However, in this case that was not an issue. No incentive mechanism was implemented in this experiment for the completion of the survey. The personal contact of the researcher with each participant made the participation in the survey a matter of personal and professional respect. However, the effective completion rate was small, as 92 participants did not complete the survey (18 %). These limitations are not exclusive to this kind of online survey technique [14,15].

These results, namely the criteria reported by the respondents, can be incorporated in machine learning algorithms to perform clustering tasks in ways that mimic experts' actions. Also, the obtained clustering results will be used as a ground truth or benchmark for new clustering algorithms that deal with perceptual clustering of floor plan designs.

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Preface

This year's, CDVE 2015 conference returned to its Mediterranean home – Mallorca, Spain. The 12th International conference on Cooperative Design, Visualization and Engineering, CDVE 2015, was held during September 20–23, 2015 by the Mediterranean Sea at Alcudia, Mallorca.

The papers in this volume reflect the fact that we are ready and confident to answer the challenge from a completely new computing landscape. The popularity of cloud computing, social media, and big data has been the driving force behind research and development in our CDVE community.

A number of papers address the topic of big data and its relation to cooperative work. They focus on information modeling, intensive task management, and how to use cloud technology to foster cooperation, etc.

Dealing with social network issues is the topic of another group of papers in this volume. They cover creating programming languages to automate cooperative processes, social network information visualization, and the ranking of cooperative research teams by analyzing social network data.

Using mobile devices for cooperation seems to be another trend in the papers. The application areas are especially wide, which show the great potential of mobile devices in supporting cooperative applications. There are papers concentrated on mobile e-learning, online interaction for museums, mobile e-commerce, and even the cooperative monitoring of the delivery of fresh products. Each application area may have its own specific issues to address in order to optimize the efficiency, usability, and effectiveness of the cooperation.

Crowd sourcing is again one of the major topics among the papers. There are interesting papers about applying crowd sourcing to architecture design, making client decisions in e-commerce, etc. In fact we should continue to explore this new way of cooperation and expect more achievements in this direction.

In the field of cooperative engineering, there are many research results reported, such as in the collaboration for product design, operation, and process control, enabling networked enterprises to realize interoperability, etc.

With respect to the theoretical analysis and modeling of group behavior, there are reports based on the analysis of real case data, using Baysian networks to model team behavior. The study shows that using Baysian networks in analyzing and modeling team performance from a psychological perspective is feasible. We believe that this achievement will contribute to enriching the theoretical study of cooperative team work.

To see the great progress made in the fields of cooperative design, visualization, and engineering has been a great pleasure. I would like to thank all of our authors for submitting their papers and presenting their hard work. They are at the frontier of technological advancement for the benefit of society.

I would like to thank all of our Program Committee members, volunteer reviewers, and Organization Committee members for their continuous support of the conference. My special thanks go to my colleague, the Organization Committee Chair, Dr. Sebastián Galmés Obrador, and my university – the University of the Balearic Islands – for their constant support and encouragement of this conference. The success of this year's conference would not have been possible without their generous support.

September 2015 Yuhua Luo

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