Title
An investigation into the cognitive, metacognitive and spatial markers of creativity and efficiency in architectural design

Short title
Creativity and efficiency in design

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Abstract

During design, architects are thought to navigate their way through a hierarchy of perceptual and cognitive actions, occasionally visiting higher order metacognition as to regulate their cognition and self-assess their strategies. The precise role of metacognition in design needs yet to be explained and measured. This paper contributes to the domain of design studies by introducing methods that enable understanding the impact of creativity on cognitive and metacognitive activity, and the regulation of constraint relaxation in architectural design. Our hypothesis is that there is a pattern that characterises the association between episodes of metacognition and the structure of problem spaces and their sub-ordinate tasks. The structure of tasks could be externalised from semantic data. In a design experiment, a group of 12 architects were required to think aloud whilst designing an architectural office. Their drawing activity was video recorded. Both design solutions and verbal comments were analysed and modelled. A separate group of expert architects assigned creativity and efficiency scores to design solutions. The solutions were evaluated spatially. Linkography and macroscopic analysis were used to discern distinct patterns in cognitive and metacognition activity. Entropy models of linkographs were computed to assess how changes on entropy correspond to metacognition. Knowledge graphs were further introduced to assess the structure of knowledge applied in the form of design constraints. We assessed how creativity and efficiency correlate to experiment variables, cognitive activity, metacognitive activity, functional distribution of spaces in design solutions, and the type of design constraints applied. It was concluded that creativity positively correlates with number of original ideas, perceptual cognitive design moves, and number of structural, material-specification, and technical design constraints. Efficiency negatively correlates with design moves that entail looking at previous depictions, number of design constraints that define the orientation of the layout, and attend to structural, and aesthetical criteria. The findings provide insights on the relationship between creativity, cognition, metacognition, and the structure of knowledge reasoning in design.

Keywords: metacognition, creativity, efficiency, knowledge graph, linkography.

Introduction

At essence, architectural design is a creative activity. It is creative in the sense that design is a search for satisficing solutions that minimize conflicts between different design requirements (Simon, 1957). In defining creativity, Boden (1990) differentiated between psychological creativity (P-creativity), and historical creativity (H-creativity). P-creativity is related to the designer's frame of reference during the process of design. Yet, what is new to a designer may not be necessarily genuinely new to the design community. From that perspective, H-creativity depends on the frame of reference of a professional community through evaluating the historical discourse in the design's domain of knowledge. The definition of H-creativity could be quantitatively defined through comparing generated spatial layouts to a large set of architectural styles (Hanna, 2007), although such definition remains to be reductionist, as it does not attend to other qualities such as building material, the vertical dimension, the style of construction, and the finer grained description of designed layouts. It can also be argued that architects would have accumulated knowledge of architectural styles throughout their education and architectural practice, hence they posses tacit knowledge of the history of design progress. Designers' expert knowledge can be used to assess how creative designs are compared to past designs. In linking a designer's frame of reference with the community's frame of reference, creativity attains social value. So there is a margin of subjectivity in designers' expert judgment that can be reduced through attaining a level of agreement.

When evaluating creativity, there are non-trivial challenges in defining the frame of reference, particularly in what concerns the quality or value that is being assessed; is it purely aesthetical or does it have to do with function? In architecture, the manner in which building functions are programmed could be considered as a metric of creativity. Yet, efficiency in the spatial distribution of functions is not necessarily correspondent to higher levels of creativity. It is probably difficult to define a set of benchmarks to evaluate creativity and efficiency in designs, considering that there is a large universe of design solutions for every architectural design problem. Creative designs could belong to the larger universe of probable designs, but efficient designs would belong to a smaller cluster of possible designs where the performance of building function is highly optimized. A design solution can be considered as an emergent product of a set of local actions that respond to problems both locally and globally. P-creativity (Boden, 1990) is defined as the number of original ideas in the design process. H-creativity could be evaluated by an external committee of expert designers and is dependent on their expertise, idiosyncrasies and design education.

The main research question to be examined in this paper will be, is architectural design essentially meta-problem solving of ill-structured problems by the processes of finding succession of well-structure problems to solve?

The overall question can be unpacked into various sub-questions from cognitive and architectural design perspectives:

How is information processed from the environment (the design problem and design solution), through to perception, cognition, and metacognition, in order to make judgments about drawing actions? Is there a pattern that regulates this process? Does this pattern differ for designs that are scored as highly creative compared to designs that are scored as least creative?

Metacognition involves knowledge about cognition or the cognition of cognition (Flavell, 1976). More specifically, metacognition refers to a "higher-order executive capacity to monitor lower-order representations and to assess the fidelity and strength of these signals, in order to update a model of the probability that one is making correct judgments" (Legrand et al, 2020; Yeung and Summerfield, 2012). According to Shea and Frith (2019), metacognition is "a representation or evaluation of another cognitive state or process". Metacognitive parameters include "confidence (certainty/uncertainty), fluency, familiarity, and precision". Metacognition enables the monitoring of our thoughts, memories and perceptual information in order to inform learning, development and communication (Fleming et al., 2012; Heyes et al., 2020; Shea et al., 2014). Meta-problem solving may involve finding successive well-structured problems in order to solve an overall ill-structured problem. In architectural design, metacognition is presumably the higher order regulation of relevant knowledge/memories that are recalled and instrumentalised where needed to support decision-making.

Metacognition is thought to involve (Jacobs and Paris, 1987);

- Declarative knowledge; that is the ability to evaluate knowledge.

- Procedural knowledge, which involves both heuristics and strategies. The more certain one is about representations and goals the more easy it is to construct strategies.

- Conditional knowledge; that is the ability to determine why and when to use declarative and procedural knowledge.

The nature of the problem in architectural design is thought to be more of a graph of interlinked sub-problems than it is of a secession of well-defined sub-problems that branch into hierarchies. The role of a designer is to assign preferences for solving sub-problems and this process defines the solution space. Variations on the solution space are minimised by the application of constraints over the course of design process.

In general terms, metacognition involves planning, monitoring and evaluation of tasks. This research attempts a description of metacognitive processes in architectural design and its role in creativity. It is thought that metacognition in architectural design involves monitoring the constraints' criteria by which architects reason about. We attempt to model this process through the coding and mapping of knowledge-based constraints over the course of design activity.

Furthermore, we investigated the nature of design in architecture and how architects structure and prioritise information about constraints, actions and strategies. Building on Simon's description of problem spaces (1977), we made an attempt to define the problem space that characterises architectural design as a dual search in the domain of the design problem and the domain of design solutions. We started with the assumption that there is a discursive language that describes every knowledge domain relevant to architecture, and we questioned whether there is a syntax of design that is a theory of metacognition that brings together different domains of knowledge relevant to design decision-making. The assumption is that a constraint relaxation process is applied by designers to filter out designs from the universe of probable solutions, to the universe of possible solutions, to eventually define a universe of satisficing solutions. Of interest, is whether there is a pattern that characterizes how constraints are applied over the course of the design process, and what level of metacognitive activity is involved in regulating decision-making during this process.

In the following sections, a list of aims and assumptions shall be identified. The contribution of this research to cognitive science and design research shall be outlined. The methods used in analyzing design solutions and design process shall be explained, including; creativity and efficiency scoring, spatial statistics, protocol analysis studies (linkography), and semantic coding of cognition, metacognition, design constraints, problem spaces, and knowledge graphs. These methods shall be applied to identify patterns in metacognition and knowledge-based design constraints. The discussion section will present correlations between creativity and efficiency, and experiment variables, cognition, metacognition, functional allocations in design solutions, and design constraints.

Aims

The main aim of the research is to investigate whether; creativity and efficiency scores – as assessed by expert knowledge- would have an impact on; 1. The spatial distribution of spaces in the proposed design solutions, 2. The cognitive and metacognitive activity in design and the corresponding structure of information and structure of knowledge utilised in design reasoning. These aims can be further tested and verified through the following list of hypotheses;

- Spatial distribution of partitioned spaces in the design solutions: Creativity and efficiency have an impact on the spatial distribution of spaces in the design solutions and on the ratio of space allocated for circulation to layout area.
- Highly creative designs compared to least creative designs: A design process that leads to a creative design displays a structured pattern of coupling between cognition, metacognition, design knowledge applied in the form of constraints, and information flows.
- Experiment variable: Creativity positively correlates with number of words in the verbalised transcript and task period. Efficiency negatively correlates with number of words in the verbalised transcript and task period. Both creativity and efficiency positively correlate with experience.
- Cognitive coding of design: Creativity correlates with aesthetical and perceptual cognitive segments[1]. Efficiency correlates with the number of functional, goal driven, and knowledge retrieval cognitive segments.
- Metacognitive coding of design: Efficiency positively correlates with the number of metacognitive segments. Creativity is less influenced by metacognition.
- Spatial distribution of functions: It is likely that both creativity and efficiency positively correlate with the number of spaces per layout. Efficiency negatively correlates with the amount of space wasted on circulation.
- Design constraints: Efficiency correlates with the number of constraints applied to define the spatial features and configurations of the layout, the functional constraints that define functional relationships between different zones, and other well-defined constraints that further define the functional performance of the layout. Creativity is less influenced by these constraints, and more likely to be influenced by other ill-defined constraints such as aesthetics.

Significance

The paper contributes to knowledge in design methodology research by introducing and developing methods for modelling the relationship between metacognition, and knowledge-based reasoning in architectural design. Knowledge-based design constraints are coded as knowledge graphs for each block of design activity that defines a coherent set of operations relating to one problem space. This research builds on previous experiments (Al-Sayed et al., 2008, 2010), by attempting to discern distinct spatial features that characterize creativity and efficiency in design solutions. Creativity and efficiency are evaluated by a committee of expert architects. The design solutions are evaluated spatially to look for any correspondences between the scores assigned and the distribution of room size in the designed layouts. The semantic data of the design process was coded and modelled into linkographs, distinguishing different types of cognitive (Suwa et al., 1998; Goldschmidt, 1992) and metacognitive activity and knowledge-based reasoning stated within design moves. We compare cognitive and metacognitive activity and knowledge-based reasoning in the design processes that were assessed to be highly creative and least creative. The assumption is that the association between cognition, metacognition and knowledge-based reasoning is distinct in these two design processes. The efficiency of design process could be inferred from task period, word count, number of design moves, and productivity in linkographs (Goldschmidt,1992) -to be later defined in the methods section.
The study introduces advanced metrics in order to further our understanding of the structure of cognition, metacognition, and the structure of information processing and knowledge-based reasoning during the design process. Entropy modelling of design protocols was previously used to measure linkographs (Kan et al, 2007, El-Khouly and Penn, 2012). The paper demonstrates how entropy modelling of linkographs could help understand how

[1] Segments shall be later defined as design moves (Goldschmidt, 1992).

metacognition corresponds to changes on the structure of information during design. Knowledge graphs were introduced in order to understand the structure of design reasoning.

Method

In order to investigate whether creativity can leave traceable patterns or markers on the design outcomes and on the process of design, this paper will use a range of methods to; quantify and analyse design solutions, and represent and analyse cognitive activity during design processes (macroscopic analysis of verbal protocols and linkographs). A design task will be presented to a group of architects. The architects will be required to solve a well-defined design problem. A separate committee of expert designers will assess the creativity of design solutions. The tessellation in the spatial grid representing the design outcomes will be analysed (figure 1). Cognitive analysis will be applied to the design processes to find distinct patterns in creative design.

A description of the design experiment

Twelve design cases -previously studied in (Al_Sayed et al., 2008, 2010; Al_Sayed and Penn, 2020)- are reintroduced in this paper. Architects were asked to think aloud. The intuitive design task was limited to 15 minutes. A video camera recorded the drawing process and the architect's verbal expressions whilst describing his/her thoughts during the design process. The verbal comments were later transcribed in order to use them in protocol analysis. The protocol analysis considered semantic expressions without including physical acts. The design brief was limited to a set of functional spaces that form the basic requirements for an architect's office. Considering that architectural design problems are predominantly ill-defined, in that they are very likely to be a product of ill-defined and conflicting constraints, the scope was to limit the variation on how the brief could be interpreted. The program that sets the narratives for the relationships between the functions listed in the brief is likely to have an impact on the spatial attributes of the design outcome. In order to simplify the design task, architects were required to allocate the functions listed in the brief into an empty 2D layout (see Table 1). The layout was a hypothetical rectangular floor plan in a skyscraper with two access points from two cores (Shpuza, 2006). There are challenging problems with regards to the layout settings and its massive size, the number and pattern of columns, and the two cores that link it with the external environment.
We have attempted to control the experiment settings by using a 2D architectural layout rather than a 3D architectural layout, to limit the task to partitioning empty spaces and allocating functions to the spaces available. It is likely that a 3D task would have introduced more complexity into the solution space, making it difficult to compare design solutions spatially. Yet, a 3D design task would have led to creative variations on the solution space, making it easier to assign creativity scores to design solutions. This would be attempted in future research.

Table 1 Design task including a brief for an architect's office, and an existing layout, cited in (Shpuza, 2006).

Fig. 1 Grid representation of layout 10. A grid unit equals 1.4375m x 1.4375m.

Modelling cognitive activity

The protocol analysis used to model design was constructed from macroscopic analysis and linkographs. The macroscopic analysis of verbal protocols is a content-based method that was proposed by Suwa et al. (1998) to analyse design activity. In Suwa et al., the design process is segmented using protocol analysis of physical actions and semantic expressions.

For the purpose of our research, physical actions (e.g. hand gestures) were ignored, but semantic expressions were recorded during the design process. In Suwa et al.'s model of categorizations (Appendix 1), the semantic expressions were segmented into design actions. Their description separates physical, perceptual, functional, and conceptual cognitive actions, and they provide detailed subcategories. Suwa et al's model of categorization was applied only partially in this paper. Only (L- action) types were considered, each L-action represents the state when designers look at previous depictions and refer to them semantically. Perceptual, functional and conceptual actions will be fully considered as long as the subjects verbally express them. Perceptual actions (P-action) will be recorded whenever the architect refers to visual features or spatial relations. Functional actions (F-action) apply when an architect considers interactions between artifacts and people/nature, and account for the psychological reactions of people. Conceptual actions may occur during the process of knowledge retrieval (K-action), or whenever an architect makes preferential and aesthetical evaluations (E-action), or when an architect defines a goal (G-action). The segmentation model decodes every segment in relation to a corresponding reference. For instance, talking about cores defines one segment, whilst talking about design teams defines another segment. Further detailed segmentations refer to different cognitive actions as defined in (Appendix 1).

In a linkograph model (Goldschmidt, 1992), cognitive activity is recorded, segmented and rebuilt into a relational structure that links design moves by matching their semantic meaning. The linkograph's protocol is segmented into a set of 'design moves' with directed links. A 'design move' is explained as "an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed" (1992). Links among moves are determined arbitrarily by the observer, and are notated in a network. The design process is interpreted as a pattern of linked moves that comprise the graphic network of the linkograph. Goldschmidt identified two types of directed links: links connecting to preceding moves – 'backlinks'; and links connecting to subsequent moves – 'forelinks'. Moves that have dense linkage connections; namely critical moves (CM) can be considered as indicators for design productivity. An example of a linkograph is represented in Figure 2, where the transcribed verbal comments are segmented into design moves (moves 1 to 12). Design moves were linked by nodes whenever they exhibited an association in terms of content.

In the original scheme of a linkograph, Goldschmidt referred to four main types. In Case 1, design moves are completely unrelated, indicating low potentials for idea development. In Case 2, design moves are completely interconnected, hinting to a fully integrated process in which successive ideas may suffer from fixation and lack of diversity; this leaves fewer chances for novel ideas. In Case 3, each design move is linked only to its subsequent move; this signifies a progression in the process with low potentials for idea development. In Case 4, design moves are partly interrelated, indicating a productive design process that provides plenty of opportunities for idea generation and development.

In order to highlight differences in nodes' clustering, a Nonparametric Density Estimation (NDE) feature was used to distinguish patterns in the nodes' point density (Kan and Gero, 2008). The bivariate density estimation projects a smooth surface that describes the density of nodes in a linkograph at each point in that surface. The nodes are mapped on a two dimensional space, and a set of contour lines are set at quantiles in 5% intervals. The contours are rendered to show the density of nodes in a linkograph. This means that 5% of the nodes are below the lowest contour, 10% are below the next contour, and so on. The highest contour has about 95% of the points representing the nodes below it indicating to clusters that contain the highest concentration of nodes within the contour boundary. These clusters may represent moments of 'fixation' in the cognitive activity, where architects focus on solving certain problems. The nonparametric density method is computed by dividing each axis into a fixed number of binning intervals. The number of points is then counted in each bin. Following that, a smoothing kernel standard deviation is set. A bivariate normal kernel smoother is applied using a fast Fourier transform (FFT) algorithm and inverse FFT to do the convolution. Following this procedure, a contour map is created using a bilinear surface patch model. This method is explained in Rodriguez and Stokes (1998) and applied in SAS software. In this paper, the Kernel Standard Deviation was set to 6 to enable a comparison between all linkographs. A statistical representation of clustering in the node densities was favoured over a structural description of the linkographs (Gong et al., 2009; El-Khouly and Penn, 2012). The latter was thought to present a wide range of variation in the structure subject to the representation of design moves.

Entropy measures the degree of order from a node in a topological graph using Shannon's formula of uncertainty (1948);

$$s_i = \sum_{d=1}^{d_{max}} -p_d \log p_d$$

where d_{max} is the maximum depth from vertex v_i

p_d is the frequency of point depth d from the vertex.

In the topological network of a linkograph, entropy is the distribution of design moves in terms of their depth from a specific design move. If depth from a design move to other design moves is evenly distributed, entropy will be higher. If depth from a design move to other design moves is unevenly distributed, entropy will be lower, and depth from the design move is asymmetric. Entropy is thought to correspond to how easy it is to traverse to a certain depth within the linkograph network from a specific design move *DM*, that is how easy it is to link back and forth to design moves that precede or follow *DM* (low disorder is easy, high disorder is hard). Sudden changes between high and low disorder may have some associations with the type of cognitive activity and the diversity of constraints, and possibly with metacognition.

Fig. 2 A model of the linkograph's segmentation scheme.

Coding design constraints

The linkograph's design moves were further coded in terms of the type of design constraints utilised in design reasoning. The following categories of design constraints were coded (see Appendix 2 for further description of each constraint);

1. Spatial constraints: Spatial constraints are described as any set of actions that are likely to change the spatial configurations of design. We distinguish; Partitioning, Orientation, Visibility, Accessibility, Adjacency, Circulation, Occupation, Integration, and Shape constraints.
2. Functional constraints; referring to design moves that verbally describe one function or more from the list of functions that are listed in the design brief.
3. Other well-defined constraints: We refer here to constraints that do not belong to the previously- explained categories, but can be quantified –to a great extent- using numerical operators and mathematical functions. We list here; Lighting, Environmental, Structural, Dimensions, Material, Technical, and Furniture constraints.
4. Other ill-defined constraints, referring to constraints that are qualitative in nature. Some aspects of certain constraints, such as economical constraints, can be described quantitatively, although such descriptions are subject to the definition of value. The list of ill-defined constraints considered in this study are listed as; Aesthetical, Economical, Cultural, and Emotional constraints.

Modelling problem spaces and blocks of design operations

Problem space classifications can be traced back to Klahr and Dunbar's (1988) categorisation of dual space search into "hypothesis space" and "experimental space". This corresponds to Alexander's "analysis" versus "synthesis" model of design (1964), considering that “analysis” -as the decomposition of design problems into subproblems- is a search into the “hypothesis” space, whilst “synthesis” – as the set of operations and experiments conducted in search for a design solution- corresponds to the “experiment” space. Klahr and Dunbar’s model of “hypothesis” space versus “experimental” space (1988), and Alexander’s model of “analysis” versus “synthesis” (1964), both correspond to Hillier and Leaman’s model of “interpreted universe” versus “constructed universe”, linked by the “manipulable set” (1974). The molecule that defines the local dynamics of cognition in this model is defined in Hillier and Leaman’s terms as the “conjecture-test” process, considered to be the basic unit of design by which designers test their assumptions against a set of constraints in order to further refine the solution space. Goel and Pirolli (1992) identified the hierarchy of design problem solving by making the distinction between modules, submodules, and statements. With all three levels, the control structure appears to be cyclical and repetitive throughout design. The structure of problem spaces in models of scientific discovery can be further classified into 4 problem spaces; representation space, hypothesis space, paradigm space, and experiment space (Schunn and Klahr, 1995). A visual comparison of the design methodology models and models of scientific discovery discussed here was presented in table 2.

There are caveats that need to be taken into consideration when constructing analogies between models of design and models of scientific discovery, although key research in the field of design methodology bears association with other domains of knowledge (e.g mathematics (Alexander, 1964), and linguistics (Hillier and Leaman, 1974)). The majority of research reviewed above distinguished two types of problem spaces. The first problem space is associated with problem definition, that is defined as the hypothesis space in models of scientific discovery, or the “requirements space” in models of design methodology. The “requirements space” is constructed through analysing and interpreting the design problem. The second problem space is associated with defining, synthesising, constructing and experimenting on the solution space. Hillier and Leaman, defined a dynamic molecule that links the hypothesis space to the experiment space through the “conjecture-test” operation. Architects are thought to build conjectures of design solutions from information learnt from the design problem, and from their experience, and test these conjectures through manipulating, testing, and changing the solution space. Schunn and Klahr (1995) added to the hypothesis space and experiment space, a representation space and a paradigm space. If a paradigm space were to be interpreted in Kuhnian terms (1962), the notion of a paradigm would be seen as representative of an architectural theory. Architectural designers acquire a tacit knowledge of architectural theories, and history of design in their education. This knowledge informs and influences design practice and frames the idiosyncrasies of designers. Creating a paradigm space that is significantly different from documented paradigm spaces in architectural theory could be identified as historical creativity in Boden’s terms (1990). Representation space is defined differently within the context of design compared to sciences. Suwa and Tversky (2003) argued that generating new representations is a function of perceptual ability to reorganise parts of drawings into the whole, together with conceptual abilities measured by fluency in generating new and related ideas. Fluency is a parameter of metacognition. Suwa and Tversky acknowledged that perception is a function of mental transformations, and conceptual abilities are a function of knowledge.

In the analyses presented in this paper, we distinguished two types of problem spaces; one that is related to the brief (problem space 2) and one that is related to defining the spatial features of the design solution (problem space 1). The design process is mainly a product of alternating problem space 1 (indicates actions related to the layout) and problem space 2 (indicates actions related to the brief). Within each problem space there are blocks of coherent design operations. These are distinguished and modelled by translating the semantic transcripts into a pseudocode as illustrated in appendix (3).

Table 2 The definition of problem space in models of scientific discovery and models of design.

Modelling design constraints sequencing into knowledge graphs

Knowledge graphs were constructed from semantic data by coding statements within design moves into design constraints. Each design constraint is a node in a network, the relationship between design constraints is represented as edges in the graph network. A knowledge graph of design constraints was mapped for each block of coherent operations in the design process. Knowledge graphs were visualised in Cytoscape software (Su et al, 2014), using indices of Betweenness Centrality both for nodes and for edges. Colour range of nodes represents a range of betweenness centrality values for each design constraint. The thickness of the edges represents values of betweenness centrality for edges (thick for higher values). It is theorised that an architect navigates a universe of knowledge-based constraints during design and utilises each type of constraints in order to reason about design decisions. Higher betweenness centrality of nodes representing knowledge-based design constraints means that those constraints are visited more frequently as designers navigate their way from the problem definition space to the solution definition space. Higher betweenness centrality of edges indicates that the route between two types of design constraints is visited more often during the course of design. This modelling is used to illuminate the relationship between design constraints at different design phases, namely; what constraints are visited recursively? And how variations on the type of design constraints selected associate cognitive and metacognitive activity? These questions shall be further investigated in the results section.

Results

Assigning creativity and efficiency scores to design solutions

The main criterions used to evaluate design solutions are creativity and efficiency. Six MSc SDAC students (raters)[2] were to assess a set of design proposals[3] for an architectural office in terms of ‘creativity’ and ‘efficiency’. The judgment is based on their ‘expert knowledge’ as architects. The postgraduate students had acquired architectural knowledge during their undergraduate education and years of professional practice in architectural firms. During the first term of their postgraduate programme, the architects acquired an explicit analytical knowledge of architectural space using network science as a method for representing and analysing architectural layouts enabling them to evaluate spatial accessibility and social behaviour using scientific models. This level of knowledge qualified them to assess the efficiency and creativity of architectural layouts. The number of raters needs to be increased in the future to improve on the accuracy of ratings. Unfortunately, the ratings assigned to the layouts varied in their level of agreement. Based on measures associated with the Consensual Assessment Technique (CAT), a technique for measuring agreement between raters on assessing creative products (Lee et al., 2011), the overall Kappa value (produced in JMP statistical software) was slightly higher than 0, indicating an agreement between raters for a given layout that is slightly higher than chance (0.07 for creativity and 0.04 for efficiency). The rater’s agreement with him or herself and other raters for a given layout varied between (11% and 20% in measuring creativity scores) and between (6% and 13% in measuring efficiency scores).

[2] MSc Spatial Design: Architecture and Cities (SDAC), 2015/16 cohort, at the Bartlett School of Architecture, University College London

[3] The design proposals belong to a case study that was presented in Al_Sayed et al (2008). A detailed description on the terms of the experiment, subjects, and data used and generated by the experiment is available in; https://discovery.ucl.ac.uk/id/eprint/4928/1/4928.pdf. The original layout belongs to Weyerhaeuser Company SOM - Sidney Rodgers & Associates Tacoma, WA, USA.

Pairwise correlations between each pair of raters' creativity scores across all the design solutions yield one high correlation (r=0.348). This correlation is not statistically significant (p=.348, N=12, and this is before doing Bonferroni correction for multiple tests. However, all but 2 of the correlations were positive, which by a binomial test is significant at p=.0067 (P=0.5, N=15, successes≤13). This indicates that there is some level of agreement about the order of creativity scores.
When assessing pairwise correlations between each pair of raters' efficiency scores across all the design solutions, the greatest correlation found was (r=0.64), the test was found statistically significant (p=.64, N=12, after doing Bonferroni correction for multiple tests. However, only 7 out of 15 correlations were positive (N=15, successes≤7).

Following the calculation of mean and median scores across raters for each design solution, it was concluded that the medians act as the "ground truth" of the creativity and efficiency scores. The median can be thought as discounting outlying opinions. The mean/average creativity scores assigned to the layouts yielded proposal (layout 7) made by [AB] as the most creative design proposal, marking the highest average 'creativity' score (C-score), whilst the design proposal (layout 2) made by [KS] was reported as the least creative. Average efficiency scores (E-score) yielded layout 3 as the most efficient design proposal, whilst layout 7 designed by [AB] was reported as the least efficient (Table 3). It is difficult to establish what makes efficiency in the designers' judgment. One physical metric could be ratio of circulation to layout area, an efficient layout minimizes circulation area whilst connecting all spaces. This does not count the inner circulation area within rooms. The definition of a circulation space is limited to those spaces that are defined as corridors or lobby areas. The ratio between circulation spaces to layout area corresponds to efficiency scores. Layout 3, marked with the highest efficiency score has the least circulation area, and layout 7, marked with the lowest efficiency score, has one of the largest circulation areas. These distinctions do not apply to layouts 4, 6, 11, and 12, all appearing to have smaller circulation ratios, and are marked as average in terms of efficiency.

There is a general agreement between raters about the designs that are scored as least and most creative, and the designs that are rated as least and most efficient. This is rendered out in low STD and Kappa values for these particular design solutions compared to other design solutions. The standard deviation for efficiency scoring correlations was higher (0.33) in all pairwise correlations compared to the standard deviation for creativity scoring correlations (0.13), therefore we proceeded by examining the design processes that led to the design outcomes rated with the highest and least creativity scores, and we excluded efficiency scores from this analysis. The mean values that were used for creativity and efficiency scores were -in later sections- correlated to all other experiment variables, cognition, metacognition, design constraints, and functional distribution of designs. Correlations that were found significant were reported in the analysis/discussion section.

Table 3 Average 'creativity' scores (C-scores) and 'efficiency' scores (E-scores) based on raters' expert knowledge. The scores (1-12) are averaged based on 6 observations; where higher scores indicated lower creativity or efficiency. STD and Kappa values were included to show variability and agreement levels respectively. Ratio of circulation to layout area was included to inspect its relation to efficiency.

Do creative designs and efficient designs have distinct spatial features?

Measuring on the scores assigned and the distribution of space size in the designed layouts, it is difficult to establish whether higher creativity scores are related to the distribution of space size. Most layouts have a large number of small spaces (<100 grid points) and few large spaces (Figure 3). Generally, there are no sharp distinctions in the density of smaller spaces up to 100 grid points and density of larger spaces above 100 grid points in relation to creativity and efficiency scores. Layout 3 scored as the most efficient appears to have a more regular pattern of change in the distribution of space size, with a large density of smaller spaces under 100 grid points, a smaller number of larger spaces between 100 and 150 grid points, and finally two clusters of larger spaces peaking at 230 and 290 grid points. It is not clear whether we can recognize creativity or efficiency from the distribution of room/space size in the designed layouts. Further analysis of the geometry is needed including shape proportions (Al Sayed, 2014), and other spatial metrics and features.

Fig. 3 Distribution of areas defined by functions in the designed layouts. Areas measured by number of grid units per layout. A grid unit equals 1.4375m x 1.4375m

Modelling the protocols of highly creative designs and least creative designs
In this section, we analysed the design processes that led to the most and least creative designs using macroscopic analysis and linkography. The macroscopic analysis showed higher frequencies of perceptual, functional and aesthetically-driven actions in AB's design process compared to KS (Figure 4), despite the fact that the duration of both design processes were very close -AB consumed 38 minutes, whereas KS consumed 32 minutes. This suggests that a highly creative design is a product of a cognitive activity with higher frequencies of cognitive actions. The linkography analysis showed remarkable differences between AB and KS (Figure 4 & 5 respectively). When setting the nonparametric density estimation models to similar kernel standard deviation levels, AB's linkograph showed a larger number of clusters than KS's linkograph. The clusters in AB's case are distributed at different levels; one aligning the horizontal axis linking sequential design moves, one in the middle connecting problem-definition, drawing activity and solution-definition stages, and a cluster at the top of the linkograph linking problem-definition and solution-definition stages. KS's linkograph showed a large cluster at the problem-definition stage, and a cluster connecting drawing actions and the solution-definition stage. Number of design moves, number of critical design moves (> 8 links), and number of original ideas pronounced verbally by AB are more than double the ones in KS's linkograph. The link index is relatively higher in AB's linkograph (2.82) compared to KS's linkograph (2.6). Goldschmidt (1992) had previously found a correlation between design productivity and link index (ratio of links/moves). This indicates that higher productivity during design may yield higher creativity in design outcomes. This finding needs to be generalized on a larger population before confirming it true.

This section will describe and discuss the results concluded from mapping design constraints data table, design constraints in the knowledge graphs, cognitive actions (Suwa et al, 1998), and metacognitive actions (declarative, procedural, and conditional) against the density of design moves and entropy of design links in the graph network of AB's linkograph. The design moves were coded from the verbal data in (Al_Sayed et al., 2008), and were built into a linkograph. The linkograph's density was computed and modelled as described in the method section. Additionally, entropy was measured in the topological network of the linkograph.

Design constraints (described in appendix 2) and cognitive actions (Suwa et al, 1998) were mapped against the linkograph's model. We marked clusters that are highly dense and projected them against entropy and design constraints to distinguish any regularities that couple density of design moves, entropy in the linkograph, cognitive actions, metacognitive actions, and succession of design constraints (figures 4 and 5).

The mapping of a linkograph against coded content of design moves (cognitive actions, metacognitive, and design constraints coding) indicates a correspondence between clusters of dense design links (closer to the Y axis) and entropy (figure 2). There is also an association between changes on entropy and metacognitive actions. In both design processes, knowledge graphs that represent the relationships between design constraints, were highly dense and structured during the phases (design blocks) that precede changes on entropy. There is some evidence on constraint relaxation coinciding with metacognition in AB's and KS's design processes. Metacognition is associated with phases that witness higher diversity on the types of cognitive activity, and higher diversity on the types of design constraints introduced. Phases that are characterised by an interplay between perceptual and functional cognitive actions, and a recursive application of function-occupation design constraints witnessed lower frequencies of metacognitive activity. In the first part of AB's design process we found an association between low density knowledge graphs and higher density of metacognitive design moves. We also found a higher frequency of metacognitive design moves as designers shift from one design block to another design block, each defining a coherent task. There is no evidence on an association between metacognition and lower density of knowledge graphs, or phases that separate design blocks, in KS's design process. There are no notable patterns in the association between the three most visited design constraints in the knowledge graphs and metacognition, other than a higher frequency in conditional metacognition corresponding to the frequent use of environmental and cultural constraints in AB's design process.

Fig. 4 Mapping the density and entropy of a linkograph alongside design moves coded by cognitive actions, metacognitive actions and design constraints. Nonparametric Density Estimation of linkographs representing the design process performed by AB. The X axis represents the sequential progress of design moves over the period of the design session. Nonparametric Density Estimation produced using JMP, The Statistical Discovery Software, Version 5.1. Entropy's parameters are; range (0.5 to 2.751), average (2.211), standard deviation (0.3). Knowledge graphs were mapped for each block in the design process. Knowledge graphs were visualised in Cytoscape software, using indices of Betweenness Centrality as to identify nodes of knowledge that were frequently visited in problem solving.

Fig. 5 Mapping the density and entropy of a linkograph alongside design moves coded by cognitive actions, metacognitive actions and design constraints. Nonparametric Density Estimation of linkographs representing the design process performed by KS. The X axis represents the sequential progress of design moves over the period of the design session. Nonparametric Density Estimation produced using JMP, The Statistical Discovery Software, Version 5.1. Entropy's parameters are; range (0.5 to 2.751), average (2.211), standard deviation (0.3). Knowledge graphs were mapped for each block in the design process. Knowledge graphs were visualised in Cytoscape software, using indices of Betweenness Centrality as to identify nodes of knowledge that were frequently visited in problem solving.

Analysis/Discussion

How creativity and efficiency correlate with different attributes of the design process and design solutions

Creativity and efficiency are not fully independent. There is a correlation of 0.51 between these two scores. We have listed in the introduction our assumptions on whether creativity and efficiency correlate to experiment variables, cognitive coding of design, metacognitive coding of design, spatial distribution of functions in the layouts, and the number of design constraints applied during the course of design. Positive and negative correlations were considered if they were above 0.35 or below 0.35 respectively. We have listed our findings below;

- Experiment variable: Creativity correlates slightly with number of words in the verbalised transcript and experience. Efficiency negatively correlates with task period, (table 4, a).
- Cognitive coding of design: Creativity positively correlates with number of design moves, number of design moves with original ideas, perceptual design moves, goal-driven design moves, and aesthetical critical design moves. Efficiency negatively

correlates with number of design moves with original ideas, looking at previous depictions design moves, perceptual design moves, and goal-driven design moves, table 4, b).

- Metacognitive coding of design: Creativity correlates positively with declarative and conditional metacognition. Efficiency negatively correlates with conditional and total number of metacognitive design moves (table 4, c).
- Spatial distribution of functions: Creativity positively correlates with the number of spaces per layout, and the ratio of corridor to layout area. Efficiency negatively correlates with the number of spaces per layout, and the ratio of corridor to layout area, (table 5, a).
- Design constraints: Efficiency negatively correlates with the number of constraints applied to define orientation of the layout, shapes, depth related configurations, technical, structural, material, and aesthetical requirements of design. Efficiency positively correlates with constraints applied to define the functional occupation of spaces. Creativity positively correlates with the number of design moves that have addressed adjacency relationships, spatial configurations, dimensions, shape-relationships, structural, material, technical, and aesthetical requirements. Creativity negatively correlates with the number of design moves that have attended to lighting and emergency evacuation planning requirements, (table 5, b).

Correlations that are above chance for these observations (>0.53) or (<-0.53) are noted as follows (excluding datasets that contain a small count of observations);

- Creativity positively correlates with number of original ideas, and perceptual cognitive design moves, and efficiency negatively correlates with design moves that entail looking at previous depictions (table 4, b).
- Creativity positively correlates with the number of structural, material, and technical design constraints. Efficiency negatively correlates with the number of orientation, structural, and aesthetical design constraints (table 5, b).

Table 4 Correlations identifying the relationship between; a. creativity and efficiency, and experiment variables, b. creativity and efficiency, and cognitive attributes based on a linkograph representation, c. creativity and efficiency, and metacognitive design moves.

Table 5 Correlations identifying the relationship between; a. creativity and efficiency, and spatial and functional attributes of the proposed designs. B. creativity and efficiency, and the types of constraints applied throughout the course of the design process.

Conclusions

This paper reports an investigation into the markers that distinguish creativity in design protocols, and creativity and efficiency in design solutions. Creativity and efficiency in designs are assessed based on expert knowledge. The designed layouts are analysed spatially to distinguish features that are associated with creative and efficient designs. A committee of experts was asked to assign creativity and efficiency scores to the designs. The verbal protocols of designers were modelled to check how cognitive activity, metacognitive activity, and knowledge-based reasoning differs in designs that lead to a creative solution compared to designs that are assigned low creativity scores. The spatial distribution of spaces in the designed layouts did not show considerable differences in size regardless of the scores assigned. It was possible to distinguish a relationship between efficiency and the ratio of circulation to layout area. Highly efficient designs had a smaller circulation area compared with least efficient designs. A creative design appears to be an outcome of a process that has higher ratio of linkages between design moves in linkographs. Moreover, a design process that yields creative outcome shows systemic pattern of clustering that builds up hierarchically from the local scale of sequential design moves to the global scale, linking the problem-definition stage, the drawing activity stage and the solution-definition stage in a linkograph.

The analysis of cognitive and metacognitive activity yields interesting associations with the sequence and graph structure of knowledge-based constraints. Metacognition is associated with changes on entropy in the graphical network of a linkograph and is preceded by highly structured and dense knowledge graphs representing relationships between design constraints. There is also an association between changes on entropy and metacognitive actions. Metacognitive actions seem to also coincide with frequent changes on the type of cognitive actions applied during the design process. The type of cognitive actions that are prevalent during high entropy phases are either functional or perceptual. There is an evidence on constraint relaxation coinciding with metacognition in the design processes examined. Metacognition is associated with phases that witness higher diversity on the types of design constraints introduced. Phases that are characterised by a recursive application of function-occupation design constraints witnessed lower frequencies of metacognitive activity. Higher frequency of metacognitive design moves were noted as designers shift from one design block to another design block, each block defines a coherent task. There are no notable patterns in the association between the three most visited design constraints in the knowledge graphs and metacognition, other than a higher frequency in conditional metacognition corresponding to the frequent use of environmental and cultural constraints in creative design. These findings are subject to how constraints are defined and coded from the content of the design moves, and how design moves and design links are coded and modelled in a linkograph.

In the analysis/discussion section we examined correlations between creativity and efficiency, and experiment variables, cognitive activity, metacognitive activity, functional distribution of spaces in the layout, and design constraints. It was concluded that creativity positively correlates with number of original ideas, perceptual cognitive design moves, and number of structural, material, and technical design constraints. Efficiency negatively correlates with design moves that entail looking at previous depictions, number of orientation, structural, and aesthetical design constraints.

These findings remain to be experimental. They are subject to designers' interpretation of what makes a creative and efficient design solution. The numbers of cases to compare are also very limited, and the circumstances underlying the original experiment – which was intended to compare two groups of architects with different types of expertise- may have influenced the dataset and the results of the analysis. Future studies will re-examine the methods of assessment by introducing more robust settings and metrics of evaluation to the case study including Creative Product Semantic Scale (CPSS) and Consensual Assessment Technique (CAT) (Lee et al., 2011) methods to support the judgment criteria and measures set by the committee of experts.

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Appendices

Appendix 1

General	General	Word Count	Number of words in the semantic transcript
		Task period	The duration of the design process in minutes
		Experience	Academic and practical experience in architectural design.
	Linkographs variables	Number of Design moves	Total number of design moves coded for each design process. A “design move’ is explained as ‘an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed” (Goldschmidt, 1992).
		Forelinks	Number of links connecting to subsequent moves
		Backlinks	Number of links connecting to preceding moves
		Total links	Total number of Links among moves as determined arbitrarily by the observer.
		Forelinks %	Percentage of links connecting to subsequent moves
		Backlinks %	Percentage of links connecting to preceding moves
		Total%	Percentage of Links among moves as determined arbitrarily by the observer.
		Link Index	Link index is the ratio of links to moves. Goldschmidt (1992) had previously found a correlation between design productivity and link index.
	Linkograph	creative CM8	Total number of critical design moves (that have more than 8 links) that can be assessed as creative, presenting original ideas.
		Number of original ideas	Total number of original ideas in each design process.
Cognitive coding of design protocols	Macroscopic coding* of design moves and critical design	L_Moves	Physical design moves that represent looking at previous depictions
		F_Moves	Functional design moves that represent exploring the issues of interactions between artifacts and people/nature (e.g. Functions, circulation of people, views, lighting conditions), and/or considering psychological reactions of people (e.g. fascination, motivation, cheerfulness)
		P_Moves	Perceptual design moves that represent; attending to visual features of elements (e.g. Shapes, sizes, textures), attending to spatial relations among elements (e.g. proximity, alignment, intersection), and/or organizing or comparing elements (e.g. grouping, similarity, contrast).
		E_Moves	Conceptual design moves that represent making preferential and aesthetic evaluations (e.g. like-dislike, good-bad, beautiful-ugly)
		G_Moves	Goal-driven design moves that involve Setting up goals
		K_Moves	Design moves that involve retrieving knowledge
		L_CMs	Physical critical design moves (that have more than 8 links) that represent looking at previous depictions
		F_CMs	Functional critical design moves (that have more than 8 links) that represent exploring the issues of interactions between artifacts and people/nature (e.g. Functions, circulation of people, views, lighting conditions), and/or considering psychological reactions of people (e.g. fascination, motivation, cheerfulness)

		P_CMs	Perceptual critical design moves (that have more than 8 links) that represent; attending to visual features of elements (e.g. Shapes, sizes, textures), attending to spatial relations among elements (e.g. proximity, alignment, intersection), and/or organizing or comparing elements (e.g. grouping, similarity, contrast).
		E_CMs	Conceptual critical design moves (that have more than 8 links) that represent making preferential and aesthetic evaluations (e.g. like-dislike, good-bad, beautiful-ugly)
		G_CMs	Goal-driven critical design moves (that have more than 8 links) that involve Setting up goals
		K_CMs	Critical design moves (that have more than 8 links) that involve retrieving knowledge
		Total CM8	Total number of critical design moves (that have more than 8 links)
Metacognitive coding of design.	Metacognition	Declarative metacognition	Declarative knowledge; that is the ability to evaluate knowledge.
		Procedural metacognition	Procedural knowledge, which involves both heuristics and strategies. The more certain one is about representations and goals the more easy it is to construct strategies.
		Conditional metacognition	Conditional knowledge; that is the ability to determine why and when to use declarative and procedural knowledge.
		Total metacognition	Total number of metacognitive design moves as defined by (Jacobs and Paris, 1987), involving; declarative knowledge, procedural knowledge, and conditional knowledge

Appendix 2

Spatial and functional configurations of design solutions	Number of spaces per layout	Tessellation	Number of spaces in each design solution, each space is defined as a convex space.
	Functional area distribution in design solutions	Ratio of Corridor to Layout area	Ratio of main circulation area to the overall area of a design solution.
		Circulation area	Area of main circulation routes in each design proposal.
		Head office	Area allocated for the head office in each design solution.
		secretary	Area allocated for the secretary in each design solution.
		Waiting area and exhibition	Area allocated for the waiting area and exhibition in each design solution.
		meeting rooms	Area allocated for the meeting rooms in each design solution.
		Telecommunication offices	Area allocated for the telecommunication offices in each design solution.
		consultants	Area allocated for the consultants in each design solution.

		design teams and directors	Area allocated for the design teams and directors in each design solution.
		IT offices	Area allocated for the IT offices in each design solution.
		technical studies	Area allocated for the technical studies in each design solution.
		construction expertise unit	Area allocated for the construction expertise unit in each design solution.
		management offices	Area allocated for the management offices in each design solution.
		Kitchenette	Area allocated for the kitchenette in each design solution.
		Partitioning	'Partitioning' design moves; where architects verbally describe actions that are directed to draw partitions in the spatial layout.
		Orientation	'Orientation' design moves; referring to design moves that are directed to change the orientation of elements of the design solution or the overall layout in relation to other elements or the external environment.
		Visibility	'Visibility' design moves; where there is clear reference to the visual configurations of the layout.
		Accessibility	'Accessibility' design moves; where there is clear reference to accessibility between two spaces or more within the layout's spatial settings.
		Adjacency	'Adjacency' design moves; where there is clear reference to adjacency relationships between two spaces or more within the layout configurations.
		Circulation	'Circulation' design moves; where there is clear reference to circulation within the layout, or within spaces in the layout.
		Occupation	'Occupation' design moves; where there is reference to the occupation of each space within the layout.
	Spatial constraints	Spatial configurations	'Integration' design moves; referring to the centrality or depth in the spatial configurations of the layout.
		Dimensions	'Dimensions' design moves; referring to the dimensions of the layout or elements within the layout.
		Shape	'Shape' design moves; referring to shape properties and proportions of the layout or parts of the layout.
	Functional constraints	Functional	Functional constraints; referring to design moves that verbally describe one function or more from the list of functions that are defined in the design brief.
	Other well-defined constraints	Lighting	'Lighting' design moves; referring to artificial or natural lighting considerations.
		Environmental	'Environmental' design moves; referring to environmental considerations (e.g. energy efficiency, temperature, humidity).
		Structural	'Structural' design moves; referring to the material structure of the building, and any issues that relate to building physics.
		Material	'Material' design moves; referring to the building material used for different elements within the layout.
Design constraints		Technical	'Technical' design moves; referring to technical considerations (e.g. smart grid, ventilation technologies).

Other ill-defined constraints	Emergency	‘Emergency' design moves; referring to emergency and evacuation planning.
	Furniture	‘Furniture’ design moves; referring to furniture.
	Aesthetical	‘Aesthetical’ design moves; referring to the aesthetical evaluation of the layout or elements within the layout.
	Economic	‘Economical’ design moves; referring –for example- to issues that may increase or decrease the value of a property, or issues related to the management and operation of the building which are likely to have economic implications (e.g. the number of users that are needed to service parts of the layout and their annual salaries).
	Cultural	‘Cultural’ design moves; referring to cultural values that characterise the social organisation that resides in a building.
	Emotional	‘Emotional’ design moves; referring to the emotions of users, and how the design of a building may influence the feelings of users or observers.
	Building site	Design moves that involve using constraints that are determined by the external 'building site'.

Appendix 3

A sample of AB’s transcript and its corresponding pseudocode:

A transcript of AB’s verbal comments	Pseudocode
	Problem space 1
	Code block 1

1. So regarding the **office plan layout**, it is a **rectangular shape**,
2. **two main cores**,
3. **a lot of columns**,
4. I have **two main elevations left and right**,
5. I am not quite sure about this area here, is it just for the shape of the building from outside,? Or is it not?
6. What about this columns here,
7. is there any neighbourhoods here, can I open the side, can I have open views, I need like to think about this things,
8. regarding the inside. There is a clear network for the columns, which will affect the divisions of this functions,
9. but I need to understand first **how can I reach the functions according to the main points which will affect the circulation around the cores**;
10. and how this two cores will be working together,
11. because I am designing something for one team or for one firm,
12. this is in general the first impression about what I can see now.
13. Now I guess I need to study first the **areas**, because I believe that this is about **30 meters width and maybe 90 or 80 length** for the space –
14. I wish I can know the **height of the space** –
15. because I need to understand if I can design this space as a **multilevel space**,
16. ok I will consider it as a **flat one floor**.
	Design move 1 to 16
	Class Layout
	{
	Layout dimensions ();
	Rectangle (x1, y1, x2, y2);
	Core1 (x1, y1, x2, y2);
	Core2 (x1, y1, x2, y2);
	Column grid = [];
	Main elevation 1 ();
	Main elevation 2 ();
	Entry point 1 ();
	Entry point 2 ();
	Layout area = x;
	Internal height = h;
	Layout level = L;
	}

	Code block 2

17. I think according to the new theory for the working environments I guess it will be great if I can **design an open space** for the work,
18. because this will create a friendly environment for the architects,
19. and this will affect the impression for any client who will be visiting the office; because if I am a client and I need to see what is happening inside the office,
20. this will be great to **have partitions in an area** or another,
21. but I can be in touch visually with the people who are working inside,
22. and in the same time **I can use the corners or the areas around the cores**.
23. To **put the functions which don’t need this kind of connectivity between the people who are in and the people who are out, or the people who are working in the middle of the space,**
	Design move 17 to 30
	Class layout design
	{
	Open space in area (x1, y1, x2, y2);
	Configure partition (x1, y1, x2, y2);
	Define middle area ();
	Define periphery area ();
	If (function ∈ list of isolated functions):
	{
	Allocate function to a Corner in periphery area;
	Corner = [

24. so I think I need, normally I prefer to **draw the outline or the boundary of the plan**, 25. because I can feel the dimensions, because now the **area is almost, 30 meters multiplied by 90 so it is 2700 m^2**. 26. I think I will **start designing the major zones which reflect the brief.**. 27. Let's say that I need to do that step by step or the design should be step by step, 28. because **I have for example zone here, and I have a zone here , a zone here, a zone here** - 29. it is quite big – 30. **a final zone here, I have this main zones**,	C1(x1, y1, x2, y2), C2(x1, y1, x2, y2), C3(x1, y1, x2, y2), C4(x1, y1, x2, y2),] } Layout dimensions (30 meters, 90 meters); Layout area = 2700 m^2; Define zone (); Zone = [zone1, zone2, …]; }
	Problem space 2
	Code block 3

31. according to the brief **I will look first to the main area where the architects work, because this is the main body of the project, and I think I need to design open space with open views,**
32. and with **easy access to the lifts and to the toilets and to the rooms of services and this stuff**.
33. And **this will occupy, waiting area**,
34. I think I need first of all this is on the first level,
35. on the second level; I need to find a way to **connect this core with this core**,
36. then **this zone will be divided into two zones c1 and c2,**
37. then again I need to go back to the brief and look for the functions because I started to manage the plan.
38. Maybe I will design **if I consider the first entrance will be from this area to this area here**,
39. **this is the main entrance, with a waiting area**,
40. and **this waiting area will connect with back of house for people who are working here**;
41. and **this will take me to the head office with a private secretary** as you asked;
42. then **from this area here or from this boundary I should visually connect with the people who are working here**.
	Design move 31 to 42
	Class allocate functions to zones ()
	{
	Set preference for design teams location ();
	Set preference for waiting room location ();
	Draw corridor (Core1, Core2);
	Zone z = rec(x1, y1, x2, y2);
	Zone z = [c1(x1, y1, x2, y2), c2(x3, y3, x4, y4)];
	Set preference for entrance location ();
	Set preference for waiting room location ();
	Set preference for head office and secretary location ();
	}

	Problem space 1
	Code block 4

43. It might be a nice idea, to **have here an interactive wall so this interactive wall** I can use it as an exhibition for the firm for the office,
44. and in the same time **it is flexible boundary between the area before and after,**
45. because before you get inside the firm you have an impression and after you come inside you have another impression, because this will affect the way of working;
46. because I believe according to my personal experience from my work in the office, we have two personalities before getting inside the office, and after getting inside the office,
47. so I prefer to be more flexible inside this space, to work more relax, in a comfortable way,
48. rather than staying with the secretary or the offices here or the IT or the technicians, or those people who are working in this part or in this zone.
49. So I think, lets say on the same time **I need to use some kind of new shapes for the design** because I will not forget that I am designing an office for an architect, and this will affect the shape of the space; because, especially now, architects prefer strange shapes maybe, so maybe I prefer.
50. What **I need to design here is another enclosure**
51. **to have a new shape** because the circle in general gives you the impression of going out.
52. So this is the main core here,
53. yeah **it is additional wall**,
54. which will be on the edge of your current core,
55. **so I can use this spaces as storages or something but I will have a new wall or a new boundary**;
56. this will give us an impression of continuity in the space,
57. at the same time **I can start to understand the first point in the plan that I need to start from here**.
58. Then I need to get inside the working space,
59. from here I need, maybe this will be just a common area,
	Design move 43 to 59
	Class additional features ()
	interactive wall = (x1, y1, x2, y2);
	boundary = (x1, y1, x2, y2);
	draw circle shape 1 (x1, y1, r1);
	draw circle shape 2 (x1, y1, r1);