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

***Short title*
Creativity and efficiency in design**

Kinda Al Sayed

University of Sussex, UK

School of Engineering and Informatics

University of Sussex

Chichester 1

Falmer

Brighton

BN1 9QJ

Telephone number ++44(0)7878094468

K.Al-Sayed@sussex.ac.uk

Peter Cheng

University of Sussex, UK

*peterch@sussex.ac.uk*

Alan Penn

University College London, UK

a.penn@ucl.ac.uk

Number of manuscript pages 28

Number of tables 5

Number of figures 5

***Appendices***

**Appendix 1**

|  |  |  |  |
| --- | --- | --- | --- |
| General experiment variables | General experiment variables | 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. |
| Cognitive coding of design protocols | 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.  |
| Linkograph indicators of productivity and creativity | Link Index | Link index is the ratio of links to moves. Goldschmidt (1992) had previously found a correlation between design productivity and link index. |
| 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. |
| Macroscopic coding\* of design moves and critical design moves (CMs > 8 links) | 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 protocols | 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. |
| Design constraints | Spatial constraints | 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 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. |
| Technical | ‘Technical’ design moves; referring to technical considerations (e.g. smart grid, ventilation technologies). |
| Emergency | ‘Emergency' design moves; referring to emergency and evacuation planning. |
| Furniture | ‘Furniture’ design moves; referring to furniture. |
| Other ill-defined constraints | 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**

**Sample of** **AB transcript and its corresponding pseudocode:**

|  |  |
| --- | --- |
| 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. 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, 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 m2. 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, 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. 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,  | Problem space 1Code chunk 1Design move 1 to 16Class 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 chunk 2Design move 17 to 30Class 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 =[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 m2;Define zone ();Zone =[zone1, zone2, …];}Problem space 2Code chunk 3Design move 31 to 42Class 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 1Code chunk 4Design move 43 to 59Class additional features()interactive wall = (x1, y1, x2, y2);boundary =(x1, y1, x2, y2);draw circle shape 1 (x1, y1, r1);draw circle shape 1 (x1, y1, r1); |