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DIRECTED LINKOGRAPHY AND SYNTACTIC ANALYSIS

Comparing synchronous and diachronic effects of sudden emergence of creative insights on the structure of the design process

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Abstract

This paper reports on a study of the emergence of creative insights in the architectural design process. Using detailed ethnographic observations of designers working on an architectural design task, and coding these using linkographs, we identify two poles of design creativity: incremental improvement and the sudden creative insight. We show how these can be identified in the structure of the linkograph, giving rise to the possibility of better understanding the conditions under which creativity and innovation take place.

Linkography is directed in relation to the time of emergence of design utterances. It is characterised as a pivotal structure of a multi-level hierarchical network. A quantitative model is proposed to capture the structure of events and sudden changes occurring in the design process using syntactic measures of space syntax and urban graphs. Two situations are compared: synchronous designing using 'directed linkography' looking at the backlink relations and the completed state of the linkograph. Local, global measurements and directed j-graphs are correlated with design contents and descriptions for the concept development.

Our interest lies in capturing events of drastic changes and investigating the transformation of the associated interim products. Such events are hypothesised, reflecting significant transformation in concept reasoning and the configuration of the linkograph. Through this model, we aim to answer the question: why would sudden insights divert the network to a different structure state?

Keywords: *Sudden Insights, Linkography, Syntactic Analyses, Structure and Design Reasoning*

Theme: *Modelling and Methodological Developments*

Introduction

There has been great interest in design research in interpreting the relation between reasoning and the emergence of creative insights. *Linkography* is a modelling tool widely used to represent the relations between segments of the design process and to code the *dependency* relationships between them. It is seen as a *multi-level hierarchical structure* comprising pivotal nodes. Many attempts have aimed at quantifying critical moves occurring during the design process. Goldschmidt, on first introducing linkographs (1990), developed a *link index* model indicating a measure for *critical* moves and design *productivity* (Goldschmidt, 1990; 1991). Kan and Gero adopted Shannon and Weaver's *probabilistic theory* (1949) and related the *richness* of design to *entropy* measures based on a hypothesis: creative events are related to *uncertainty* and *surprise* (Kan and Gero, 2008; 2009; Gero et al., 2011). A model was developed recently by El-Khouly and Penn (2012b) to describe the design process based on qualitative and quantitative analyses.[1]

In this paper, syntactic analysis is adopted to characterise multi-level networks in linkographs using *depth* and *centrality* measures to infer the structure beyond the emergence of creative insights. Different types of insights are investigated with the aim of revealing the structure of reasoning in design processes: *incremental* insights versus sudden breakthroughs. *Directed* linkography quantifies the network of relations that is created for each node with the preceding events. It looks at the *backlink* relations only and compares the results with the global network. Justified graphs (j-graphs) are used to represent the structure of each utterance that emerges and to enquire whether insights appear within *shallow* or *deep networks*. We ask, *why would an insight with a shallow structure transform to become deeply structured? What is the impact on the design process and generation of solutions after this transformation?* The value of this *investigation* is pertinent to proposing research methods and models to reveal the *formation of novel concepts and human creativity* in the design process.

1. Background

1.1 Creative Insights and Design Reasoning

Serious attempts to provide a taxonomy of design action include that of Suwa et al. (1998) who proposed classifying design actions into four macroscopic levels: physical, perceptual, functional and conceptual. However, our concern in this study lies with reasoning in design with the aim of investigating the context beyond the emergence of creative insights. We propose two categorical modes: incremental and non-incremental. *Incremental* reasoning provides a consistent route to preserve an initial conceptual idea by structuring the process of development through a sequence of interrelated steps. The concept is dependent on retrieving knowledge from preceding events and providing details through transformations of the earlier idea. Creative insights emerging in this context reflect a discursive and/or systematic type of development provides the ability to reframe the initial solution. *Non-incremental* reasoning provides an investigatory approach, which provides diversity to explore ideas and the ability to restructure the design problem and reintroduce the whole situation. Creative ideas appear as *sudden mental insights* or *breakthroughs* emerging unpredictably in the design process.

[1] El-Khouly and Penn (2012a) first introduced the method of character strings of information, known as 't-code' measures, to quantify the linkograph by computing three measures: 'complexity', 'entropy' and 'information content' for each design node. T-code string measures compute only the bottom level of direct relations that are made at each node sub-network (un-hierarchical measure), where syntactic analysis measures 'depth' for the structure.

The *incremental* view argues that *stimulus responses* are retrieved from memory and structured by a 'trial-error-correction' design approach (Weisberg, 1986), reflecting the *rational* paradigm in 1960s. We assume that Hillier's (1996) principle of design echoes the logical approach of Popper (1963) and Simon (1969). Hillier considers design to be a knowledge-based process; structured by knowledge, with architects as social programmers. The *non-incremental* view argues that design problems are solvable through *rapid cognitive restructuring* and creative ideas emerge from within an *insightful*, *unconscious* and *discontinuous* context. Once an insight is realised, the problem solver can quickly implement its solution (Metcalfe and Wieße, 1987; and see also the Gestalt school).

Types of insights can be distinguished in different ways. Insights are either dependent on memory to retrieve good ideas, or they rely on *unconscious actions* beyond awareness. Two pertinent points to the emergence of insights are investigated in this paper by using syntactic analysis: whether (1) incremental insights appear in a shallow network of relations, with many direct links within the linkograph (indicated by high integration value, low mean depth and real relative asymmetry [RRA]), or (2) sudden insights are deeply structured within the linkograph (indicated by low integration value, high mean depth and RRA). The proposed method aims to reveal the structure of the network for each creative insight, configure the patterns in linkographs, and identify the contexts of the emergence of insights.

1.2 The Capacity for Creative Thinking

Goel (1995) distinguished two types of transformation of ideas in the design process. *Vertical* transformation develops the initial concept by adding more details to it; *lateral* transformation changes the existing concept to explore new ones, leading to a *divergent* style of thinking. Divergent thinking is an essential *capacity* for creativity (Robinson, 2010). *Intelligence* requires certain types of deductive reasoning and divergence helps to build good arguments. To think laterally is to be able to see many ways to interpret a question, not just linear or convergent ways, and to see multiple answers rather than just one (ibid).

Convergence causes integration and cohesiveness between those ideas (Kan et al., 2007). *Interconnectivity* and *diversification* formulate the configuration of linkograph and significances can be illustrated. On the one hand, if a sequence of moves is very integrated, in an extreme case it could lead to a saturated state: a fully interconnected pattern. Saturation reflects premature engagement with a prevailing concept, undermining design novelty and reducing chances for creative insights. A strong association with a particular concept causes *fixation* and can be a *hindrance*. On the other hand, high diversification could lead to a disconnected linkograph: variant ideas are irrelevant, sparse, and segregated and no converging ideas are taking place in the process, lessening the chance of progression. A *balanced* state, however, reflects *homogeneity* of design forming a structured process. A structured linkograph states a creative process and shows the probability of novel ideas transpiring. Different linkographs were tested and characterised according to the configurations below through syntactical and character strings t-code analysis (El-Khouly and Penn, 2012a).

We argue that sudden insights reflect a 'subconscious' process of the brain, whereas incremental insights reflect 'conscious' actions. Archimedes' '*Eureka*!' moment, many significant discoveries in history and breakthroughs occurred while the inventor was occupied in a different context doing something else. Conscious actions are reflected by the interrelated chunk of patterns in the linkograph resembling a direct dialogue with the sketch. Sudden insights emerge when the unconscious action collides with the conscious state giving the advantage of incubation; the longer period of incubation makes the collision more effective in disconnecting the linkograph.

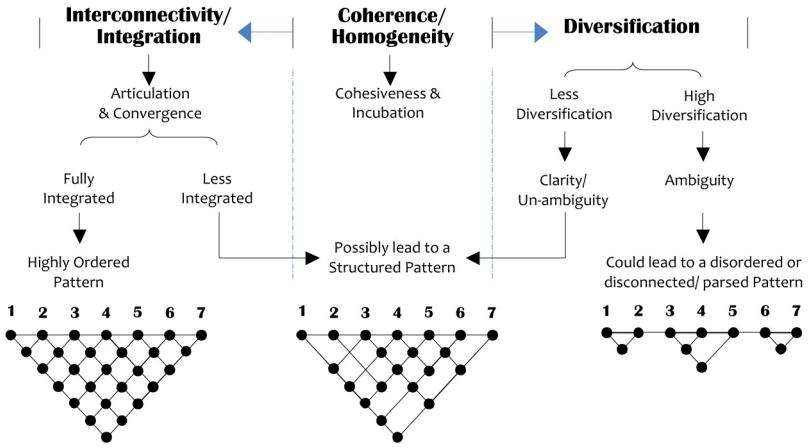


Figure 1: Implications of convergence vs. diversification on the configuration of linkographs

1.3 Identification of Sudden Insights: '*Eureka*!' and '*Aha*!' Moments

A sudden mental insight moves perception from its current situation to a different independent state. To identify the emergence while designing, lateral transformation from one *sketching episode* to a totally different one is proposed to reflect the transformation of perception occurring in the mind where each episode reflects a certain conceptual idea. From detailed ethnographic observations of designers it is apparent that reflecting on earlier design sketches while designing the current one plays an important role in allowing unpredicted glimmers of inspiration to suddenly occur. Multiple exchanges of ideas between different artefacts and media stimulate the emergence of sudden flashes. Architects demonstrate specific idiosyncrasies while designing, such as *back/fore linking*, recycling an idea between different projections, tracing drawings, zooming in/out, verbalisation and using confirmation words, signs and gestures, body/hand language, annotations and scribbles. All actions were transcribed, coded for linkography, and investigated for any sudden insights occurring while preparing a detailed analysis for each design experiment.

The identification of sketching episodes to construct the linkograph in our model accords with the following propositions: Schön's definition of the 'invention and evolution of ideas' (1963) as: 'treating the new in terms of the old', 'a displacement of ideas from the old situation to new one'; Köestler's conception of the 'bisociation of matrices'[2] for 'the creative act' (1964) as operating on more than one plane, the former may be called "single-minded" and the latter "double-minded" presenting the transitory state of unstable equilibrium where the balance of emotions and thoughts is disturbed, Goldschmidt's definition of a design 'move' (1994) as: 'a step, an act, or an operation that transforms the design situation relative to the state in which it was prior to that move'; Akin and Akin's identification of 'sudden mental insight' (1996) as: 'any sign on perceiving a notion to break out a frame of reference and shift to a new one'; Csikszentmihalyi's definition of the 'creative process' (1996) as: 'flow and the psychology of discovery and invention'; and Johnson's conception of a 'good idea' (2010) as two thoughts colliding, one that has incubated for a long time in the mind with another arising from the present situation.

2 The term 'bisociation' was coined to distinguish routine skills of thinking on a single plane and the creative act (Koestler, 1964).

1.4 Coding *Dependency* Relations

Design moves are coded based on two sets of creative contribution (Sternberg, 2003): actions that 'preserve' continuous reflections with the mind and actions that 'defy' continuous reflections. *Preserving* reflection proceeds on the initial concept taking various forms of activity, such as *replication*, *redefinition* or *advanced incrementation*, in the same design state. *Defying* reflection introduces a new item to the design state. It has a different taxonomy of actions to change the design situation: *divergence*, *synthesis* and *reconstruction*. This model is built on the range of transformations that a design idea is susceptible to. Creative insights are determined and judged according to this qualitative framework. Figures 2-a and 2-b illustrates snapshots of the coding processes between sketching episodes.

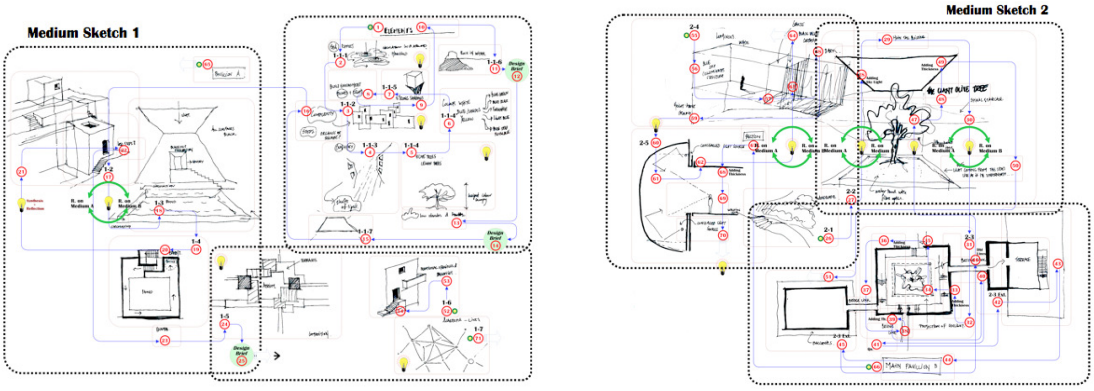


Figure 2-a: Snapshots of coding different sets of drawings and sketching episodes considering the order of occurrence and reflective practice

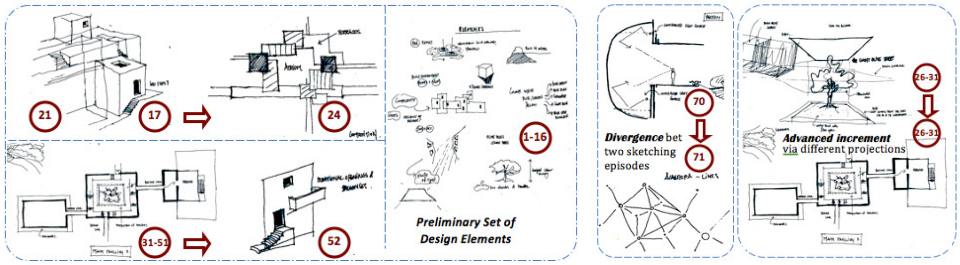
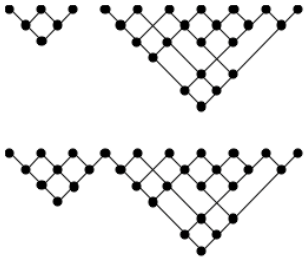


Figure 2-b: Snapshots of the procedure of coding the sketching episodes and transformation of ideas forming utterances of the design linkograph

1.5 Linkography is a Configuration of Pivotal Structure, 'Bridging' Nodes as Creative Hinges

We argue that radical paradigm shifts occurring during the design process most probably cause splits between the patterns of the linkograph. The transformation of ideas and emergence of insights are forms of paradigm shifts. If sudden flashes occur rapidly, the structure of the design process, the design problem and the conceptual idea are subject to a drastic change. The whole situation might be restructured, seemingly causing *disconnecting* or *bridging* nodes in the linkograph's pattern.



Rapid disconnections reflect a scattered process between different subsets of ideas while bridging is a *synthesis* process. A linkograph containing pivotal nodes of transformation is able to represent the state of coherence and structure, endorsing aspects of creative thinking: (1) *unexpected discoveries* as *unintended consequences* and *surprises that keep the design exploration going in reflective conservation with the situation* (Schön and Wiggins, 1992); and (2) reinterpretation dialogue between '*seeing that*' and '*seeing as'*, which correspond to *reflective criticism* and *analogical reasoning* (Goldschmidt, 1991; 1994). These aspects of the creative process are considered as driving forces to explore novel ideas. Introducing *discontinuity* into a previous concept is a key factor in creative problem solving (Weisberg, 1993). Therefore, such critical actions are matters of investigation enquiring into causes of discontinuity in the linkograph.

Some of the most observed factors are the multiple exchanges of ideas between different products and back/fore linking. The processes of unexpected discovery and reinterpretation split the linkograph into separate networks that can be connected via bridging nodes. We argue that the importance of a linkograph lies in its configuration of such pivotal nodes to reveal the creative moves in the design process. The configuration between sub-networks in the linkograph takes any of the following relations: *overlaid interrelation, intersection or sparse* (see Figure 3).

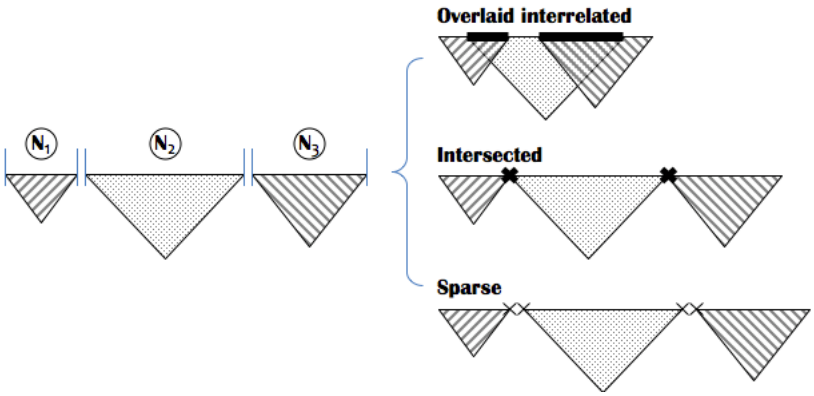


Figure 3: Configurations for possible relations between sub-networks in the linkograph

2. Paradoxical Point: *Local* versus *Global* Measurements

Two situations are compared in this study. The first considers the *time of emergence* for each segment in the linkograph by looking at the *backlink* relations with the preceding vertices on a *local* level, while the second ignores the time factor and concatenates *back* and *fore* relations for each vertex to process depth measures at a global level over the whole linkograph. The first situation is '*directed linkography*', which processes measures at each network (node) synchronous to the emergence. The second is '*undirected*' and explains the diachronic impact of insights after the completion of the whole linkograph, with the preceding and following actions. The paradox resulting throughout this comparison is when one vertex gives two drastically deviated values from local to global levels for the same design content. What does the reasoning design imply for two different integration values for one single action? We extend the enquiry into: *are sudden insights likely to occur in highly structured or shallow networks?*

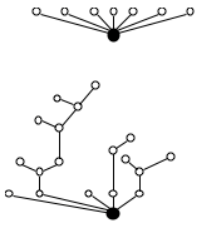
Relevant to this context, our motive for using different measures to quantify the linkograph is to characterise its multi-level hierarchical structure. Perplexing results are observed after processing syntactic and character string t-code measures on different cases; impulsive values do not follow a firm rule. Moreover, the correlation between syntactic and t-code measures are

seen to be inconsistent.[3] What has been revealed is that each measure indicates a different structure state of the linkograph. While t-codes demonstrate merely direct relations created at the bottom level of structure, syntactic (*depth*) measures characterise the multi-level hierarchy; taking into account all matrices of relations amongst vertices while weighing the sub-network for each. Thus, we conclude that syntactic and t-code measures are incomparable.

Concerning the emergence of insights, we argue that an insight imposes a certain structure on the following actions in the design process according to its content. Once a fixation is received, the designer attempts to break that frame of reference by generating a new insight or solution and shifts to another one. This explains the evolution of thoughts and interim artefacts along the process. Directed linkography provides an objective tool to weigh the linkograph via either syntactic or t-code measures. It assesses the value of those insights occurring at an early stage that are either thrown away or are useful for synthesis at final stages of design. Whether generated based on the preceding actions as *advanced incrementation* or as *sudden*, the applications of different measures are important in order to distinguish different characteristics of insights and linkographs from different levels. Two roles for the structure of network are derived:

1. High integration → low mean depth (MD) → low relative asymmetry (RA) → a shallow system

2. Low integration → high mean depth (MD) → high relative asymmetry (RA) → a deep system



Both types can be detected through j-graphs. Shallow and/or deep structures reflect different states of incremental reasoning and dependency on the preceding actions, but a disconnected structure might enable sudden insights to occur. A sudden insight occurs when high diversification between thoughts takes places instead of cohesiveness and incubation. The emergence of insight is beyond human awareness. By introducing this tool, we aim to reveal the context of reasoning behind the emergence: whether it is dependent on the precedent or not.

3. Applications of Directed Linkography

This method can be used to compare two situations in the design process: one concurrent to the emergence of nodes and the other retrospective, looking at the whole linkograph after completion. In the following cases, *local* and *global* measures are applied to the linkographs. Before embarking on the analysis, a number of common features are first demonstrated providing insights into the quantitative method:

1. Each node has (n_i - 1) possible values if we look forward to the rest of the graph based on the position '*i*'. The design process is a hybrid of 'conscious' and 'unconscious' actions; the trajectory of development cannot be determined or predicted in advance to reshape the final design. Our interest at this stage is therefore directed to the *backlink* relations reducing possibilities to a minimum.

2. We must be aware that the starting point has no *back* relations and is abandoned from the estimation (flattened) as well as nodes 2 and 3 if fully linked. Grained networks are fully saturated delivering no RRA values (real relative asymmetry).

[3] The applications of character string t-code measures (t-complexity, t-entropy, and t-information) are explained in detail in El-Khouly and Penn (2012a; 2012b).

3. The local measure for the end point is itself the global measure for the whole system since the linkograph is completed, looking back at all the preceding actions (directed to time).

3.1 *Syntactic* Measurements for Linkographs

This section introduces the estimation method of syntactic measures to quantify linkographs to the community of design research. For a linkograph network of five nodes, formed on the following relations:

- Vertex 2 has one backlink relation to 1, thus (2> 1).
- Vertex 3 has no backlink relations with nodes 2 and 1, (3⊁ 2, 1).
- Vertex 4 has two backlink relations with the preceding actions 3, and 2, thus (4> 3, 2) and (4⊁ 1).
- Vertex 5 has three backlink relations with the preceding actions 3, 2, and 1, thus (5>3, 2, 1) and (5⊁ 4).
- Estimating the syntactical measures *integration, betweenness* or *closeness centrality* takes into account the relations amongst all vertices in the estimation process for vertex 5, 4, 3, 2 and 1, which can be extracted into a two-way matrix presented in figure 4-a.
- According to the j-graph for node 5, the *depth* ' for this node equals 5 and the *mean depth* MD = D/(n-1)= 5/(5-1)= 1.25
- Integration can be estimated from the following equations:
  - Integration = 1/real relative asymmetry RRA
  - RRA = real asymmetry RA/relativised real asymmetry RA_d
  - $RA = 2(MD_i - 1)/(n-2)$ → 'n' is the size of system
    - RA = 2(1.25 – 1)/(5-2) = 0.17
    - RRA = 0.17/(0.352) = 0.47
    - Integration at node 5 = 2.13

- However, the string of information for node 5 is: '1110' comprising backlink relations to nodes 3, 2 and 1 with no relation to node 4, knowing that the computation of string t-codes resembles the basic level of direct relations in a multi-level structured system. The extraction method is illustrated also in Figure 4-a.
- If the system of relations at node 5 changes slightly, avoiding the relations of (5⊁ 3) and (5⊁ 2) for instance, the linkography of Figure 4-b gives a slightly different j-graph but a significant difference for the integration value. In this case RRA = 1.42 and integration for hypothetical node 5 = 0.7

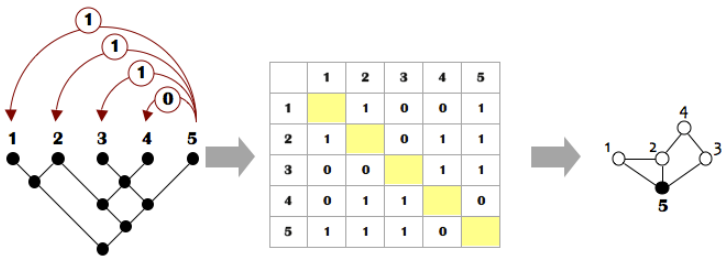


Figure 4-a: Two-way matrix of relations for the whole system requisite to process syntactical measures for node 5, the j-graph, the extraction of string of information prior to compute t-codes

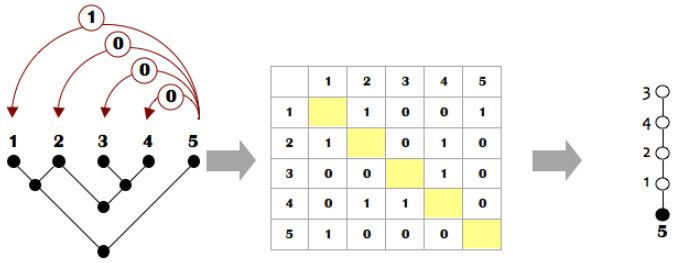


Figure 4-b: Two-ways of relations for a hypothetical system for node 5 based on avoiding two relations with preceding nodes, the j-graph, and string t-code – integration value changes drastically

The estimation of depth at each node is based on backlinks (j-graph); depth measure is estimated for the shortest number of steps required to go from one vertex to the other vertices in the network. See Appendix 1, which gives examples of depth measure for the linkographs in Figures 4-a and 4-b using directed estimation.

To conclude from these examples:

1. Syntactic measures reflect the complexity of the linkograph. Depth measure quantifies the sub-network of relations for each vertex within the whole. String t-codes reflect the basic level of the direct relations only.
2. Syntactic measures capture the structure of events and detect any slight changes occurring on the flow of the network of relations better than t-codes. Thus, the structure of reasoning beyond the emergence of insights is revealed.

3.2 Network Analysis: *Centrality* Measurements for Linkographs

The relative importance of any vertex within a network can be determined through *centrality* measures. It provides an indication of how important (well-used) the vertex is within a network. In the analysis of linkographs, the following can be used:

- **Depth** is the natural distance metric between all pairs of nodes, which is defined by the *length of their shortest paths*. The farness depth for a node is the sum of its distance to all other nodes in the network. High depth reflects a deep structure.
- **Closeness centrality** is a measure of how long it will take to spread information from a vertex to all other nodes sequentially. It is considered the inverse of the farness depth; the more central a node is, the lower its total distance (depth) from all other nodes.
- **Betweenness centrality** quantifies the number of times a node acts as a 'bridge' along the shortest path between two other nodes. It indicates the control of a human on the communication between other humans in a social network (Freeman, 1977). Vertices that are predicted to occur on a randomly chosen shortest path between two randomly chosen vertices have a high betweenness.

4. Applications to Architectural Design Processes

Our proposition makes an association between qualitative and quantitative analyses to evaluate design *novelty*, based on capturing the structure of events in linkograph and correlation with design contents: *actions* and *interim products*. Directed linkography describes the design process in light of qualitative descriptions of *concept development* and *dependency* between *sketching episodes*. The aim is to provide an objective tool to detect the *emergence of insights*, describe various *modes of reasoning* and *formation of concepts*. *Reliability* of this model is assured by

examining the *segmentation* process, *dependency* codes, and *identification* of insights with the *quantitative* outcomes in a cyclic framework to arrive at self-regulation state.

In the following section two cases demonstrating different states of design are described applying directed linkography. The task is to design '*A Pavilion for your country at Expo Shanghai 2012*' within a one-hour time limit. The brief is unstructured giving the designer free rein. Video protocol, serial order of sketching, and the architect's retrospective comments are transcribed and coded. Applying directed linkography, results are presented as follows.

4.1 Case Study 1

4.1.1 Qualitative Description and Annotation of Linkograph

This design case represents Britain's pavilion, addresses conceptual elements such as: 'diversity of British society', 'life and sports', and 'science and history of the empire'. The process started insightfully then ideas were recalled in one site plan sketch. The transformation happened through bridging nodes. Figure 5-a presents the linkograph for this process annotated with the design contents and transformations of concept. Figure 5-b presents the computation method processing directed versus directed measures.

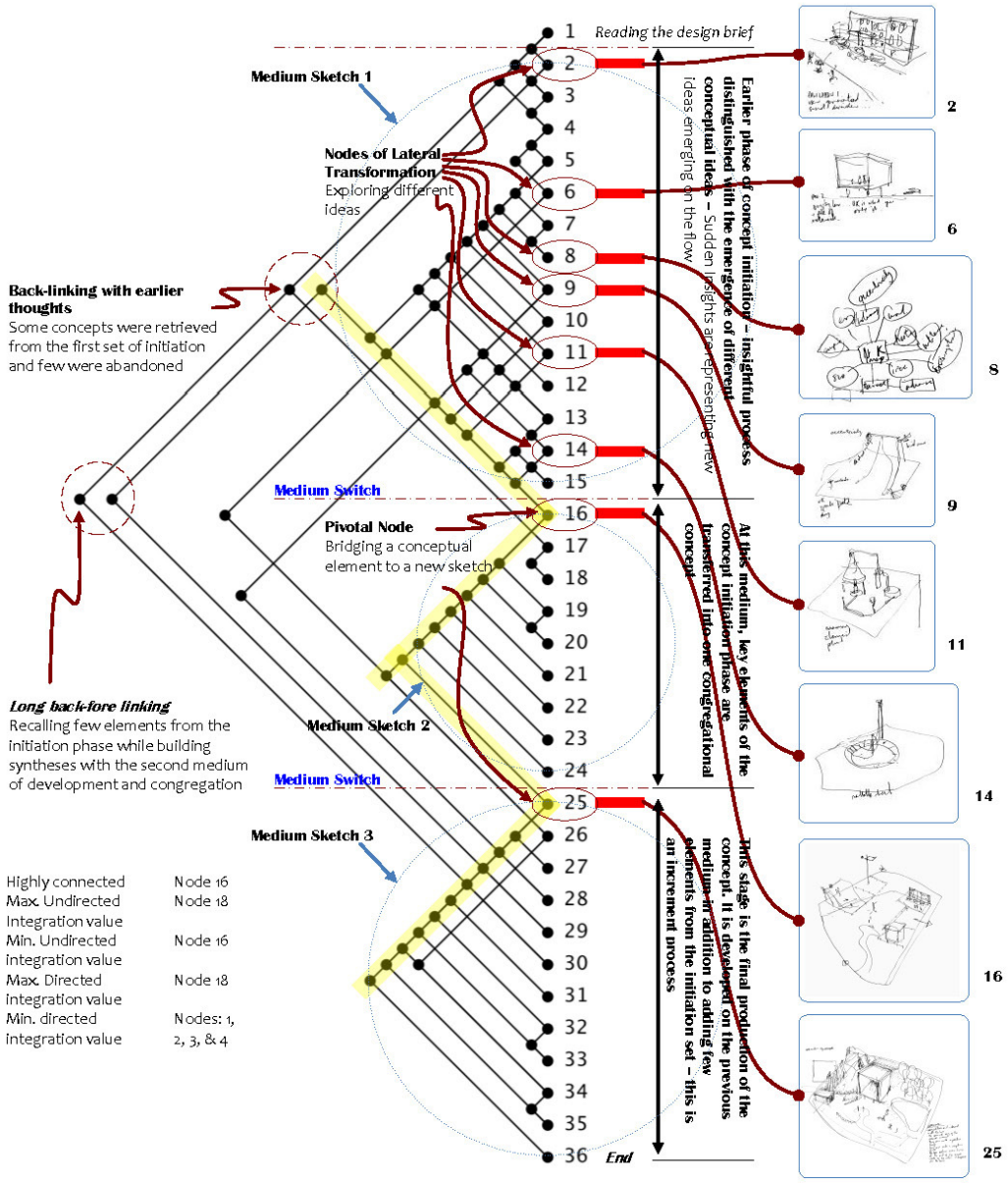


Figure 5-a: Annotation of creative insights, sketching contents, concept transformations via back/fore linking and sketching exchanges

4.1.2 Quantitative Analysis and Annotation of Linkograph

1| Node 16 is the highly connected vertex in the whole system. It represents the starting point of a new sketching episode after articulating some independent conceptual elements for the design idea at the first medium (nodes from 2:15). At node 16, the designer congregated the forms of the concept initiation phase to the new site plan sketch. It is a clear example of a bridging node, an insight that has emerged as knowledge transferred between different media sketches.

2| Equally integrated systems (of similar size) are observed for the series of nodes 19:24, then for the series of nodes 27:36, where each series reflects actions that were held in a certain medium sketch. Values are almost identical on directed and undirected scales for integration, closeness centrality, and for betweenness centrality.

3| The system is flattened at the early stage of the process. It is fully connected for the first three nodes giving zero RRA values.

4| Median systems deliver average on all measures (on balance to the whole network and to the directed measurements), which simply means that it is neither deep nor shallow in absolute terms.

5| Betweenness centrality:

Quantifies the number of times a node acts as a 'bridge'. Nodes 13, 16 and 25 represent three different cases when comparing directed and undirected results.

Node 13 bridges backlink relationships with its previous nodes with a relative value on back-directed betweenness measures; however, its effect on the following nodes is almost negligible according to the undirected measure. It is then bridging on a local level not on a global network.

Node 16 is an example giving different values of betweenness centrality results between directed and undirected methods. But it is considered a 'bridging' vertex since directed and undirected measures indicated its effect. The impact has increased from 0.2 on the directed scale to reach 0.6 on the undirected scale. This means that this node has a crucial role in transferring a certain idea and on structuring the following process and the overall system. It supports our hypothesis that the emergence of some creative insights could have a significant impact in some cases so as to structure the design actions. The insight imposes a structure of design concept on the following actions to the extent of binding the interim products to a particular transferred idea. This result has been checked with our qualitative model by judging the relations between the interim sketches before and after the emergence of each creative insight and was found to match.

Node 25 is a different example. The emergence has a significant impact on the following process and is considered to be a bridge transferring preceding knowledge to a new medium sketch. However, it isn't yet bridging on emergence since the directed betweenness equals zero while the undirected scale shows a value of 0.4 overall.

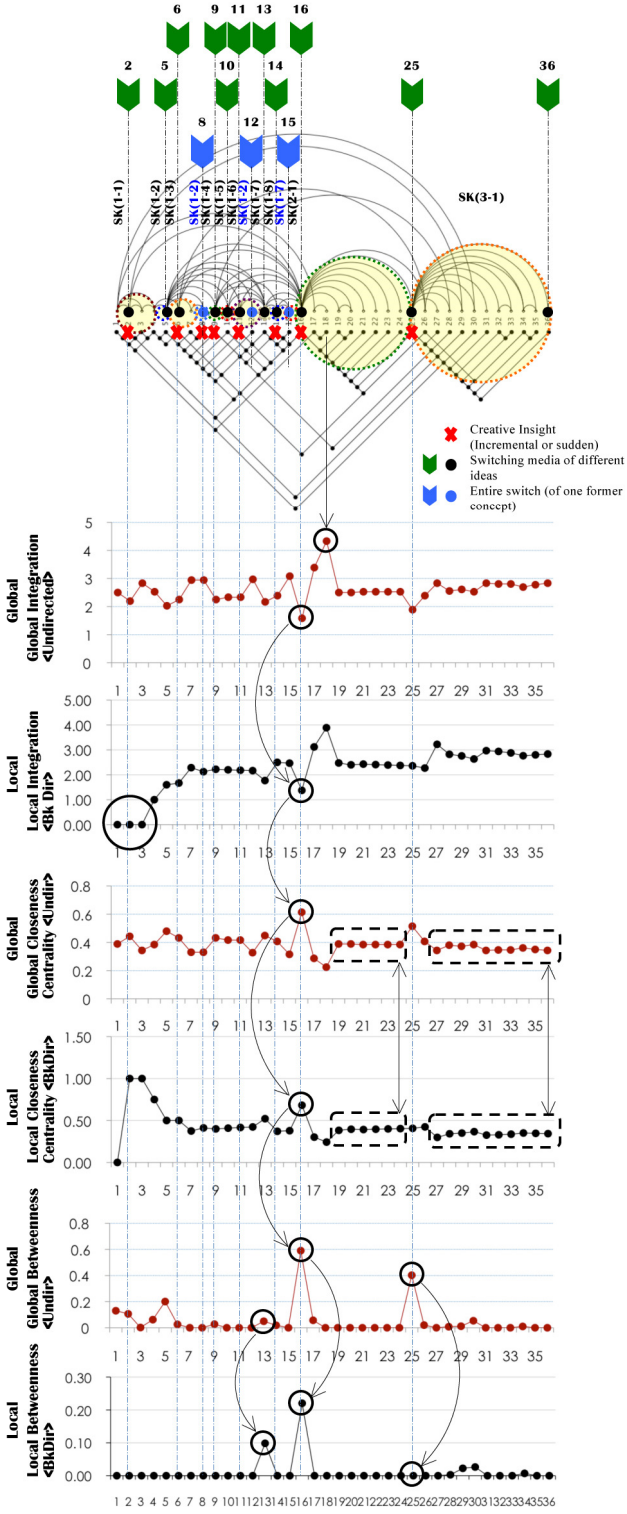


Figure 5-b: Annotation of quantitative measures over linkograph – undirected versus directed measures

4.1.3 Contrasting Directed and Undirected J-Graphs for Creative Insights

This method can be extended to compare directed and undirected j-graphs and investigate the context of the network beyond the emergence of sudden insight. See figures 6-a and 6-b for this case study.

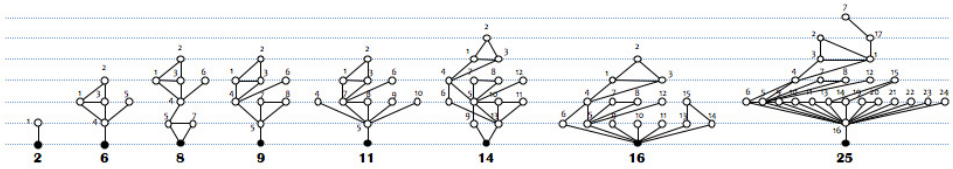


Figure 6-a: Creative insights represented by directed j-graphs for backlink relations

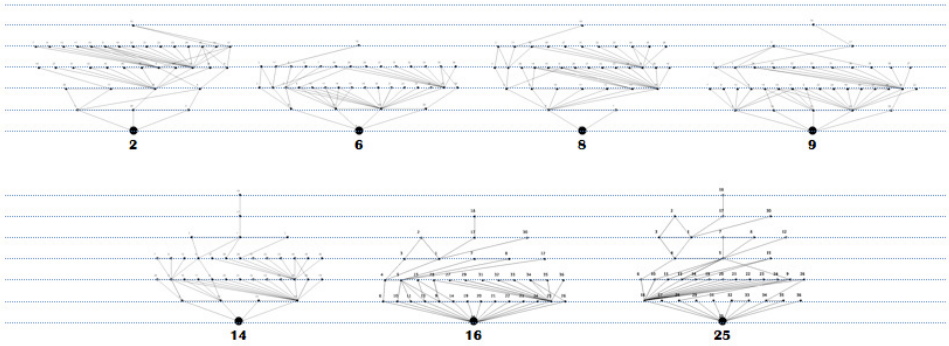


Figure 6-b: Creative insights represented by undirected j-graphs, concatenation of back and forelinks

4.2 Case Study 2

4.2.1 Qualitative Description and Annotation of Linkograph

This design case represents the Greek pavilion and addresses conceptual elements such as: 'sunlight and shadows', 'complexity of interlocking masses', 'trees and bushes', 'blue sky', 'sea ripples', 'rounded circulation', and 'rocks in water'. The process started insightfully, sketching each element independently. Each insight was then recalled to form a concept. Five pavilions were congregated in one master layout.

The fourth pavilion is a sudden change occurring on the prevailing stream. The concept is independent, representing 'immigration of Greeks' all over the world. It caused disconnection in the linkograph with no relation to the preceding or following events. This is a unique event, distinguished within the structure by applying directed linkography. Figure 7-a presents the linkograph for this process annotated with the design contents and transformations of the concept. Figure 7-b presents the computation method processing directed versus directed measures.

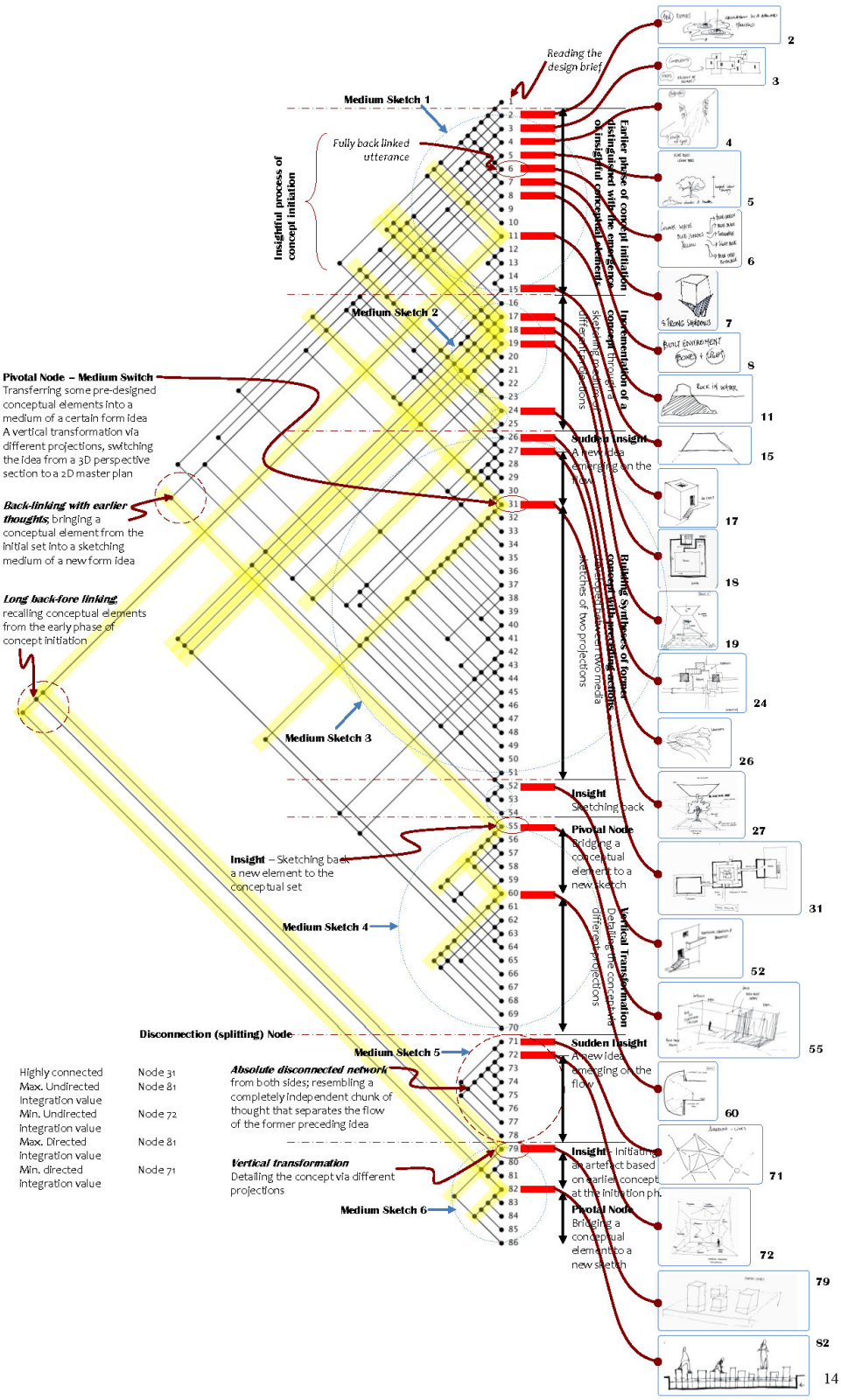
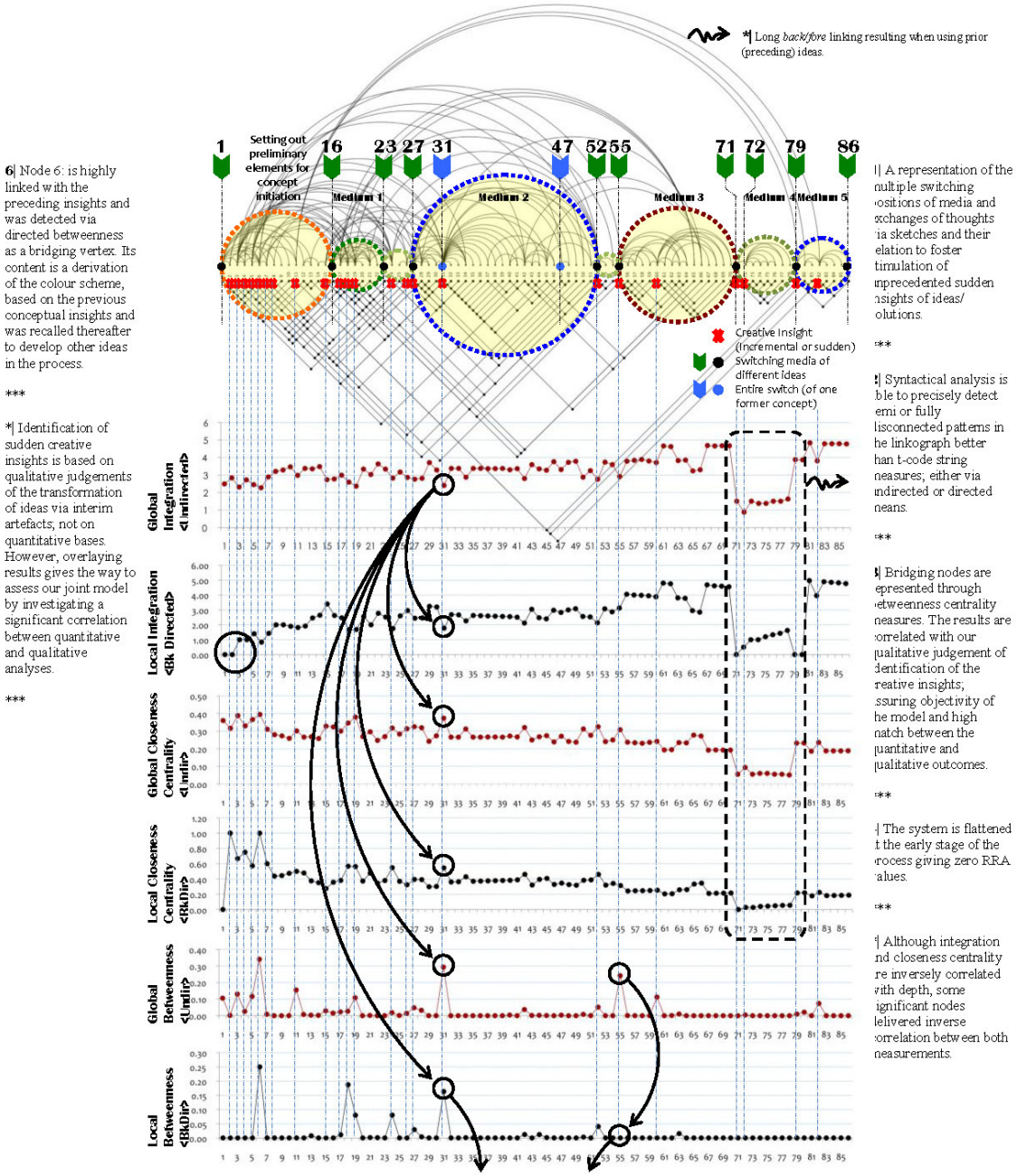


Figure 7-a: Annotation of creative insights, sketching contents, concept transformations via back/fore linking and sketching exchanges

4.2.2 Quantitative Analysis and Annotation of Linkograph



5| Node 31 is an example for a highly connected vertex but represent a deeply structured system with relatively low integration value either directed or undirected. Other bridging nodes are also stated via betweenness centrality measures. Both directed and undirected betweenness give precise results according with our identification of the pivotal nodes.

6| Node 55 is an example giving different values of betweenness centrality results between directed and undirected methods. The emergence has a significant impact on structuring the following process that resumed until a new insight has emerged on the flow. It became a bridge transferring preceding knowledge to a new medium sketch, however it wasn't yet bridging on emergence since directed betweenness equals zero.

Figure 7-b: Annotation of quantitative measures over linkography (undirected contrasted to directed values)

4.2.3 Contrasting Directed and Undirected J-Graphs for Creative Insights

This section compares directed and undirected j-graphs and investigates the context of the network beyond the emergence of sudden insight. See figures 8-a and 8-b for this case study.

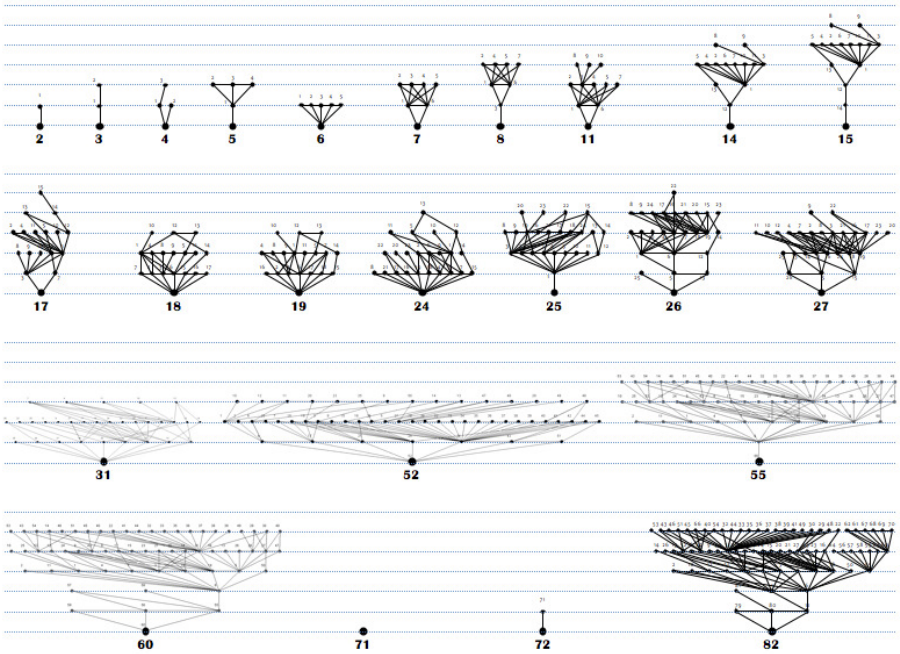


Figure 8-a: Creative insights represented by directed j-graphs for backlink relations

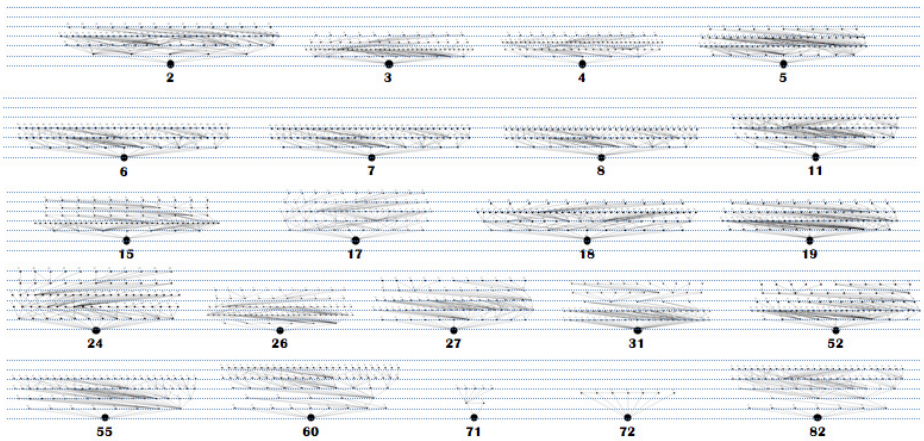


Figure 8-b: Creative insights represented by undirected j-graphs, concatenation of back and forelinks

5. Results and Discussion

This study presents a new method of looking at the design process. *Directed linkography* is a quantitative tool to detect the emergence of insights. By investigating venues where a *bridge* or *disconnection* occurs between different ideas, the impact of emergence on the overall structure is highlighted.

Two different situations are compared: *synchronous emergence* looks at *backlink* relations with preceding events (*local* measure), and the *diachronic* process of steps looks at *back* and *fore*

relations after completion of the whole design process. This method describes the overall structure of design from *top-down* and from *bottom-up*.

This study is developed from previous work modelling the design process where two quantitative methods are first applied to design linkographs: (1) *string t-code measures* looks at a basic level of *direct* relations (El-Khouly and Penn, 2012a; 2012b); (2) *syntactic analysis* measures *depth* for each vertex estimating *direct* and *indirect* relations. This tool is better at capturing minor and major changes in the multi-level hierarchical structure. The proposed method is evaluated according to the following criteria:

5.1 A Proposed Framework for the Evaluation of Directed Linkograph

1. The ability to capture different states of design, modes of reasoning and types of creative insights.
2. Giving rise to the possibility of better understanding the conditions in which creativity and innovation take place, this method reveals the following effects:
   i. Incremental insights show *continuous reframing* on one former idea.
   ii. Sudden insights demonstrate rapid *restructuring* of the problem.
3. The accuracy of quantifying a multi-level graph is guaranteed jointly using *syntactic* and *t-code* measures: e.g. *depth* measure illustrates *disconnections* and *hierarchy*, *betweenness centrality* for *bridging* nodes, and *entropy* indicates *uncertainty* per node as well as *complexity*.
4. J-graphs describe the structure of the network for any insight at and after emergence.
5. The impact of significant events occurring is assumed to stimulate the formation of novel concepts, through investigating the relation between '*emergence*' and '*context of reasoning*'.
6. The following items are illustrated via directed linkography:
   i. Connectivity of vertices.
   ii. Integration of vertices with the structure of networks.
   iii. Multi-level identity for the network.
   iv. Capture of the sudden changes in the structure of reasoning and emergence of insights in the linkograph.

5.2 Multiple Configurations for the Impact of Emergence of Sudden Insights on the Structure of the Design Process

From a range of recorded observations, in different design situations, to describe the impact of sudden creative insights on the design process, the following configurations are derived:

5.2.1 Configuration of Bridging Nodes

Bridging nodes transfer information from one idea to the next, which might cause collision between an old thought and the current situation. A creative solution may result from the sudden flash resulting from this unexpected collision. Figure 9 shows the following configurations that are outlined as contributing to structuring the design process:

1) **Case 'a'** represents a state where a design idea is initiated, developed and extensively improved. This chunk of thought is followed by a pertinent incremental insight occurring. The emergence has a relatively low effect on structuring the following process, especially where insights are integrated in the prevailing flow.

2) **Case 'b'**: the creative insight could have a tremendous effect on the structure of

the folowing process if it imposes a concept that is significantly reflected on the following actions and interim products. In this design situation, the insight acts as a *frame of reference* that continues until *hindrance* is experienced, requiring another insight to occur and exploration of another *frame* to overcome the problem experienced.

3) **Case 'c'**: represents the emergence of insights, weakly connected with the preceding actions, but imposed on the flow, shifting the design to a new state. In this situation, the emergence shifts the design trajectory to a completely new paradigm, restructures the problem and redirects the concept to a significant lateral transformation. It imposes a specific structure on the upcoming events, tying the design concept to a new frame of reference.

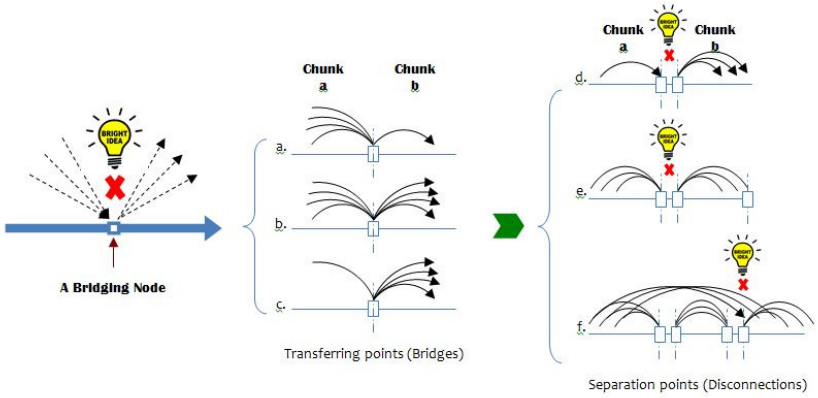


Figure 9: Multiple configurations for the impact of sudden insights on the structure of the design process

5.2.2 Configuration of Independent and Disconnected Events

The emergence of sudden insights could result in shifting the flow to a completely different state. In this situation, the new paradigm radically shifts the process, leading to disconnection of the pattern of design synthesis. Two or more separate chunks appear in the linkograph, embracing *disconnection* nodes within its pivotal structure. Diagrams of different configurations are outlined in Figure 9 as follows:

4) **Case 'd'**: the disconnection separates the linkograph completely into two indepdendent chunks of thought. In some states of design, the first stage might be hindering the process without providing inspiration to solve the problem, which a completely different idea could do.

5) **Case 'e'** presents two different situations. In spite of being sequential, both chunks of ideas are separate in their contents, developed independently. However each course of action may possibly nourish another idea that appears later or at the end of process.

6) **Case 'f'** shows a unique situation. The designer might diverge from a prevailing concept to explore a different one, gambling on another solution. A decision might then be taken to return to the old concept and develop it. This appears peculiar in the linkograph when a separate chunk appears in the pattern, while links are connected between *early* and *later* stages. A collision between old and present hunches might then occur following the decision to return to the old stream, giving rise to sudden insights.

5.3 Advantages of Directed Linkography

The advantages resulting from the directed linkography method are centred on the following points. First, the ability to distinguish different types of structures is associated with description of insights. The difference between sudden and incremental insights swings between deeply structured and shallow networks. According to the study sample, creative insights vary between both states. The more an insight appears to suddenly oppose the prevailing flow, the more the structure becomes shallow. This sudden change increases and in some cases causes a full disconnection.

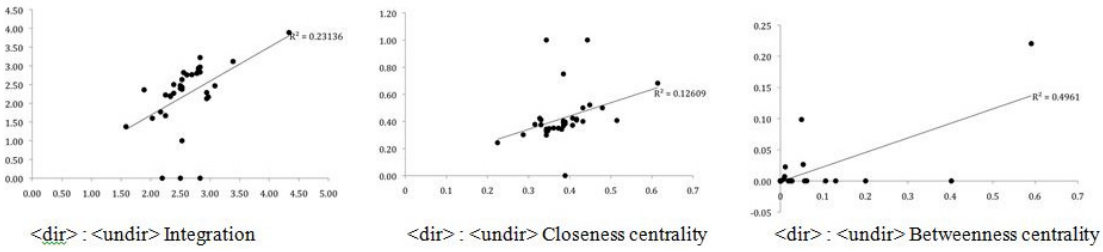
Second, the characteristics of networks for sudden insights are considered shallow with 'few' or 'no' relations with the precedents. Incremental insights are significantly structured with backlink relations, dependent on the precedents, often represented by the deep structure.

5.4 Correlation between Directed and Undirected Measures – Synchronic versus Diachronic Situations

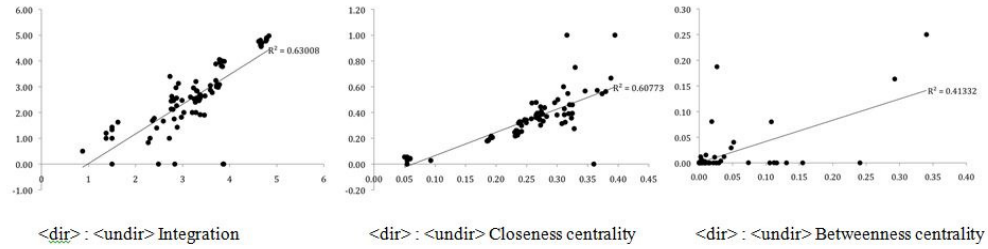
According to our investigation, the differences between directed and undirected measures are shown in Table 1, correlation values are presented in the scatter graphs of Figure 10.

Design Case	1st Measure	2nd Measure	R value	Relation
Case 1	<dir.> Integration	<undir.> Integration	0.48	Uncorrelated
	<dir.> Closeness centrality	<undir.> Closeness centrality	0.36	Uncorrelated
	<dir.> Betweenness	<undir.> Betweenness	0.7	Correlated
	<dir.> Integration	<dir.> Closeness centrality	-0.62	Uncorrelated
	<undir> Integration	<undir.> Closeness centrality	-0.94	Uncorrelated
Case 2	<dir> Integration	<undir> Integration	0.79	Correlated
	<dir> Closeness centrality	<undir> Closeness centrality	0.78	Correlated
	<dir> Betweenness	<undir> Betweenness	0.64	Correlated
	<dir> Integration	<dir> Closeness centrality	-0.27	Uncorrelated
	<undir> Integration	<undir> Closeness centrality	0.09	Uncorrelated

Table 1: Correlation values between directed and undirected measurements



Case 1: R^2 values reveal the change between directed and undirected measures



Case 2: R^2 values reveal the change between directed and undirected measures

Figure 10: Correlation values between directed versus undirected for each measurement category

5.4.1 Reading Correlation Values for Case 1

1. Results are uncorrelated for *integration* and *closeness centrality* reflecting the drastic change in the whole system being local compared to global.
2. The majority of nodes have imposed the structure after the emergence of insights when the characteristics of the pattern is significantly changed.
3. Vertices are either structured to the preceding actions or, conversely, linked forward to the following ones with few backlinks.
4. *Betweenness centrality* measures are highly correlated. Bridging nodes continue transferring knowledge between chunks of thoughts from the local to the whole network. Ideas for those events are preserved along the process constituting the main pivots in the whole structure.

5.4.2 Reading Correlation Values for Case 2

1. Results show significant correlation for the *integration* and *closeness centrality* values, reflecting stability of the system.
2. Although a disconnected zone occurred and was placed within the network it was treated separately as an isolated island. The former network is highly structured with no drastic changes captured in the structure from local to global levels.
3. *Betweenness centrality* measures are highly correlated; assuring a similar imperative role for those bridging nodes that maintained transferring knowledge between preceding and following activities.

5.4.3 Results of Cases Cross Analysis

1. In both cases, the impact of sudden insights on the design process is represented using the comparative tool of directed linkography.
2. Directed j-graphs for a spectrum of design insights reveal that both 'incremental' and 'sudden' insights have significant impact on the following actions and interim products.
3. Creativity is structured in both cases. The emergence of apparently sudden insights, produced by the subconscious, enable the designer to structure the next steps according to the ideas transferred.[4]

4 The story of Archimedes is a clear example of our reliance on structured creativity. He had realised the principle of floating bodies subconsciously. His Eureka insight structured his following actions into discovering that 'the displacement of water is equal to the volume of the floating shape', leading to the buoyancy principle. To discover whether the king's crown was of pure gold, he structured the following mathematical work accordingly: (1) he derived an equation to estimate the mass of the crown, and (2) he estimated density by dividing mass by the volume of water displaced, and concluded that the density was lower than that of pure gold proving that a cheaper and less dense metal had been substituted by the dishonest goldsmith.

6. In conclusion

Our aim of enquiring into design creativity and the formation of novel concepts, whether 'structured' or 'arbitrary', has revealed the need to develop an analytical tool that considers the dimension of 'time' to reveal the design process. This requisite is growing in the area of design research, in order to answer the question: '*how do sudden creative insights structure the design process?*'

This can be investigated by processing the linkograph contrasting *directed* and *undirected* measures in correlation with descriptions of the contents and events taking place in the design process, such as verbal protocols, visual materials and any externalised artefacts. Linkographs are widely used in the area of design cognition research. The dependency relationships between design utterances can be examined throughout our proposed method of directed linkography. The relations are weighed by looking at the synchronous emergence of events and comparing the local network to the global structure for each design action after final completion. To reach a better understanding of the formation of novel concepts and design creativity, this quantitative method is proposed to detect the emergence of creative insights and in particular to capture any exceptional sudden changes to the prevailing order of the linkograph; assuming the influence of those insights on the evolution of good ideas and the formation of creative processes.

From the observation of many architects, it seems that *designing* processes basically rely on the *imposition of order on arbitrarily provoked ideas*. This kind of order could be seen as an internal cognitive structure imposed by the designer, or as a reflection resulting from the interaction with different material culture or artefacts, forms, objects, drawings or any types of external cognitive structures. Architects explore design ideas in a way that seems random but underlies *cognitive order*: thinking in two or three dimensions, sketching or scribbling, switching between different design media, building new syntheses, enriching the design process with good ideas and so forth. Most often the design process starts with an insightful phase where ideas about some conceptual elements are tossed around looking for one or more on which to base the concept.

Our derivation for this quantitative model is predominantly built on the actual characteristics of linkographs, considered as multi-level, hierarchical and pivotal structures. The measure of depth is being adopted to investigate the relations between ideas with the precedents of content with reference to time. The examples of applications showed exceptional states of design that varied from being completely disconnected from the course of design actions to conversely being highly structured on the prevailing flow. Our intention of examining this model is only partially achieved in this paper as space limitations preclude the inclusion of more case studies in detail.

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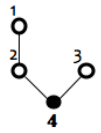
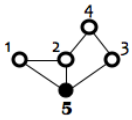
Appendix 1: Depth Measure for Directed Linkography:

1) Application to Figure 4-a:

- Node 2: has only one backlink to node 1, (2> 1), depth of one level only is required to go from node 2 to node 1, thus depth for node 2 equals 1 step.
- Node 3: has no backlink relation to nodes 2 or 1 and thus the network of this node is flattened with zero depth.
- Node 4: has backlink relations to nodes 3 and 2 but no relation with 1; however, to go to node 1, the steps required have to be counted through node 2 since node 2 has a direct relation to node 1, thus depth for node 4 equals: 1+1+2 = 4 steps.



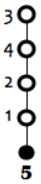
- Node 5: has backlink relations to nodes 3, 2, and 1, but has no direct relation to node 4. However to go to node 4, there are two shortest step ways, whether via node 2 or node 3 with 2 steps required. Thus, the depth for node 5 equals: 1+1+1+2 = 5 steps.



2) Application to Figure 4-b:

- The hypothetical case of Figure 4-b gives totally different depth measure. For the directed graph of node 5, it has one backlink direct relation to node 1 with no direct relations to nodes 4, 3 and 2 (knowing that any forelink from node 1 is not counted in our estimation for the backlink directed graph). Thus, depth of the directed graph for node 5 equals 1 step.

- However, for Figure 4-b, the estimation for the global depth measure for node 5 can take into account all back and forelink relations in the estimation process. Thus, node 5 has one direct relation to 1. However to go to node 2, 2 steps have to be taken via node 1. To go to node 4, three steps have to be taken via nodes 1 and 2. And finally to go to node 3, 4 steps have to be taken via nodes 1, 2, and 4. Thus the total depth of the undirected network for node 5 equals: 1+2+3+4 = 10.



3) Application to Figure 4-c:

- Figure 4-c is a linkograph with 21 vertices. Node 15 is the highly connected overall. Generating the j-graph for backlink relations for node 15, directed RRA value = 0.127, and directed integration = 7.87, which constitutes a very high value and reflects a highly ordered shallow system. At this case, node 15 is not expected to be reflecting a sudden creative insight; it is highly linked to most of the preceding vertices (78.5%), which is explained by very low probabilistic entropy.

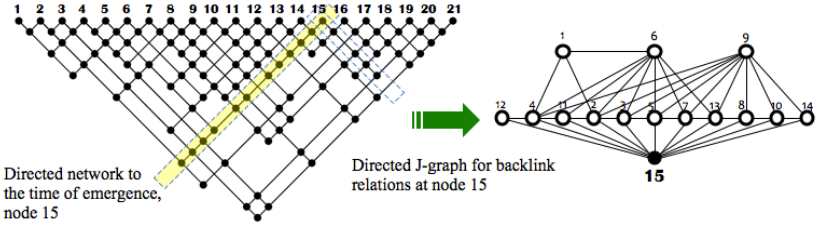


Figure 4-c: Back directed j-graph for node 15 – the highly connected in the whole linkograph