Conversation and Critique within the Architectural Design Process: A Linkograph Analysis

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Conversation and critique are central to architectural design practice as they function as tools for probing and further improving design ideas. We study the kind of design activities that take place in such conversation and critique within the architectural design process. We use linkographs to characterise the design process taking place during conversation. More precisely, we study conversations between design teachers and design students. In this article, an example design process is considered that takes place via a traditional face-to-face meeting. Using the resulting linkograph, we are able to assess the kind of design activity taking place during such sessions of conversation and critique.

Introduction

In this article, we will investigate a specific kind of architectural design engagement. Namely, we focus on the interaction among architectural designers during a session of conversation and critique concerning presented design ideas. We do this via an experiment that consists of a design team, a design teacher, and a specific design task.

In the experiment, the design team presents their design using a slideshow presentation. This presentation takes place after the first month of a design process that spans about three months, and it functions as an intermediate presentation of results. The design teacher gives feedback on the presented design, in close interaction with the design students. We have analysed this process of conversation and critique as if it were a traditional design process. More precisely, we analyse it using think-aloud pro-

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tocols and linkographs. In this case, the statements produced during the actual conversation are used as the instances of the think-aloud protocol. We try to identify 'design episodes' and analyse to what extent such design episodes can be subdivided into smaller design episodes in which smaller design experiments are performed and smaller design decisions are made. By doing this work, we hope to relate the larger picture of the design process to the specific design activities and design decisions that took place in the design process at hand.

We start in section 1 with documenting the background of this study and the reasons why we would want to analyse conversation and critique in this manner. In sections 2 and 3, an outset and methodology are given for the experiment. In section 4, a more detailed analysis is made using linkography.

Conversation and Critique

In this study, we consider the element of conversation and critique during an architectural design process. This focus can enhance our understanding of the effect of conversation and critique on the design process:

- how is ideation taking place during conversation,
- what is the role of design fixation in the role-play of design critique,
- to what extent evolves the design during the conversation,
- how is this evolution structured and characterised.

Conversation and critique are different from a traditional preliminary sketch phase. Yet, this kind of interaction is of considerable importance as well to the design process as a whole. Pauwels et al. [1] presents a schematic outline of the reasoning processes involved in designing. This schema entirely builds around the combination of an external world, on the one hand, and the human mind and its guiding principles, on the other hand. The interaction between both is crucial. In terms of this schema [1], conversation and critique among two people can be considered as a specific kind of interaction between two human minds and their respective external worlds. The external world of the first person then mostly consists of the feedback received by the second person in the dialogue, whereas the external world of the second person mostly consist of the feedback received by the first person in the dialogue. As the guiding principles or background knowledge of the two interacting people are personal and thus inherently different, a clash occurs between the two. The conversation then aims at

finding some sort of general mutual agreement of how the design should be interpreted and how it should consequently evolve. In looking for such an agreement, not only the guiding principles of both actors in the conversation change, also the design itself evolves into something new. On this basis, we consider the design moves taking place during conversation and critique as part of a creative design process, similar to an equally dedicated preliminary sketch phase.

With every move of interaction in the conversation, a certain evaluation or reflection is performed by the actor, in this case the designer, about the external interaction. Based on this evaluation or reflection, the guiding principles of the actor change, as well as the current interpretation or interpretation of the design itself. Note that, in most cases, not only is there an evaluation or reflection performed *after* the interaction, there is also a form of reflection performed *before* the interaction. This means that the actor consciously or unconsciously considers what he or she expects as a reaction from the external element of interaction. Any act in the conversation thus starts from an internal expectation that is part of an internal conversation.

One might consequently argue that any external interaction inherently includes a form of internal conversation. Internal and external interaction might thus be considered as tightly joint elements in one recurrent and continuous interaction with a surrounding world. We can thus consider one process following the arrow lines in Fig. 1, including internal conversation and external interaction in one loop. *"Ideas are developed in the mind; they are thoughts, conceptions that serve us to reason with"* [2, p. 5].

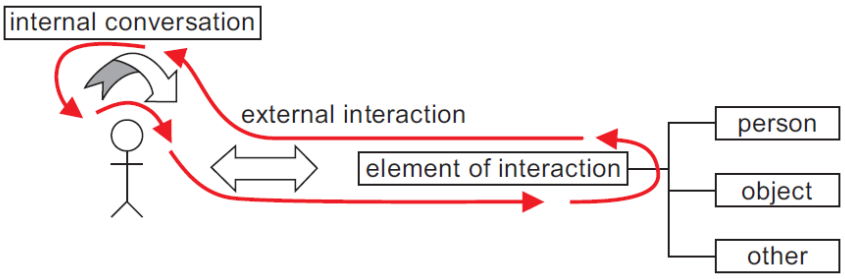

Fig 1. One loop for each interaction that a designer makes with the environment, including both external interaction and internal conversation.

Also other researchers have pointed towards the importance of conversation and/or interaction. For instance, Lymer et al. [3] considers conversation in architectural design as a *"rich site for the reproduction of architectural knowledge, in which multiple spatial and disciplinary contexts are*

embedded through representation, discourse, and embodied practice" [3, p. 197].

Case Study: Refurbishing High-Rise Buildings in Antwerp

Our case study consists of the transcript of a conversation that was made between a design teacher and a team of design students. This conversation was part of an architectural design studio that took place during 2013 in the Department of Architecture and Urban Planning, Ghent University, Belgium.

The Design Brief: Three Outdated High-Rise Buildings

Design students had received the assignment to design an alternative concept for three outdated high-rise apartment buildings in the city of Antwerp, Belgium. The three towers are located along the A12 motorway in Antwerp. Furthermore, the students were asked to investigate to what extent the concept of co-housing can be accommodated in this high-rise type of building. The design brief is highly constrained by its location. The location between a residential area and the busy motorway presents a delicate urban context. Other constraints need to be addressed as well:

- The buildings on the site need to incorporate about three hundred living units along with the facilities needed for *co-housing* and a *parking area* large enough to accommodate needs of the inhabitants and their visitors.
- Attention should be paid also to the *quality of the area surrounding* the high-rise buildings. The combination of the residential area, the area surrounding the high-rise buildings and the high-rise buildings themselves present considerable challenges in terms of *scale* and *feeling of safety and comfort*.
- *Sunlight* needs to penetrate not only into the building units within the high-rise buildings, it also needs to reach the residential area and the area surrounding the high-rise buildings.
- Considerable *fire safety* and *accessibility* constraints are present as well in the kind of high-rise buildings in the design context. For instance, fire safety and accessibility regulations implicate the need for compartmentalization measures, the need for large, separate evacuation staircases, the introduction of circulation shafts enclosed with fire doors, the prohibition of apartments spanning three floors, and so forth.
- The need for *privacy* within the living units.

• *Fluctuating wind turbulence* on the terraces and at the base of the high-rise buildings.
• *Structural constraints* inherent to any high-rise building.

The Considered Design Conversation

The particular conversation that is handled in this article dates 30 October 2013 and lasts for about 1 hour. In this conversation, the student team presents their work of the last week by means of a slideshow presentation and a building model. The slideshow consists of 8 slides displaying schemas and sketches that are used for reference during the conversation. In the conversation, the design team starts explaining the current design status while referring to their slides. During the presentation, the design teacher gradually starts to give feedback, making the presentation evolve into a discussion that influences the design process.

The design for the high-rise buildings that is presented in the current case study, starts from the *co-housing* concept. The design team hereby aims to implement cohousing at different scales (unit scale / community scale / tower scale / tower group scale / area scale - Fig. 2).

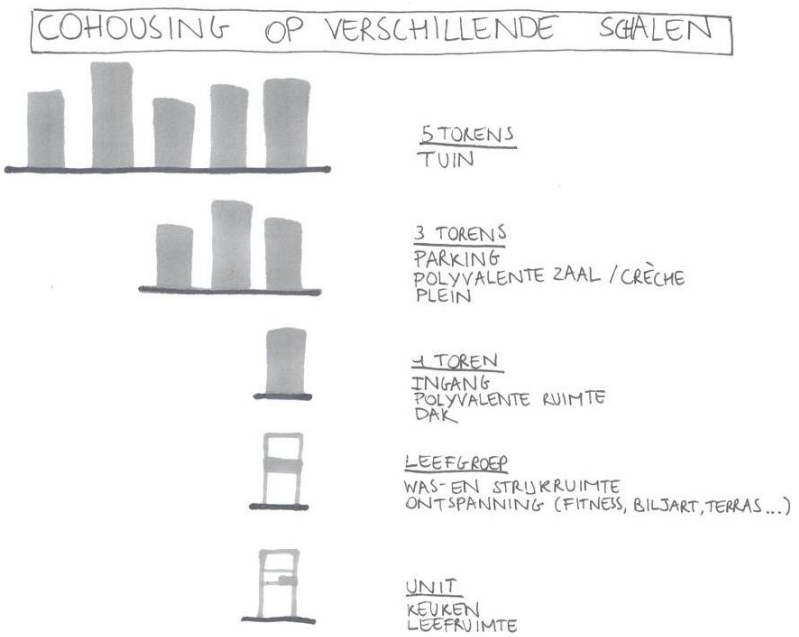

Fig 2. The presentation of the cohousing concept, which is to be implemented on five scales: an area scale, a tower group scale, a tower scale, a community scale, and an individual unit scale.

Apart from the scaled co-housing concept, the design team aims at incorporating *flexibility and variation* in the tower design. For example, the design team decides to diversify the type of units provided in the tower: large apartments, double-storey duplexes, small individual studios, and so forth. Also the *façade* follows this design intent, and finds its form through the patchwork of units, terraces and circulation shafts that are composed behind this façade. How this translates to a sound and logically formed *building structure* is also included in this part of the design conversation.

Finally, a large part of the design conversation also deals with the design of the relation between the high-rise buildings and the surrounding area, which includes *a parking and a park area*. The presentation of the design team ends with a sketch that represents the main idea behind this relation. Most importantly, an extra ground level or *deck* (+1) is introduced at the base of the towers. Beneath this local ground level, parking space is provided; and on top of the ground level, a surrounding park area is provided. This elevated ground level curves down to the actual ground level in areas without a tower.

Method: Linkograph Analysis

The session that is considered in this article was audio-recorded, transcribed and analysed using linkography, which is a well-documented and proven method to quantitatively study design processes. The method was first introduced by Gabriela Goldschmidt in 1990 [4]. The Function-Behaviour-Structure (FBS) ontology [5] was used within the linkograph analysis to assess which kinds of design moves are at play in the critical conversation between the design teacher and the design student team. For the actual analysis, the LINKOgrapher tool [22] was used.

Linkography

Processes of design thinking are most commonly analysed with protocol studies [6,7]. In this method, a track record is obtained from designers involved in design activity through think-aloud protocols [8]. Example studies were documented by Ennis & Gyeszly [9] and Kavakli & Gero [10]. Although diverse methods exist to analyse protocol studies, linkography can be considered as one of the most successful. Linkography is a method for representation and analysis of design processes focusing on links among design ideas. The method was first introduced to protocol analysis for assessing the design productivity of designers [4]. It was then further developed by Goldschmidt [11-13] and used by others [14-18].

Linkography has been established as a quantitative evaluation technique in protocol analysis to study designers' cognitive activities.

In order to produce a linkograph, the recorded design protocol is transcribed and subdivided into small segments of approximately one sentence. This typically results in a spreadsheet file with a chronological list of all statements made in the design process. Each resulting segment is considered a *design move* and given a sequence number, typically using the same spreadsheet file. Goldschmidt defines a 'design move' as *"a step, an act, an operation which transforms the design situation relative to the state in which it was prior to that move"* [11]. Second, the protocol study is analysed for associations between the distinct design moves, resulting in a network of links between the design moves [19], which can also be recorded in the same spreadsheet file. Goldschmidt hereby distinguishes two types of links: backlinks (links from a particular design move to a *preceding* design move) and forelinks (links from a particular design move to a *subsequent* design move). The way in which these two types of links come about, and the way in which they ought to be interpreted is comprehensively outlined by Goldschmidt in 1995 [11]. *"For each move we pose but one question: is it linked to every one of the moves that precede it in a given sequence of moves such as a design unit? We use a binary reply system of 'yes' and 'no' only, and the sole criterion used to determine linkage or its absence is common sense, in the context of the design task. Thus we establish links among a given move and previous moves, and these links are called backlinks, because they go back in time. With hindsight, linkography allows us to specify the links that a move makes to subsequent moves. These links are the move's forelinks, because they go forward in time. In contrast to backlinks, which can be determined at the time a move is made, forelinks can be determined only after the fact, when the entire process is completed, and as a consequence of having registered all backlinks. The two kinds of links are very different conceptually: backlinks record the path that led to a move's generation, while forelinks bear evidence to its contribution to the production of further moves."*.

Using a linkograph, typically recorded in the earlier mentioned spreadsheet file, the design process can be analysed in terms of the patterns in the linkograph, which display the structure of design reasoning. Using the Link Index (LI) and Critical Moves (CM) parameters, a quantitative analysis can be made of the protocol study [11,20]. The LI parameter equals the ratio between the total number of links and the total number of design moves in the linkograph. A high link index then supposedly indicates a productive design process, as the produced design moves are highly related to each other, and many of the links thus were productive in creating a coherent design process. The CM parameter indicates design moves with a

high number of forelinks or backlinks. A critical move can thus be understood as a design move that had a high impact on the design process, and, as such, also on the eventual design product.

Nevertheless, Kan and Gero [19] argue that the LI and CM parameters are not the best indicators of design productivity, by arguing that a fully saturated linkograph, which thus has a high LI and a high CM number, indicates no diversification in ideas, hence less design productivity. They point towards using entropy measures as indicators of design productivity. Shannon [21] defines entropy as a measure of information. The measure of information carried by a message or symbol depends on the probability of its outcome. If there is only one possible outcome, then there is no additional information because the outcome is already known, thus resulting in a low entropy value and a low design productivity [17]. We will use both measures (LI and CM; entropy) to analyse the studied design conversation.

The FBS Ontology

To further improve the analysis of a linkograph, a Function – Behaviour – Structure (FBS) ontology [5] can be used. The terms used in the ontology are schematically shown in Fig. 3, for reference.

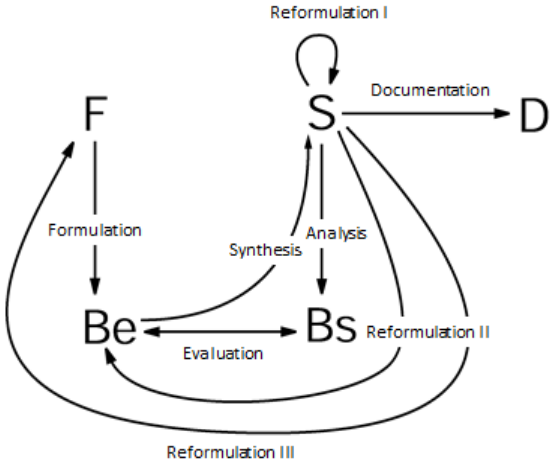

Fig 3. Schematic overview of the FBS coding scheme.

The FBS ontology allows coding the character of the design moves identified in the linkograph. The coding scheme consists of the six following codes.

- Requirements (R)
- Function (F)
- Behavior derived from expectations (Be)
- Behavior derived from structure (Bs)
- Structure (S)
- Documents or design descriptions (D)

A brief description of the FBS ontology and its six codes is given by Kan et al. [18], so we do not elaborate on this any further in the remainder of this paper. When combining the FBS ontology and linkography, the kind of change initiated by every single design move in a linkograph can be formally characterized. The design process is hereby considered as a process that starts from a set of requirement (R) and function (F) statements, which are continuously analysed (Bs), evaluated (Be) and synthesised into structure (S) statements. Eventually, documentation (D) statements are produced, documenting the structure coming out of final design decisions. After encoding, eight design transformation types can be considered (Fig. 6) [22-23]: formulation (F -> Be), synthesis (Be -> S), analysis (S -> Bs), evaluation (Bs <-> Be), documentation (S -> D), reformulation I (S -> S), reformulation II (S -> Be), and reformulation III (S -> F). These transformation types will be referred to below as 'FBS processes'.

LINKOgrapher

For making the analysis of the considered case study, we used the LINKOgrapher tool [22]. This tool relies on an input spreadsheet file that encodes the distinct design moves, the links between the design moves, and the FBS codes affiliated to all design moves. Using this information, the LINKOgrapher tool not only generates a visual representation of the resulting linkograph, it also makes a set of graphs and calculations based on the linkograph and the FBS codes. These include link index tables, entropy value tables, Markov models and other more general statistics.

Results

A linkograph has been generated for the considered design session. We generated this linkograph using the method discussed above. Namely, we made an audio recording of the session in which the design team and the design teacher had a critical conversation. This audio recording was transcribed in an Excel spreadsheet, segmenting the whole session in design

moves. Then, we added the FBS annotations and made the links between the design moves as we saw fit. The full linkograph is available online [24], including the original spreadsheet file and some of the documents that can be generated for the linkograph using the LINKOgrapher tool. For reference, a part of the linkograph is shown in Fig. 4.

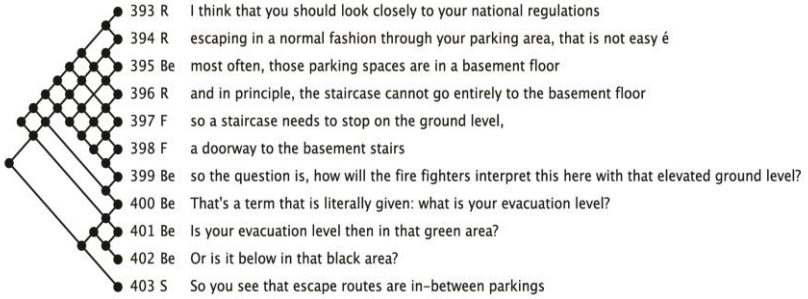

Fig 4. A randomly chosen part of the linkograph that is generated by the LINKOgrapher software. On the right, the transcript is shown of the diverse design moves. Left of these design moves, the FBS qualifications are shown (Be, S, R, etc.). On the extreme left, the links between the design moves are indicated with lines and dots.

Figure 4 also shows what is meant by the earlier mentioned FBS processes. For instance, the process of going from design move 402 to 403 involves a transition from a design move annotated as Behavior derived from expectations (Be) to a design move annotated as Structure (S), which is considered as a process of Synthesis (Be->S). When considering only the sequence of design moves, without the forelinks and backlinks, one refers to the *syntactic* occurrences of the FBS processes (e.g. 'Synthesis'). Alternatively, one can also consider the *semantic* occurrences of the FBS processes, meaning that not the chronological sequence of design moves is used, but the actual links between the design moves are considered. In the case of Fig. 4, the design moves 400 and 403 can be considered as a semantic occurrence of the FBS process 'Synthesis' (Be->S) and the sequence from move 402 to 403 is not taken into account as a semantic occurrence of an FBS process.

It must be clear that segmenting the transcript in design moves, annotating the design moves, and deciding which design moves are linked, is subject to personal judgement. As Goldschmidt [11] indicates as well, *"the sole criterion used to determine linkage or its absence is common sense, in the context of the design task"*. In order to minimise the influence of personal judgement, it would be highly valuable if the design process was an-

alysed by a third party as well, so that the conclusions can be further verified. Therefore, we have provided our initial data in [24].

General Statistics

The complete linkograph counts 811 segments or design moves and 4383 links between those design moves. Each design move is thus linked to about 5,40 other design moves, resulting in a link index (LI) value of 5,40 [11]. This is a high value, considering that Goldschmidt marks a LI value of 0,83 as low and a LI value of 1,73 as high [20]. This might be one of the first differences between a common preliminary design or sketch process and a critical discussion as it is studied here. Namely, the high LI value might be explained by the fact that the studied conversation contains a significant amount of repetition. Initial ideas are coined, both by the design team and the supervising design teacher, and they are continuously referred to by them later on in the conversation when they aim to explain or defend the coined ideas. For more individually oriented design processes, it might be more often the case that designers continuously build on some initial idea and move forward towards a design concept and structure. In a critical design conversation, more effort is invested in finding mutual agreements on the functions, structures and goals that should be reached.

In the online schematic display of the full linkograph [24], an indication is included of the design episodes that were outlined for the considered design process, using the linkograph visualisation and the protocol study contents. Six main design episodes were identified: an introduction episode (moves 0-14); a duplex principles episode (moves 15-177); a shaping the façade episode (moves 178-357); a structural design episode (moves 358-495); a design of the urban context episode (moves 496-779); and a summarizing episode (moves 780-811). When looking at the LI values for these individual design episodes, equally high LI values are found. Namely, the LI values are, in sequential order: 3,21 (episode 0-14); 4,54 (episode 15-177); 3,96 (episode 178-357); 4,36 (episode 358-495); 4,68 (episode 496-779); 3,54 (episode 780-811). These LI values only take into account links that fall entirely within the considered episode and thus do not link to design moves in the other design episodes.

FBS Issue Distribution

Each design move has an FBS code assigned, resulting in the following frequencies for each of the FBS codes (Table 1) and their corresponding processes (Table 2). As can be seen from Table 1, most of the design effort goes to expected behaviour (Be), behaviour derived from structure (Bs) and structure (S), which is to be expected in such a design conversation.

Table 1 FBS issue distribution over the linkograph.

FBS code	Number of occurrences	Percentage of occurrences
R	35	4,3%
F	75	9,2%
Be	211	26,0%
Bs	253	31,2%
S	217	26,8%
D	20	2,5%

The FBS process distribution (Table 2) can be considered in 4 ways, of which each is represented by a separate column in Table 2. It is especially important to note the difference between *syntactic* and *semantic* occurrences of FBS processes. Only the latter take into account the existence of links between the design moves: *"B>A is a valid transition process if B is linked back to A in the linkograph."* (Pourmohamadi and Gero - [22]). Therefore, we consider the two rightmost columns in Table 2 as the more significant indicators of the frequencies in which the different FBS processes occur.

Table 2 FBS process distribution over the linkograph.

FBS process	Number of syntactic occurrences	Percentage of syntactic occurrences	Number of semantic occurrences	Percentage of semantic occurrences
Formulation (FBe)	23	6,5%	105	5,5%
Synthesis (BeS)	41	11,6%	230	12,1%
Analysis (SBs)	78	22,1%	362	19,0%
Evaluation (BB)	78	22,1%	538	28,3%
Documentation (SD)	3	0,8%	9	0,5%
Reformulation I (SS)	93	26,3%	330	17,3%
Reformulation II (SBe)	31	8,8%	236	12,4%
Reformulation III (SF)	6	1,7%	93	4,9%

As can be concluded from the statistics in Table 2, most attention goes to analysis (SBs) and evaluation (BB), followed by Reformulation I (SS). This image of the design process corresponds to our earlier conclusions based on Table 1: the goal of the conversation is to assess an existing design proposal in order to improve it. Hardly any documentation (SD) is taking place, in which structural design decisions (S) result into explicit documentation.

A more detailed understanding can be found by looking at the distribution of FBS codes over the complete linkograph timeline (window set to

80). In this respect, the graphs shown in Fig. 5 to 8 were generated by the LINKOgrapher software (available also online [24]). In Fig. 5, all six FBS codes are shown on the linkograph timeline, indicating that design moves deal most often with Structure (S), Behaviour derived from structure (Bs) and Expected behaviour (Be) throughout the entire conversation, as indicated before. Additionally, one can notice how diverse 'peaks' appear to be generated by the design moves that focus on Requirements (R), further reinforced by local peaks of design moves that focus on Function (F).

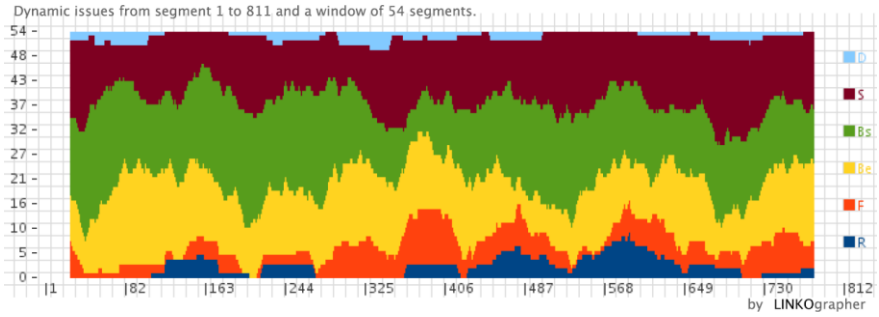

Fig 5. Overview of the FBS code distribution over the complete linkograph timeline, as it is produced by the LINKOgrapher software (see original image online [24]). From top to bottom, the following FBS codes are represented: documentation (D – light blue); structure (F – purple); behaviour derived from structure (Bs – green); expected behaviour (Be – yellow); function (F – orange); requirements (R – dark blue).

When looking specifically at the design moves that focus on Function (F), these peaks can be distinguished even more clearly. The linkograph data additionally shows that the distribution of design moves focusing on Structure (S) complements the distribution of design moves focusing on Structure (F) (Fig. 6). In other words, peaks in the F issue distribution coincide with valleys in the S issue distribution, and vice versa.

From this observation, one can conclude that the design decision process appears to start at the appearance of a certain requirement (R), or even more prominently, the appearance of a desirable functionality (F). Based on that, certain evaluations and analyses are made (Be - Bs), eventually leading to certain (ad hoc) decisions regarding Structure (S). These (ad hoc) decisions do not lead to documentation in the current design conversation, but supposedly, they will lead to documentation in the time period following this conversation, when the design students go back to their more individual design environments. In Fig. 7, an overview is given of the dynamic FBS processes occurring in the design conversation, showing

peaks in the rightmost part of the graph that coincide with the rightmost peaks in Fig. 7 and the associated critical moves.

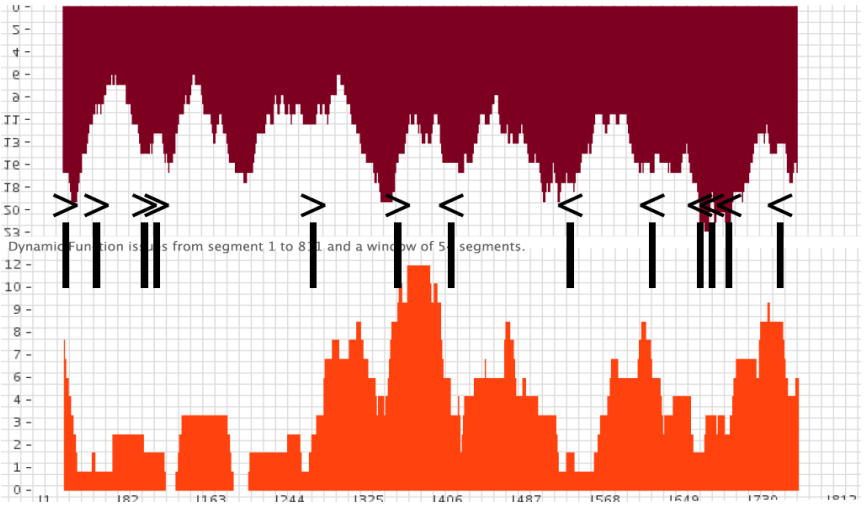

Fig 6. Distribution of the design moves that focus on Function (F – below) and Structure (S – above) (see original image online [24]). Also, critical forward links (>) and critical backward links (<) are indicated.

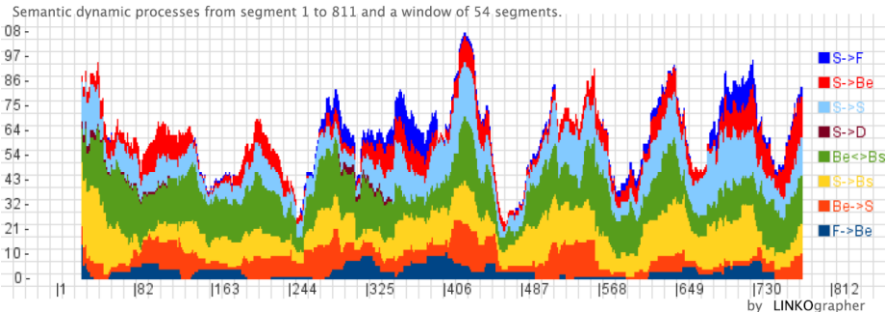

Fig 7. Distribution of the FBS processes throughout the linkograph timeline (see original image online [24]).

Critical Design Moves

Critical moves (CM) can be distinguished using the number of backlinks and/or forelinks starting at specific design moves. In terms of forelinks, design moves 26, 70, 131, 135, 288, 373 are the most critical (Table 3). These design moves indeed correspond to design ideas and intentions to

which are often referred during the conversation and seem to steer the ideation process.

Table 3 Critical design moves in terms of forelinks, with an indication of the design move number, the content of the design move, and the assigned FBS code.

Number	Content	FBS code
26	We have two areas for circulation	S
70	I had hoped that you would have reached something using that duplex principle	Be
131	Yes we thought to create contrasts	S
135	but the form is 'created', so to speak	Bs
288	So that the floor plan determines the form and the look of that tower	S
373	that we parked at the bottom at ground level, and that the entrance to the building	S

In terms of backlinks, design moves 410, 555, 643, 686, 712, 721, 727, 759 are the most critical (Table 4). As can be seen in Table 4, these critical moves are most often assigned a Bs or Be code, which indicates that they are often of a evaluative or analytic nature, in contrast to the critical design moves in Table 3. Indeed, these design moves correspond to statements that can be considered as key in the *evaluation* of the current design.

Table 4 Critical design moves in terms of backlinks, with an indication of the design move number, the content of the design move, and the assigned FBS code.

Number	Content	FBS code
410	Come on, you are thinking so much about those duplexes and so forth	Bs
555	shouldn't you attach entrance points to circulation and program?	Be
643	If you don't have the freedom to say: "on the corners where we think that such a connection is feasible, we will replace the apartment by some collective area"	Bs
686	I am curious though to the way in which those different constellations give form to that park	Bs
712	Don't you have anything else to do at the ground level of a tower besides placing pilotis between which cars are driving?	Be
721	It is obvious that a discourse is emerging about the ground level that is not yet fully designed	Bs
727	but, in that case, you expect something in terms of functionality	Be
759	The way in which you are handling the living units,	S

The critical moves in terms of backward links (Table 4) can easily be recognised in the FBS processes graph in Fig. 7, as they coincide with the peaks at the right of this graph. In other words, these design moves are the end points of many of the links, which are interpreted as FBS processes in the graph of Fig. 7. They represent the key comments or conclusions for the design process. Critical design moves in terms of forward links (Table 3) can less easily be recognised in the FBS processes graph in Fig. 7. This is to be expected, as these design moves represent the starting points of such processes, which is not what is shown in this graph.

Critical design moves in general furthermore appear to coincide with the peaks in the distribution shown above in Fig. 6. This distribution represents the evolving number of design moves that are annotated as Structure (S). To conclude, the critical design moves thus represent the key structural elements in the presented architectural design, with the critical moves pointing backwards having an additional conclusive and evaluative character.

Entropy Evolution

As indicated above, entropy measures provide an alternative way to analyse the productivity of the design process (see also [17,19]). By using entropy to characterise the links in the linkograph, an assessment can be made of the extent to which a design move is unexpected or surprising in the whole of the design process. As stated by Kan and Gero [19], *"information can then be defined in relation to the surprise it produces or the decrease in uncertainty"*.

In this analysis, we will use the *horizonlink entropy* indicator that is produced by the LINKOgrapher software, following the calculation procedure documented by Kan and Gero [19]. A horizonlink is a different kind of 'link' than a forelink or a backlink in a linkograph. It is not an explicit link; rather, a horizonlink is a measure of the *distances* of links in a certain part of the linkograph. It is stated by Kan and Gero [19] that design moves are more likely part of a short term 'working memory' process, when they have a small horizonlink indicator, because they only have short-distance links. Design moves with a high horizonlink indicator include long-distance links, which are interpreted as 'incubated moves' [19]. Those links refer to reflection in action [19,25]. We follow here the interpretation by Kan and Gero [19] that *"a good design process contains unsaturated short links plus a number of long links"*. When using the entropy measure of horizonlinks, we have an indication of the unpredictability and 'chaos' that is present in certain portions of the linkograph. A low entropy measure indicates that the linkograph is either fully saturated (1) or completely

without any links (0). In both cases, the entropy is 0. A high entropy measure indicates that the linkograph has an unpredictable and seemingly random structure. According to Kan and Gero [19], this feature indicates a process in which more 'opportunity for idea development' is present and which can thus be considered more productive.

The entropy evolution for the considered case study is given in Fig. 8, overlaid with the FBS processes graph that was given earlier in Fig. 7. This graph clearly shows a number of peaks, in which the entropy indicator maximizes temporally. These peaks coincide with the peaks that were encountered in the FBS processes graph (Fig. 7). The rightmost peaks indicate the points where the critical design moves were also found.

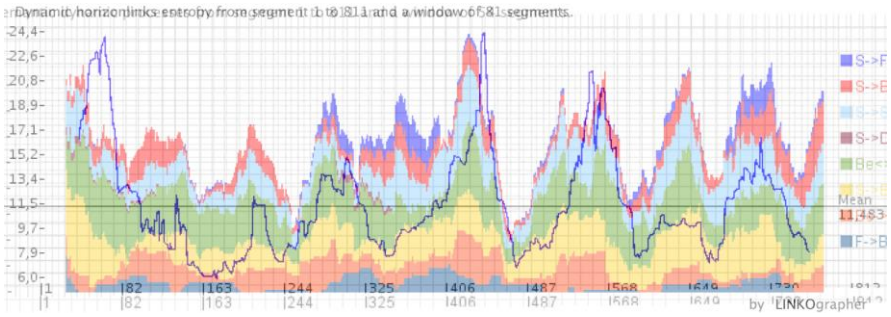

Fig 8. Horizonlink entropy evolution over the linkograph timeline, overlaid with the FBS processes graph as it was given earlier in Fig. 7. (see original image online [24]).

For the rightmost design moves in the current case study, both the horizonlink entropy indicator and the CM indicator thus point to the same (four) regions as highly productive. These peaks indicate the design episodes in which the conversation deals with the structural design and the design of the urban context of the tower, including the design of the parking spaces, public spaces and the park area. Indeed, there was quite some more discussion and less initial agreement about these topics. As a result, more opportunity for idea development is present in these design episodes. The leftmost design moves have less critical moves in terms of backward links. Also in terms of entropy, this region appears to be less 'productive'.

'Less productive' design episodes were found in the leftmost portion of the conversation, apart from the peak at the very beginning of the design conversation. The initial entropy peak can be explained as follows. In the beginning, the student design team presents the main ideas behind their design decision of the past week. References are made to these ideas from very diverse episodes in the design conversation. Hence, they are very val-

uable for the production of ideas. In the following period, which shows a lower overall entropy value, initial comments and questions are given regarding the design, providing the option to the design teacher to understand the reasoning behind the presented design decisions. Little new ideas are produced in this part of the process, also because it incorporates more agreement about the good points of the presented design.

Conclusion

Using linkographs, we have analysed a conversation in which a design team presents their design to a design teacher and receives feedback and remarks regarding their design decisions. By doing so, we give an idea of how conversation and critique can be interpreted as important parts of an architectural design process. The resulting linkograph, and the associated statistics, resulted in the following conclusions.

The link index of the resulting linkograph is high, indicating many links between the design moves and a rather dense conversation. According to Goldschmidt [20], this is an indication of a productive design process. However, it might also indicate here that designers involved in conversation and critique tend to keep referring to the same ideas, over and over again, in order to persuade the one or the other of a certain element / design move that should be included or excluded. This would indicate that the character of conversation and critique is considerably different from a traditional design session, in the sense that more critical features of the design are questioned, requiring the people involved in the conversation and critique to revisit these critical features over and over and evaluate them again and again. This can make sense in the current context of conversation and critique, as the student design team has been working on their design for about a week, working in a specific direction, and they are now returning to the design teacher, who needs to question the sometimes drastic design decisions taken. This conclusion is in line with the considerations made at the outset of this article (section 1), where it is presumed that conversation and critique tend to focus more on finding mutual agreement on concepts and ideas. The conclusion is further confirmed by the finding that design moves in the analysed conversation deal most often with structure (S), behavior derived from structure (Bs) and expected behavior (Be). Critical features in the design (S) are continuously evaluated in terms of what they are meant for (Be) and what they achieve in the design (Bs).

Analysing the conversation in terms of entropy measures indicates that the first part of the conversation is ‘less productive’ in terms of idea devel-

opment [17], in contrast to the second part of the conversation, which has higher entropy peaks at the points where critical design moves are found. Also, the entropy peaks appear to coincide with the points where critical design moves are found, which are typically those points in the conversation where less agreement is found between the design teacher and the design team. So, considering the interpretation of entropy by Kan and Gero [19], those points where the two partners in the conversation and critique disagree more fundamentally, are actually the points with the highest degree of 'design productivity'.

These two main findings of conversation and critique in architectural design (the high link index, and the importance of significant disagreement) provide very relevant feedback to designers, design students and design teachers. It is namely not only concluded that conversation and critique are highly productive, it is also concluded that they are so productive *because* they provide alternative and important opportunities for profound disagreement and questioning of the most basic concepts. So, first, conversation and critique are media of considerable value in design thinking, and these media should be maximally used instead of avoided by any designer. Second, in order for a design critique to remain as impacting and efficient as possible, not only for students, it is highly important that a critical eye is maintained and that disagreement is almost intentionally sought.

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