QUANTIFYING THE INTANGIBLE

A tool for retrospective protocol studies of sketching during the early conceptual design of architecture

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Abstract. Sketching is a craft supporting the development of ideas and design intentions, as well as an effective tool for communication during the early architectural design stages by making them tangible. Even though sketch-based interaction is a promising approach for Computer-Aided Architectural Design (CAAD) systems, it remains a challenge for computers to recognise information in a sketch. Design protocol studies conducted to deconstruct the sketch and sketching process collect solely qualitative data so far. However, the 'metis' projects aim to create an intelligent design assistant, using an artificial neural network (ANN), in the manner of Negroponte's Architecture Machine. By assimilating to the user's idiosyncrasies, the system suggests further design steps to the architect to improve the design decision making process for economic growth, qualitative self-education through the dialogue and reducing stress. For training such ANN quantitative data is needed. In order to produce quantifiable results from such a study, we propose our open-source web-tool 'Sketch Protocol Analyser'. By correlating different parameters (i.e. video, transcript and sketch built) through the same labels and their timestamps, we create quantitative data for further use.

Keywords. Design Protocol Studies; Sketching; Data Collection; Architectural Design Process; ANN; SDG 3; SDG 4; SDG 8; SDG 9.

1. Introduction

Sketching is a craft supporting the development of ideas and design intentions

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(Lawson, 2005) as well as an effective tool for communication during the early architectural design stages by making them tangible. Therefore, sketch-based interaction is a promising method for an intuitive interaction with a Computer-Aided Architectural Design (CAAD) system that naturally integrates into the design process (Leclercq and Juchmes, 2002). Early attempts to enable sketch-based interaction with information systems date back more than half a century (Sutherland, 1964). The advancing digitisation of the construction industry and the associated growing data volumes increased the use of state-of-the-art approaches of artificial intelligence (AI), such as Case-based Reasoning (CBR) and deep learning (DL). Nevertheless, up to this day the formalisation of building on the computer usually focuses on fully designed buildings, while sketches of the early conceptual design are hardly considered. Thus, it remains a challenge for computers to recognise information in a sketch that is relevant for any given application (Johnson et al., 2009), implying a limited database of sketches for training the latest technologies like artificial neural networks (ANNs). Similar to the computer, researchers cannot fully fathom the content of sketches, as the hand drawings need interpretation and every designer or architect uses their own language.

Using retrospective protocol studies, hand drawings, their underlying intentions and ideas can be formalised to differentiate variants and individual design steps on a microscopic level. It is necessary for an AI to be able to understand this vague and imprecise character of hand drawings (Johnson et al., 2009), however, the requirements for understanding need to be formalised. While previous protocol studies for architectural designing through hand drawings produce qualitative results (Suwa and Tversky, 1997), the methods of the 'metis' projects require the collection and processing of quantitative data to train an ANN. With hand drawings and the correlating design decisions, a case base is created to train an ANN which suggests further design steps to architects similar to text auto-completion on a smartphone. The ANN supports the user by introducing personalised predictions and thus, reacts to the idiosyncrasies of the user (Negroponte, 1973). Thus, the architect can focus on the creative aspects while increasing economic growth through speeding up the process and increasing architectural quality, and supporting mental health through reducing work-related stress. Further, it supports the architect in the life-long learning of creating their own 'Guiding Design Principles' (Lawson, 2004, pp. 112, 113), as the ANN learns from its specific user and the architect widens their cognitive horizon through the suggestions.

In this paper we explore if and what kind of elements can be found within sketches of early conceptual design and further, if back-referencing these elements to the current design activity, derived from design theory (Laseau, 2000; Lawson 2004; Lawson 2005), is enabled. Thus, we propose a workflow for the data collection of retrospective protocol studies of hand drawings. This includes an approach for pre-processing the raw data of the study sessions and a novel tool created for obtaining quantifiable data.

2. Related Work

Hand drawings allow designers to visualise, review, revise (Buxton, 2007) and communicate ideas. Laseau (2000) describes sketches as a container, hub and incubator of vast and different kinds of information by providing interactive feedback for the architect during the design process, as well as a way for communication, individually, within the team and with the public. The internal discourses - also observed by

Goldschmidt (1994) - is also used for advancing and improving the design through reflection, as a 'reflective practitioner' (Schön and Wiggins, 1992). The cognitive scientist Goel (1995) focuses on the imprecise character of hand drawings, identifying their ambiguity as deliberately leaving room for interpretation and thus, a medium for self-inspiration. These mental activities behind designing are clearly evident through the progression throughout the sketch. Laseau (2000) and Lawson (2004, 2005) divide this progress into different design activities of an iterative process without a predetermined order.

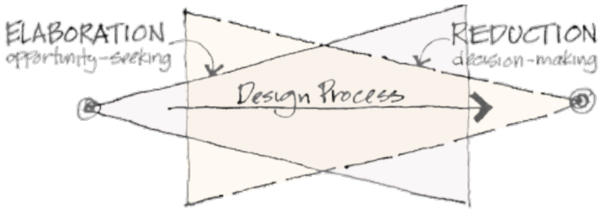

Figure 1. Koeberg and Bagnall's concept of the design process (Adapted from Laseau, 2000, p. 115)

Laseau (2000, p. 115) describes the general design process consisting of two main stages: the 'Elaboration', during which the designer maximises the data of possible solutions 'seeking opportunity', whereas the 'Reduction' aims to narrow down the notable references and applicable solutions for the specific design problem until the best possible solution is found through 'decision-making' (see Figure 1). These references - or also referred to as architectural precedents - for 'seeking opportunity' and 'decision-making' are used for both phases. They are used as a source of inspiration, design conditions and explicit information during the 'Elaboration', as well as a tool for evaluation during the 'decision-making', both phases being accommodated by reference building as a medium of communication (Richter, 2010, p. 154).

Lawson (2005, pp. 48, 49) elaborates the design process further by denying a chronological component. Rather he describes it as a combination of different building blocks fitting perfectly into each other (see Figure 2). According to the author, the design process is divided into 'analysis', 'synthesis' and 'evaluation' being the connection between the corner stones of the 'Problem' and the 'Solution'. Thus,

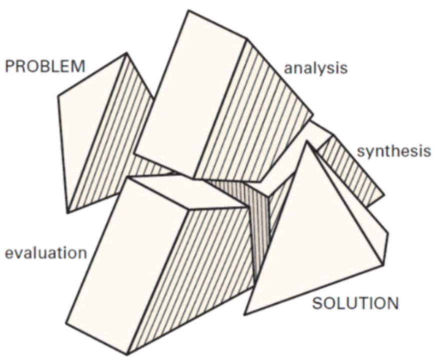

Figure 2. The design process seen as a negotiation between problem and solution through the three activities of analysis, synthesis and evaluation (Adapted from Lawson, 2005, p. 49)

Lawson (2005) concludes that every solution based on a re-iterative design process is uniquely create for the current design problem. The three blocks of the repetitive process - 'analysis', 'synthesis' and 'evaluation' - can similarly be found in Laseau's (2000, p. 13) detailed description of the design process, who defines five categories: 'analysis', 'exploration', 'discovery' and 'verification' with constant 'communication' throughout all of them. Both authors assign their respective categories to certain mental activities during the designing (Laseau, 2000; Lawson, 2005). Vice versa, these mental activities which are also referred to as the 'intention behind' (Lawson, 2004, pp. 17, 18), are identified through the currently sketched actions (e.g. modification, deletion) and elements (e.g. lines, symbols) Their combination, referred to as 'design step' within this paper and as 'design event' by Lawson (Ibid.), is an indicator for the ongoing design phase. Lawson (2005) specifically looks into sketching based on 'Graphic Thinking' (Laseau, 2000) and its external and internal dialogue. This project builds on the premise that these mental activities of the design process are generally comprised and showcased through protocol studies (Lawson, 2004, p. 15).

Design protocol studies are generally divided into 'Thinking aloud' studies and retrospective (reporting) studies. Both protocol study types deal with the problem of an artificial setting (e.g., without client and stakeholder communication, design briefings, and the general unfamiliar workspace), within a limited work environment (i.e. time limitation, limited access to other sources of knowledge) (Lawson, 2004, p. 16). However, Suwa and Tversky (1997), as well as Lawson (2004) identify a high amount of distortion of the natural workflow during the design process for the first type. '[T]alking aloud may adversely interfere with participants' perceptions during their sketching activities' (Suwa and Tversky, 1997, p. 386), because 'it introduces a degree of introspection and conscious attention to process that is abnormal [producing verbalization as] … a director of thinking that takes place as a consequence' (Lawson, 2004, p. 16) rather than true design process thoughts. In order to minimize these negative effects, retrospective reporting is employed. In order to mitigate 'selective recall' during the report of the design process, Suwa and Tversky (1997, pp. 397) offer the participants the recorded video of their sketch. Through the visual cues 'about the exact sequence of sketching, including, the timing, hesitations, returns and redrawings' (Suwa and Tversky, 1997, p. 398) the participant is guided again through their own design process. Finally, these retrospective protocol studies allow for hand drawings, their underlying intentions and ideas to be formalised to differentiate variants and individual design steps on a microscopic level (Lawson, 2004, pp. 15-17). However, protocol studies are interpreted for further use resulting only qualitative results, similarly to Suwa and Tversky (1997). Even though every design process is truly unique - because of the problems, tools and designers themselves - Lawson (2004, p. 16) sees the potential and possibility for reproducible results of protocol studies in the manner of the natural science paradigm without the attempt to characterise designing.

3. Problem Statement

For an AI-based method, it is necessary to be able to understand the vague and imprecise character of hand drawings (Johnson et al., 2009), however, the requirements for understanding need to be formalised. While previous protocol studies for architectural designing through hand drawings produce qualitative results (Suwa and

Tversky, 1997), the methods of the 'metis' projects require the collection and processing of quantitative data to train an artificial neural network (ANN). With hand drawings and the correlating design decisions as a basis, a case base of quantitative data needs to be created to train an ANN which suggests further design steps to architects similar to text auto-completion on a smartphone.

4. Approach

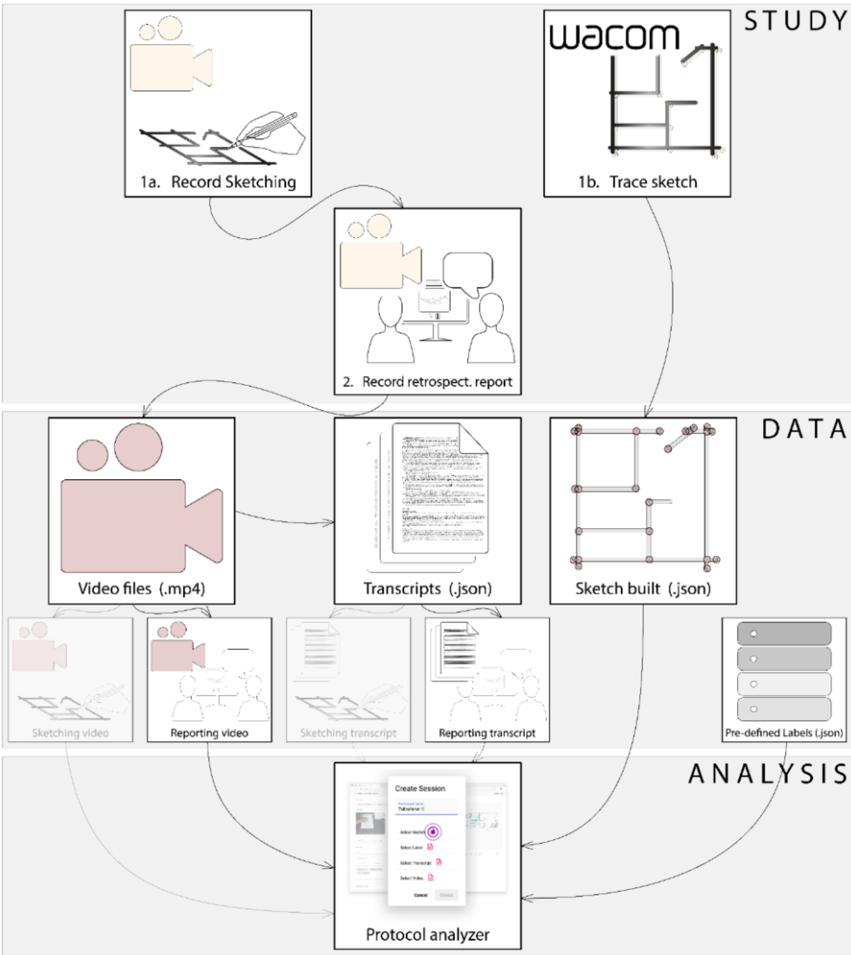

Figure 3. Data collection, data output and data analysis (greyed out: Data added after testing)

In order to obtain quantitative date, the collected data has to be quantifiable. Looking into the process of sketching, we observed two parameters that can be processed: the sketch itself and the verbalization of a retrospective study. Further, those two are related through time correlation. Thus, we propose the novel approach of our open-source web-tool called the ‘Sketch Protocol Analyser’. Within this tool we introduce another correlation method of sketch and verbalization: custom labels.

Within our process (see Figure 3), we propose three main categories: the study, the data and the analysis. During the study, the data is collected in two main stages: the first round of the interview during which the sketching is recorded using a pivoting 4k camera and the sketching is traced by drawing on a sheet of paper on top of a WACOM tablet (see Figure 4). This trace of the sketch includes polygon points for creating lines, as well as other parameters like time and pressure. During the second round of the study, the study participants are presented with the sketch video on a computer screen. While they are retrospectively reporting on their thoughts and internal dialogue, another video is being recorded introducing the time correlation. All of this data is being saved in its respective file formats using the session label created at the beginning of the study session.

Thus, we collected video files (.mp4) through the recordings and a sketch built (.json) through the WACOM tablet and accompanying app for 'Real Time Ink'. The video of the retrospective reporting is further asynchronously processed into transcripts using Google Speech-to-Text services. This transcript includes speaker tags (i.e., interviewer and interviewee) and time stamps for each transcribed word, which is reformatted befitting the .json file format.

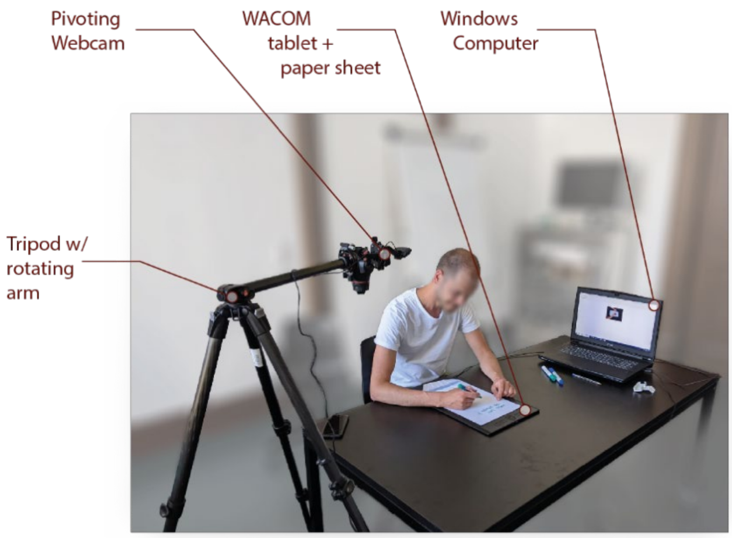

Figure 4. Set-up of the study (from left to right): Tripod with a pivoting 4k camera, paper on top of a WACOM tablet and WACOM fine-liner pen; Computer for recording and saving data

Finally, the video recording of the retrospective report, its transcript, the sketch built, and the custom labels are used as an input to the web-tool 'Sketch Protocol Analyser' for creating an analysis session with a personalised name (see Figure 3).

The study set-up (see Figure 4) and workflow were tested with two volunteering working architects. After studying the prepared design task, they were given 15 minutes to design without any specifications on style, detail, scale, or desirable final state of the sketch. Even though one of the participants was silent during the sketching, the other one verbalised the thoughts during drawing, however not in a 'Thinking Aloud' manner. It was rather short remarks during the reflection on the previously taken design activities. Further, the desire for pausing the video during the reporting became apparent if a certain design element needed longer explanation.

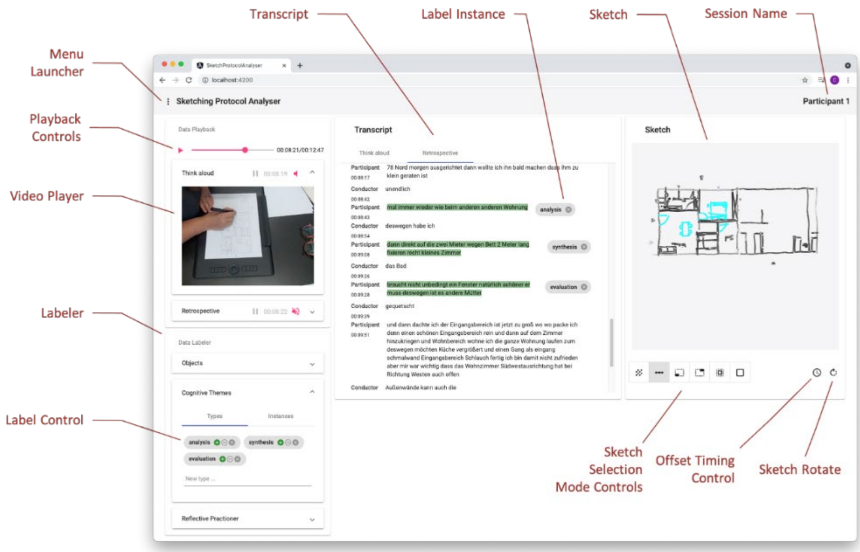

Figure 5. Interface of 'Sketching Protocol Analyser 1.2' (Adapted from Ziegler, 2021)

Figure 5 shows the graphic user interface of a sketch session of the 'Sketch Protocol Analyser 1.2', including the video recording of the sketching and its transcript, for the researcher to analyse and produce quantifiable results. On the left-hand side, the user can switch between the two videos or watch both at the same time. As soon as the videos are started the transcripts and the sketch is built. Using the buttons on the individual labels of the 'Data Labeler', the labels can be added to or removed from marked parts of the transcripts and sketches. As it can be seen in Figure 5, the created categories are: 'Objects' (e.g. 'wall'), 'Reflective Practitioner' (e.g. 'practice'), and 'Cognitive themes' (e.g. 'analysis'). For marking parts of the sketch multiple selection options are included, such as selection rectangles by dragging diagonally, individual polygon lines and semi-automatic line selection. All created files are automatically saved. The labelled components are saved as linked instances with IDs within the transcript files and the sketch built, which are referenced for each label and label category in the 'Label' .json file.

For our purposes we adapted the design phases of Lawson (2005): 'analysis', 'synthesis' and 'evaluation' within the label category 'Cognitive themes' (see Figure 5). Actions and their respective elements (e.g., 'outlining parcel') within the transcript and sketch are selected, which leads to the identification of the design intention behind (e.g. 'requesting/requested information', i.e. visualisation for seeing ratio/dimensioning/…, for 'outlining parcel'). Thus, the label of the according design phase (e.g. 'analysis' for 'requesting/requested information') is used to highlight these parts within the transcript and drawing. We aim to train the ANNs of the 'metis' projects, using this labelled data, to suggest actions and elements (also referred to as 'further design steps') depending on the recognised design phase.

5. Discussion and Future Work

Through our web-tool 'Sketch Protocol Analyser' we were able to produce quantitative data from design protocol studies. The design process is recorded and labelled in order to identify actions and elements as design steps (e.g. 'outlining parcel') and to derive design phases (e.g. 'analysis') from indicated design intentions (e.g. 'requesting/requested information'). This data produced from the 'Sketch Protocol Analyser' is suitable for further use within our deep learning (DL) pipeline for training the neural network, as its model is specifically created for using these data formats. This ANN will be trained to suggest further design steps, a combination of actions and elements, depending on the recognised design phase.

The modifications of the web-tool, after testing the set-up and analysis process, seem to have made a difference in usability and integration of all possible observations. Thus, all the data collected within the sketching process can be taken into account during the analysis.

However, for this workflow the supervisor of the protocol study still needs to interpret the data and manually assign the labels to the text within the transcript and sketch. Especially identifying the intention (e.g. 'requesting/requested information) behind taken design steps (e.g. 'outlining parcel') – even when taking the report by the participant into account – and the derived design phases (i.e. 'analysis', 'synthesis', 'evaluation') cannot be considered fully established and may also vary from researcher to researcher due to interpretation. Further, all design and sketch protocol studies are set in an artificial environment, as previously mentioned. They neglect briefings by the client, limited access to other sources of knowledge, and time and resource limits while creating in an unfamiliar work environment. Retrospective reporting is prone to distortions introduced by the 'post-hoc rationalisation of their processes. … [while restricting the time] to allow for reflection and time to pass' (Lawson, 2004, p. 16). The reflection of the architect as a 'reflective practitioner' (Schön and Wiggins, 1992) happens both during the process and after a prolonged time period.

As a next step a large-scale study has been scheduled for December 2021. The analyser web-tool is used for producing quantifiable data customised for our ANN models, which are currently being tested. Due to the global pandemic the study has not been completed yet and more appointments have been set for 2022, after employing safety adjustments for the study sessions (e.g. interviewer and interviewee in two separate rooms) to comply with the according restrictions and rules. First tests with our artificial neural network, using the labelled data of conducted sessions, show promising results of predicting the first consecutive design phase. We plan to present our complete study results at the International Conference on Computational Creativity (ICCC) 2022, as well as aim to establish our labelling approach of design phases for elements and actions as 'design steps' at the eCAADe 2022 in Leuven.

6. Conclusion

Our system enables us to produce quantitative data from design protocol studies, while previous studies resulted only in qualitative data. By adding customised labels, the user creates further parameters to be quantified, additionally to behavioural parameters e.g., timing, speed and pressure of the sketching process. Furthermore, the customisation of the labels and its open-source model gives other researchers the opportunity to transfer, translate and create specific labels for their needs.

This quantifiable data from sketch protocol studies allows us to further advance to train ANNs, suggesting further design steps, within the 'metis' projects. The intelligent design assistant supports architects by speeding up their process, allowing them to focus on their creative work, while maintaining or even increasing architectural quality.

Nevertheless, we aim for a better understanding of the role and process of designing and sketching to improve the interaction between architects and their technological support systems of the early design stages. We hope to inspire other researchers to further investigate the design process and its implications to improve the work environment for architects for increasing work quantity and meet the demands on the architectural quality, facilitating growth and quality in education, while considering the importance of reducing stress for improving architects' mental health.

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