24 Inside the Collective Mind: Features Extraction to Support Automated Design Space Explorations

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Abstract

The paper investigates the possibility to extract meaningful information out of natural language design conversation. This meaningful information, referred in this paper as features, represents possible design changes and solutions discussed during collaborative design sessions. Without relying on user input and without disrupting the natural course of the conversations, we envision an automatic implementation of these changes and solutions into a parametric model. The aim of such a system is to allow for an automatic design space exploration without interrupting the design sessions. In this direction, the paper employs mixed research methods which make use of quantitative and qualitative analysis. The results obtained indicate the possibility of extracting structured information to perform changes in various parametric models automatically. The paper also provides discussions around specific limitations, such as unclear precedents due to multimodality input.

Keywords

Natural language • Collaborative design • Design automation • Design meetings

24.1 Introduction

Collaborative design meetings involve all parties interested in developing the design of a product. During this process, the participants create a collective pool of knowledge, meant to progress the design. This knowledge is created by making use of natural language to communicate and discuss ideas, solutions and scenarios. This whole picture, is expected to be supported by state-of-the art computational tools.

Current interfaces focus on formalized queries, such as “*do that* …”, “*change that* …”, “*search for* …”, mainly used for information access or simple tasks [7]. Even though users use spoken language to query a system such as Siri, Google Assistant or Cortana, the query still gets an unnatural formalized form. Human to human conversations, more precisely multi-party conversations, represent the informal dimension of the natural language communication. Without any script to follow, the participants develop a dialogue. In most of the settings, this dialogue is centred around a specific idea. More specifically, during collaborative design sessions, design goals drive the dialogue. Each participant contributes to the development of the dialogue building the conversation on top of previous ideas, as well as bringing new ideas based on personal experience and expertise to the table [1].

Aiming at understanding the way design conversations develop, previous researchers focused on different aspects such as participants interaction [14], social dimension [10], reported speech [15], the role of communication and different artefacts [17], semantic design information capturing based on function, behaviour and structure [8], or design negotiation [12, 10]. The studies listed above represent the building blocks towards the understanding of the social dimension of the design and

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engineering conversations, as well as the way the design is developed. In the end the outcome, meant to progress the design, need to be implemented as a virtual representation of it, usually through the use of computers and computational environments. Moreover, previous research reported the need of increased use of the computer support during multi-party design and engineering collaboration sessions [17]. In contrast, the limited use of the computational support restricted the role of the collaborative sessions to coordination, in lieu of design development [17].

Over the time, the purpose of computers and computational environments to support the civil engineering industry evolved, from the basic support of representing the design in a digital form [21] to more intelligent systems [6, 16, 19, 23]. Even though these systems are advancing and offering engineers more and more capabilities, a major limitation is represented by the fact that most applications still require user attention and effort to provide input. This disrupts and hinders the creativity, through shifting the focus from design to machine manoeuvrability [1]. Moreover, most of the times, the number of explored design solutions is reduced to allow for a timely implementation and to align these with the tools' capabilities, which shifts the engineering focus away from the design exploration to software related issues. While Bernal et al. [1] propose to consider a "*less ambitious role for a computer in design tasks*", current progress in the field of machine learning and artificial intelligence push us to be ambitious.

The system we envision plays the role of a smart machine agent which continuously listens to multi-party conversations and extract meaningful information which leads to design changes, adjustments, and exploration. Then, it implements these into parametric models meant to adjust the design embodiments or to trigger various simulations. To move towards this vision, a first step is to investigate whether such constructs exist which will trigger changes in the design and the simulation models, how these are formed and the usefulness of the information communicated during design dialogues to steer the parametric models. We present the current state of the art of spoken language understanding, then we introduce the research method. The paper continues with the analysis of a set of design conversations, discussion of the results, ending with a conclusion section which provide a critical discussion the findings and develops directions of future research directions based on the limitations of the current study.

24.2 Human-Computer Interaction Through Natural Language

Human beings exchange information in a natural way through language as an intentional act [20]. We can make a separation of the act of producing the natural language communications in written and spoken. While the act of writing takes a more formal form, the act of speaking, especially when it involves more than two participants, is considered to be informal. One focus of the current human-computer interfaces is how to allow computers to understand the conversations between humans. Spoken language understanding is a relatively new research area [24]. A main requirement to conduct research in this direction is the collection of data, which mainly takes the form of audio recordings and in the literature is named corpora. Tur and De Mori [24] provides a good summary of various corpora collected by various researchers with various goals in mind. This summary includes mentions such as Augmented Multi-party Interaction (AMI) [11] and ISL meeting corpus [2].

An overview of various methods [24] covers concerns related to "*dialog act tagging*", "*dialog act segmentation*", "*discourse and topic segmentation*", "*summarization*", "*action items and decision detection*", "*agreement/disagreement detection*", "*subjectivity and opinion detection*", "*modeling dominance*", "*speaker role detection*", "*hot spot detection*", "*addressee detection*", and "*argument diagramming*". Moreover, most of these methods need to be coupled with natural language processing techniques which focus learning, understanding and production of human language by machines [7]. Nevertheless, both techniques make intensive use of various knowledge representation techniques. Usefulness of the corpora to support specific tasks is a pre-requirement of employing such modern techniques.

$$tf = n/total \tag{24.1}$$

One aim of the pre-processing analysis is to identify the purpose of a document. A useful measure for this is term frequency(*tf*), which provides information about how often specific terms occur in a corpus. Equation 24.1 presents the basic way to compute tf, where n is the total number of occurrences of a term and *total* represents the total number of words in the corpus. One limitation of this approach is that common words will have a higher frequency [3]. Instead of getting the most frequent words, we can get the most relevant ones for each document using term frequency inverse document frequency (tf-idf). The basic reasoning behind tf-idf is that it takes into account the inverse frequency of a word on a document in relation to all the other documents on which this word occurs [18]. Equation 24.2 [18] calculates the tf-idf value for each word w part an individual document d, where document d is part of a collection of documents D. In addition, $f_{w,d}$ represents the number of the occurrences of word w in document d and $|D|$ represent the length of the corpus [18].

$$w_d = f_{w,d} * log(|D|/f_{w,D}) \quad (24.2)$$

The same equations can be applied, not only for identifying the term frequency, but also identifying the frequencies of sequences of words, termed in the literature as n-grams. N-grams can have sizes from 1 to n. One word n-gram often termed as unigram analyses the occurrence of a specific word in a text. Increasing the size from 2 to n represent a modality to extract utterances with high frequency. During this analysis, the text body is cleaned using different text mining techniques. For ranking the terms frequency we employed term frequency-inverse document frequency(tf-idf) presented in Eq. 24.2.

Moreover, besides the automated analysis of the corpus, the pre-processing phase might also include manual investigation of text. The current trend focuses on automatic identification of specific features in the multi-party conversation datasets [4, 5], mainly aiming to perform specific actions based on the items already existing in the corpus. To our knowledge, there are no computational methods to identify if specific features are missing or not. Therefore, we consider that an additional step is needed to perform a qualitative analysis of the corpus to identify if there is enough spoken information which will be used to trigger changes and action in parametric models.

24.3 Research Method

Our research presented in this paper employs a multi-method research approach combining quantitative and qualitative analyses to get insight into the information generated during collaborative design sessions. Figure 24.1 presents the proposed research method. The quantitative analysis (QtA) focuses on the identification of the frequency of an adjacent sequence of n words called n-grams. The extracted n-gram will be used to support the qualitative analysis of the design conversations.

The quantitative analysis was conducted using R software and *tidyr* package [22]. The first step of the analysis consist on removing the names of the participants from the transcript, as the main focus is the analysis of the natural conversation without any focus on the participants.

The qualitative analysis (QlA) is performed in two steps. The first step is to perform a two level segmentation of the design conversation. The first level is based on conversation blocks which focus on the design of specific parts. At the second level, each 1st-level conversation block will be further analysed and segmented into 2nd-level conversation blocks aiming to identify different attitudes during design, such as proposal, acceptance, rejection, negotiation. The third step of the qualitative analysis consists of the identification and codification of the utterance which implies specific candidate actions that could potentially be used to steer the parametric models. This step is supported by the n-grams extracted during quantitative analysis. Moreover, we developed a codification schema for utterances that could trigger specific actions into the parametric models. At the current stage of this research the codification is kept simple, using three codes: embodiment, process, and query. These codes can be explained as following: *embodiment* mark those utterances which are related to specific changes in embodiment, where *process* mark those utterances used to indicate the utterances about possible

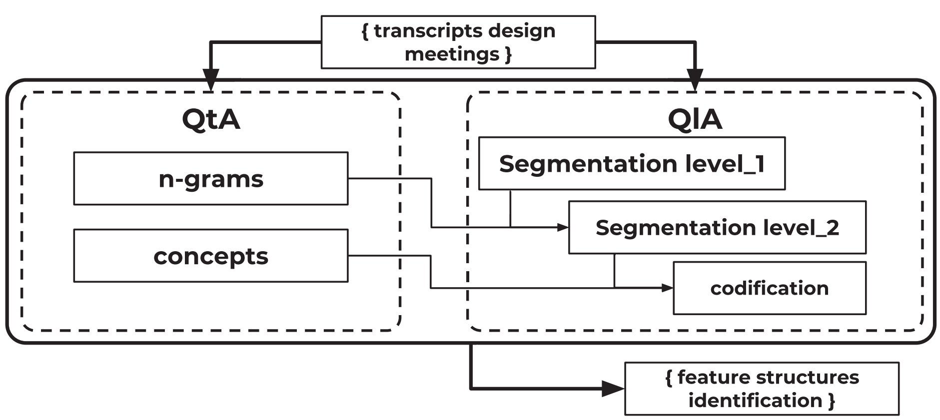

Fig. 24.1 Research method

simulations, and *query* mark those utterances related to different queries about both—embodiment and process. The qualitative analysis was conducted by manually reading and marking the transcript. A case study which implements the proposed methodology to analysing the design conversations of two real architectural design meetings is presented in the next section of the paper.

24.4 Design Conversation Analysis: Results and Discussions

The proposed stepwise methodology is use to analyse the transcripts of two architectural design meetings [9] which aim at the design of a new crematorium. McDonnell and Lloyd [13] provides a detailed description of the project and design meetings, thus we provides only a short summary. The project was in the phase after the conceptual design, already having the main feature and the main functions allocated. The stakeholders involved in the design meetings were the architects and the client. The first meeting (A1) aims to obtain the clients and building users feedback on design, concluding with some agreed actions. The second meeting (A2) is organized after 8 months and is a follow-up for the A1 meeting. The architects used the meeting (A2) to present the implementation of meeting's (A1) action points, as well as to raise additional issues and queries regarding the design. In this paper, the quantitative analysis conducted analyses the transcripts of both meetings, while the qualitative analysis conducted analyses the transcript of the first meeting (A1) only. In the following subsection, we present and discuss the results of the quantitative analysis. This is followed by the subsection on which we present and discuss the results of the qualitative analysis.

24.4.1 Quantitative Analysis

The results obtained for 2-grams are presented in Table 24.1. Within this table, meet represent the meeting of which transcript the word was extracted, *n* represents the number of occurrences for that specific word, *tf* represent a statistical measure of the term frequency, *idf* represent the statistical measure termed as inverse document frequency, and *tf_idf* represent the importance of the word for that specific document in relation to the corpus. In this study, the transcripts represent the corpus.

Additional cleaning of the corpus was conducted to remove interjections such as *errm, th, err,* etc. which are not commonly used in the formal writing, but very often during human-to-human dialogues. Analysing both transcripts, we identify words which express the attitude of the participants. A good example is the word *laugh*. This indicates in the transcripts that the participants are *laughing*. Thus, we make use of additional filtering to removing these words from the analysis. After filtering, the results obtained for unigram are partially presented in Fig. 24.2. These results show that we can identify concepts which indicates different aspects considered during the meetings and related to various design aspects.

Table 24.1 Results 2-grams—filtered

	Meet bigram		n	tf	idf	tf_idf
1	A2	Plasma screens	7	0.00883	0.69315	0.00612
2	A2	Acoustic consultant	4	0.00504	0.69315	0.00350
3	A2	Freeze dried	4	0.00504	0.69315	0.00350
4	A2	Ground level	4	0.00504	0.69315	0.00350
5	A1	Bird hide	6	0.00501	0.69315	0.00347
6	A1	West chapel	5	0.00418	0.69315	0.00290
7	A2	Artificial light	3	0.00378	0.69315	0.00262
8	A2	Heat recovery	3	0.00378	0.69315	0.00262
9	A2	Independent access	3	0.00378	0.69315	0.00262
10	A2	Memorial wall	3	0.00378	0.69315	0.00262

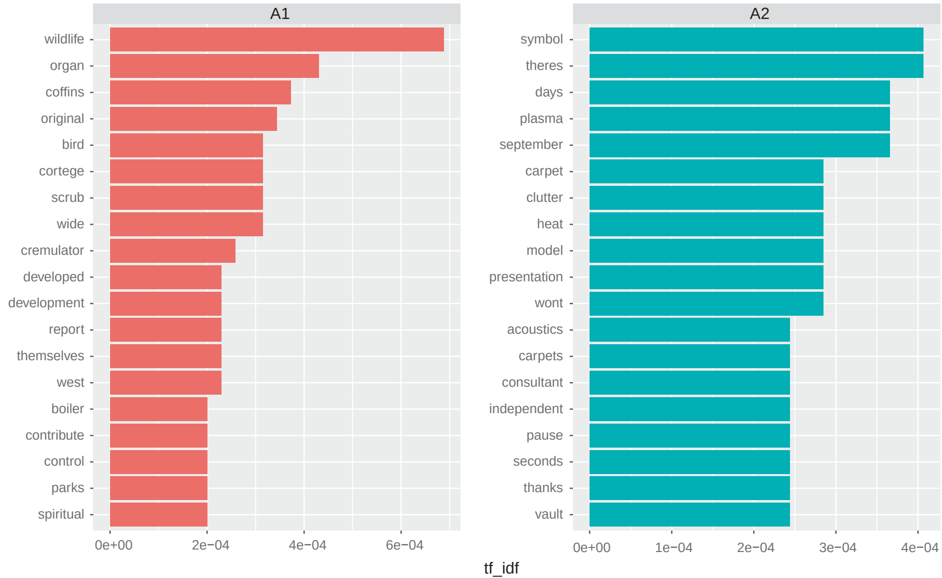

Fig. 24.2 Side by side comparison of the most frequent words used during design meetings

24.4.2 Qualitative Analysis

The results of the first segmentation step indicate that during the meeting, the design team focus on a wide variety of topics, such as increasing the size of the waiting room, circulation routes, environmental impact, materials, etc. Within this, we can classify the driving topics as the ones which initiate the discussion having as concerns (1) the design embodiments or (2) the processes. However, the two categories intersect during the design.

For example, when discussing about the size of the *waiting room* the participants make connection to the process which is supposed to take place within the boundaries of this room. Table 24.2 offers a very good illustration in this direction. Where the initiating concern is related to the rooms size, there is no direct answer, but there are concerns about the process which will take place in this room (*excerpt_4*) which leads to the quantification of the space size. Mentally implementing the process and its possible outcome, the participants provide one possible solution (*excerpt_5*).

Yet, from the computation perspective, a computer cannot implement the provided solution as more information is required to clarify where the participants are pointing to drawings for possible extensions to identify where space for additional seats will be created as pointed out in *excerpt_5*. But, without considering the provided solution, to some degree, this logic can be automated using parametric model of the room embodiment and constraints, coupled with a parametric model for the process simulation to provide various alternatives for the waiting room’s growing strategies. In this case, the participants will have to analyse the provided alternatives and select for implementation the ones which they nd suitable.

From a different perspective, in the case of the items 7 and 9-circulation routes the dialogue initiation comes from the process perspective. The extend of this design topic has impact on the embodiment of several parts of the design as presented in Table 24.3. Excerpt_1 might represent the trigger for starting the parametric model of the simulation. This will allow the

Table 24.2 Example design conversation excerpts—waiting room size

Content	
excerpt_1	*[…] the first query […] about whether you wanted the size of the waiting room increased*
excerpt_2	*I’d be interested […] what sort of set/how many seats […] you could get […]*
excerpt_3	*[…] you are unlikely to get more than about 9–10, maximum 12 seats in there […] is the room big enough*
excerpt_4	*[…] if we’ve got as ow of people walking through […] we can’t put seats through that […] we need to keep an open access […] the seating will be against the wall*
excerpt_5	*[…] extending it […] will give you seating areas here, seating areas here, as well as here and here, which effectively will double the seating capacity[…]*

Table 24.3 Example design conversation excerpts—circulation routes

Content	
excerpt_1	*The way in which the circulation works here is similar to the existing chapel […] once a service has ended […] people would leave through these doors*
excerpt_2	*We've given you double doors because of the draught issue […]*
excerpt_3	*[…] from here they ca process around the wreath court […] with the exception of certain religions […] they would actually walk through here […]*
excerpt_4	*[…] there are three possible routes, they either come through here, one[…] they go through here, two […] they can go through there, three*
excerpt_5	*[…] the only comment also I've had from the funeral directors[…] is this route here, slight concern for people over that*
excerpt_6	*[…] the second route is round the end of the pond […]*
excerpt_7	*[…] the majority of people that we get sometimes are elderly […]*
excerpt_8	*[…] we could put a bridge or something that looks like a bridge […]*
excerpt_9	*[…] it would be nice to have that […]*
excerpt_10	*[…] there is one, a very small one […] in erm the winter garden*
excerpt_11	*[…] I quite like the idea of stepping stones*

participants to identify the impact on different parts of the designed product such as doors, wreath court, the need for a bridge over the pond and what will be impact of having any kind of route over the pond on the people circulation. Again, coupled parametric models for the design embodiment and processes simulation will offer the participants the possibility to automatically explore various alternatives.

24.5 Conclusions

While design knowledge is developed through dialogues during the multi-party collaboration sessions, current human-computer interfaces still restrict the implementation of agreed solutions. The central thesis of this paper is represented by the idea that the computers can have a more ambitious role during these sessions by extracting and implementing the meaningful information directly in parametric models. Thus, the major concern oriented towards the existence of such information. After analysing meeting transcripts of two design meetings, we can conclude that parametric models can be steered based on the spoken dialogue. We were able to identify keywords and utterances that would allow to trigger parametric models and start simulation of various processes. Moreover, the conducted analysis shows that the embodiment of the design cannot be steered without meaningful input from the simulations models, as the participants always make connections to the related processes.

A limitation identified concerns the use of multi-modality during communication. As the example of the waiting room, the unclear location of possible extension indicated using the concept "here" while pointing at drawings. Without additional input to clarify "here", it makes it computationally impossible using only voice input. Another situation is when the designers present similar cases to support their design ideas. This can be seen in the example for the circulation routes, indicated as "winter garden". Computationally, a machine can reproduce the design intent of the given case if the information about the case is available. Of course, the results of this analysis are based on only two meetings, which we see as a limitation. Future data collection should focus on collecting more data from multi-disciplinary sessions, as well as from a wide variety of civil engineering projects.

The engineering models of products and processes represent an intricate network of components, subsystems, and systems. While the human mind can quickly understand the jump and transition from one element to another, mainly based on change of context, machines require training to recognize this kind of situations. Making sure that the changes are implemented on the right elements represent one of the current challenges. Future research should focus on training various models to identify when this transition occurs. Moreover, the good part of the conversation is noise and future research should train models to identify it. This will allow computers to identifying when actions are required from its side, and when nothing should happen.

References

1. Bernal, M., Haymaker, J.R., Eastman, C.: On the role of computational support for designers in action. Des. Stud. **41**, 163–182 (2015)
2. Burger, S., MacLaren, V., Yu, H.: The isl meeting corpus: the impact of meeting type on speech style. In: Seventh International Conference on Spoken Language Processing (2002)
3. Chen, K., Zhang, Z., Long, J., Zhang, H.: Turning from tf-idf to tf-igm for term weighting in text classification. Expert Syst. Appl. **66**, 245–260 (2016)
4. El-Assady, M., Gold, V., Acevedo, C., Collins, C., Keim, D.: Contovi: multi-party conversation exploration using topic-space views. In: Computer Graphics Forum, vol. 35, pp. 431–440. Wiley Online Library (2016)
5. El-Assady, M., Sevastjanova, R., Gipp, B., Keim, D., Collins, C.: Nerex: Named-entity relationship exploration in multi-party conversations. In: Computer Graphics Forum, vol. 36, pp. 213–225. Wiley Online Library (2017)
6. Fougeres, A.J., Ostrosi, E.: Intelligent agents for feature modelling in computer aided design. J. Comput. Des. Eng. **5**(1), 19–40 (2018)
7. Hirschberg, J., Manning, C.D.: Advances in natural language processing. Science **349**(6245), 261–266 (2015)
8. Kan, J., Gero, J.: Using the fbs ontology to capture semantic design information in design protocol studies. In: About: Designing-Analysing Design Meetings (2009)
9. Lloyd, P., McDonnell, J., Reid, F., Luck, R.: Dtrs7 dataset from 7th design thinking research symposium. http://design.open.ac.uk/dtrs7
10. Luck, R.: Does this compromise your design? socially producing a design concept in talk-in-interaction (2009)
11. McCowan, I., Carletta, J., Kraaij, W., Ashby, S., Bourban, S., Flynn, M., Guillemot, M., Hain, T., Kadlec, J., Karaiskos, V., et al.: The ami meeting corpus. In: Proceedings of the 5th International Conference on Methods and Techniques in Behavioral Research, vol. 88, p. 100 (2005)
12. McDonnell, J.: Collaborative negotiation in design: a study of design conversations between architect and building users. CoDesign **5**(1), 35–50 (2009)
13. McDonnell, J., Lloyd, P.: About: Designing-Analysing Design Meetings. CRC Press (2009)
14. McDonnell, J., Lloyd, P.: Beyond specification: A study of architect and client interaction. Des. Stud. **35**(4), 327–352 (2014)
15. Oak, A.: As you said to me i said to them: reported speech and the multi-vocal nature of collaborative design practice. Des. Stud. **34**(1), 34–56 (2013)
16. Pauwels, P., Zhang, S., Lee, Y.C.: Semantic web technologies in aec industry: a literature overview. Autom. Constr. **73**, 145–165 (2017)
17. Perry, M., Sanderson, D.: Coordinating joint design work: the role of communication and artefacts. Des. Stud. **19**(3), 273–288 (1998)
18. Ramos, J., et al.: Using tf-idf to determine word relevance in document queries. In: Proceedings of the first instructional conference on machine learning, vol. 242, pp. 133–142 (2003)
19. Ren, Z., Yang, F., Bouchlaghem, N., Anumba, C.: Multi-disciplinary collaborative building designa comparative study between multi-agent systems and multi-disciplinary optimisation approaches. Autom. Constr. **20**(5), 537–549 (2011)
20. Russell, S.J., Stuart, J.: Norvig. Artificial Intelligence: A Modern Approach. pp. 111–114 (2003)
21. Schultz, C.P., Amor, R., Lobb, B., Guesgen, H.W.: Qualitative design support for engineering and architecture. Adv. Eng. Inform. **23**(1), 68–80 (2009)
22. Silge, J., Robinson, D.: Tidytext: Text mining and analysis using tidy data principles in r. J. Open Source Software **1**(3) (2016)
23. Tixier, A.J.P., Hallowell, M.R., Rajagopalan, B., Bowman, D.: Automated content analysis for construction safety: a natural language processing system to extract precursors and outcomes from unstructured injury reports. Autom. Constr. **62**, 45–56 (2016)
24. Tur, G., De Mori, R.: Spoken Language Understanding: Systems for Extracting Semantic Information from Speech. John Wiley & Sons (2011)