USING DATA- AND NETWORK SCIENCE TO REVEAL ITERATIONS AND PHASE-TRANSITIONS IN THE DESIGN PROCESS

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Abstract

Understanding the role of iterations is a prevalent topic in both design research and design practice. Furthermore, the increasing amount of data produced and stored by companies leaves traces and enables the application of data science to learn from past design processes. In this article, we analyse a document-log to show the temporal evolution of a real design process of a power plant by using exploratory data analysis and network analysis. We show how the iterative nature of the design process is reflected in archival data and how one might re-construct the design process, involving iterations between many parties, including the client, external consultants, suppliers, and designers. We also show how people use different representations during the design process and how this is associated with a design phase-transition in the process. Finally, we relate our findings with the literature on iterations and discuss implications for research and practice with application to project management and process modelling.

Keywords: Design process, Visualisation, Complexity, Iterations, Network science

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1   INTRODUCTION

Today's world is fast-paced. Companies are under pressure to deliver high-tech systems and introduce innovations ahead of their competitors. Effective project planning and management of engineering design processes is key to timely project execution and system delivery. Understanding and illustrating how the design process evolves over time supports project planning and management. In particular, exploring (and exploiting) the iterative nature of the design process can provide deeper understanding of the temporal evolution of the design process. Thinking in terms of iterations instead of linear sequences helps to plan the process and to evaluate the impact on cost; for instance by using simulations with explicit probabilities of rework (Browning and Eppinger, 2002; Yassine, 2007). Whilst simulations are useful and enable creating what-if scenarios, we argue in this paper that learning from experiences by analysing data traces from previous design processes is as important. By focusing on the temporal evolution and iterative nature of the design process, such analyses can provide strategic insights to better plan future design processes and to obtain information for use in bespoke simulations.

Given the understanding that a design process is iterative (Goldschmidt and Porter, 2004; Maier and Störrle, 2011) and involves many parties (Bucciarelli, 1994), we expect that empirical data will reflect the iterative nature of the design process. Thus, we need a suitable way to exploit traces of a design process from a temporal perspective, including an empirical understanding of the iterative nature of the design process.

In this paper, we analyse the temporal evolution of a real-world design process of a biomass power plant from the perspective of a document log. The log provides traces of the process underlying the design, development, production, and erection/construction of the plant for electrical power generation now in operation. In other words, in this paper, we uncover iterations in the design process through showing patterns of document creations and completions and interactions between people over time.

1.1   Contributions of the paper

This paper makes three novel contributions. Methodologically, we show how a design process evolves over time solely by using archival data-logs. We analyse data from different angles at various levels of resolution and we use network analysis to conceptualise the document production process as an information flow network, suggesting seeing people interactions as iterations.

Theoretically, we show that the design process can be inherently iterative and can involve phase-transitions. We relate our findings to the literature on iterations and suggest points for future research.

Empirically, we provide insights from a real world design process, adding to simulations studies or studies from controlled (academic) environments. We provide evidence of phase-transitions by the predominant type of document used at certain time-periods of the design process, evidence of iterations between different functional units and suppliers, and manifestations of a 'negotiation period'. We also provide insights about how people can influence iterations during the design process.

1.2   Structure of the paper

The remainder of the paper is structured as follows: in section 2, we connect to the literature background on iterations and design process analysis. In section 3, we introduce the case study and our data; in section 4, we present our analysis and results; in section 5, we discuss and interpret our findings and their possible implications; and in section 6, we conclude by considering possibilities for future research and ways to use our findings in practice.

2   BACKGROUND AND RELATED LITERATURE

The design process is a social process involving many parties and interactions between them to reach a commonly accepted design (Bucciarelli, 1994). Designers externalise their thoughts and communicate using different representations with different purposes (Goldschmidt and Porter, 2004). Designers generate ideas and place their thoughts on documents and, as their ideas evolve, the documents they created evolve accordingly (Goldschmidt, 2014). Thus, designers can further specialise their documents or change them radically according to their ideas and the social interactions that take place during the design process (Goldschmidt and Porter, 2004). These interactions imply changes in the designers' work,

potentially adding uncertainty to it, requiring exploration of many alternatives, and making the design process iterative.

Design scholars and practitioners recognise the importance of iterations in design (see, for example, a recent review by Wynn and Eckert (2016) and survey results with design experts on iteration as one of the most important characteristics of engineering design processes by Maier and Störrle (2011)). Whilst there is agreement on the importance, one may argue that scholars and practitioners have 'mixed feelings' when it comes to the implications of iterations. On the one hand, iterations have positive effects including design progression and on the other hand, iterations are reported to increase duration and cost of a project (Wynn and Eckert, 2016). Wynn and Eckert review perspectives on iterations in design and propose an integrative taxonomy, categorising iteration stereotypes. Three general categories are proposed: iterations toward progression, iterations for corrections, and iterations for coordination (Wynn and Eckert, 2016). Progressive iterations add value to the project and contribute to refine the specifications, the solution, add functionalities, and, in general, obtain a better design. Corrective iterations are often the response to unplanned adverse events and are perceived as undesirable as they can require new work, rework, and can produce cascade effects (e.g. a solution to a problem generates other problems). Finally, coordinative iterations help to make the process more effective or efficient (Wynn and Eckert, 2016).

As one of the characteristics of design processes, iterativeness captures the design process' complexity, variability, and the ill-structured nature (Simon, 1973) of design problems. Thus, many scholars embraced the study of the design process to understand and reduce superfluous and negative iterations. In this perspective, there are prescriptive studies that consider the design process from an activity perspective only. These studies develop techniques, mostly based on Design Structure Matrices (DSMs) (Eppinger and Browning, 2012), to optimise execution time (Browning and Ramasesh, 2007), to minimise unnecessary iterations (Browning and Ramasesh, 2007; Roelofsen et al., 2008), to modularise the process (Seol et al., 2007), etc.

Other studies take a descriptive approach: they start from data or documents produced during a design process and consider how data or documents evolve over time. A temporal description of the design process can lead to new knowledge on iterations and the way designers work. Techniques like Linkography (Goldschmidt, 2014) were used to analyse how designers generate ideas and how they come back on previously generated ideas during the evolution of the design. Goldschmidt shows how the idea generation process follows a logical progression over time. Process mining techniques (van der Aalst, 2011) take a post-mortem perspective on the process: through log-data, they discover a process model (usually represented as a Petri net with focus on activities) aiming to find bottlenecks. The discovered process model can be used as comparison with the planned process model or with new ones, or for simulation purposes. Among descriptive approaches, the analysis of the evolution of digital objects, such as emails, documents created during the design process, and other data traces has been proved relevant to show patterns associated with project milestones (Gopsill et al., 2014). Complementary to Gopsill et al. (2014), we analyse traces of a design process using a document-log. Our results are in line with Gopsill et al. (2014) in that we confirm the importance of metadata for process re-construction. With this paper, we go further in that we consider documents, people, and design activities. Pioneeringly, we show how metadata reflects the iterativeness of the design process and how the analysis of metadata can be leveraged to obtain a deeper understanding of the design process.

3 CASE STUDY: DATA DESCRIPTION AND DATA PREPARATION

3.1 Data description

The dataset used comes from a multi-project international company developing biomass power plants. The dataset contains a log of the 3559 documents produced during the design process of such a plant for electrical power generation. The process spanned a period of almost four years (2009-2013), with some documents being issued up to two years after project completion. The design process involved more than 80 people and 130 design activities. For each document produced, we have the creation date, the completion date, the last transmission date, and the first issuing date.

We also find information about the creator, the last modifier, the document title, the document type (drawing, meeting minutes, functional specification, etc.), the number of pages, and the number of revisions. In addition, the log indicates whether the document was sent to the client, to site

erection/construction, to quality assessment, or to the plant quality management, and finally, we have the activity code the document is associated with. The document log does not contain the content of the document, nor does it contain the full history of the documents.

3.2 Data preparation

The document log was generated automatically by the company's data management systems and we noted that the log files had some missing data in the form of missing dates. We decided to remove all observations where both creation date and completion date were missing at the same time (303 records). The final dataset contains 3256 observations, which represent 92% of the original data. After data cleaning, we used the documentation obtained to map each person to their functional unit and each activity to their activity group. To store documents, the company uses a taxonomy indicating the document type, in combination with the indications of the activity and the functional unit the document is associated with. Labelling and categorisation was done by the case company. By company policy, each document is associated with only one activity, one functional unit, and one type. Once a document is created, the engineer uploads it to the data management and documentation system, providing all the information needed for the classification. Table 1 summarises the dataset. We aggregated all categories for which there were less than 25 documents under the label 'Others'. In addition, as the company used some external consultants for short periods, we included them under the label 'External Consultants'.

Table 1. Distribution of documents

(a)		(b)		(c)	
Activity group	**Number of documents**	**Functional unit**	**Number of documents**	**Document type**	**Number of documents**
Air and flue gas	372	Boiler design	26	Drawings	1368
Boiler and equipment design	174	Combustion	729	Foreign documents	153
Combustion system	750	Electrical design	177	Foreign drawings	866
Electrical, control and instrumentation	112	Mechanical design	177	Minutes of meetings	119
External piping	534	External consultants	47	Others	215
Others	40	Plant design	304	Part lists	174
Overall project management	189	Pressure parts design	1648	Sketches	138
PFD + P&ID	210	Project management	93	Technical calculations	52
Pressure parts design	590	Others	55	Technical documentation	74
Steel related activities	285			Technical requirements	97

4 ANALYSIS AND RESULTS: UNCOVER ITERATIONS USING DOCUMENTS

We perform a broad exploratory analysis of the case dataset with the overall objective to uncover characteristic information and evolutionary patterns of the design process at hand. We explore the dataset having three objectives in mind. First, to describe patterns of iterations during the design process as manifest through actions performed on documents. Second, to trace the temporal evolution of the design process through the documents generated during its progression. Third, to understand communication between people using documents as carriers of information.

4.1 Global patterns of actions performed on documents: Showing high-level iterations

We begin our analysis by making sense of the different actions performed on documents (creation, last modification understood as completion, last transmission, and first issuing). We aggregate the volume of actions performed on documents for each month and compute their relative proportion. Figure 1 shows the result of this analysis in the form of a temporal heat map, where each cell represents a month of work with documents. As we have four types of actions performed on documents, we have, for each month, four cells showing the proportion of each action in that specific month. The darker the colour in the figure, the higher the proportion. Figure 1 shows which actions are more predominant and when in the process they occur.

The data traces left show us the following: We observe a phase from July 2010 to September 2011 with sparse patterns of activities; what we here term a 'negotiation period'. We know that the project was

intentionally put on hold due to contracting and other reasons. This time-period appears to be mostly focused on one action, i.e. we find only issuing actions for July-August 2010. After that, we observe a period of no activities until January 2011. In this period, it is likely that the company was waiting for an answer from the client. From February to September 2011, we observe an alternation between first issues, document creations, document completions, and the first completion through the full cycle from first to last transmission logged. This sparse pattern marks the interactions with the client and the consequent iterations and changes to the design process

We can relate this sequence of actions performed on documents and the completion of the first iteration cycles to what in the literature has been termed "coordination iterations". Indeed, in this phase, the company iterates with the client to address the client's requests and to establish some baselines in order to proceed with detailed design. The first documents issued mark such a baseline or inflection point. Furthermore, this 'negotiation period' shows the uncertainty that surrounds the design process: if the client had not signed the contract, the company would have wasted two years of work. This is an example where the blank space may be more telling and explicit than the non-white space.
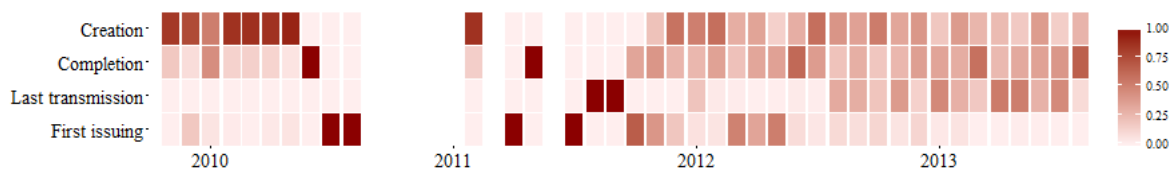

Figure 1. The figure shows the proportion of documents created, completed, transmitted for the last time, and issued for the first time for each month. The map is read by columns and a column represents one month. White spaces represent no data-logging.

From October 2011 onward, we see that the creation and completion of documents show patterns of complementarity, with periods focused more on new creations than completion and vice versa. From August 2012 until the end of the design process, we observe an increase of last transmissions, which means that people are completing the last coordination iterations. Concordantly, from January 2013 until the end of the design process, we also observe that the focus switches from the creation of documents to their completion.

To complete our understanding of the global patterns of the actions performed on documents, we need to understand the dynamics of each action. Figure 2 shows the dynamics of each action performed on documents. In this s-curve-like-figure, the proportion of documents created, completed, issued, and finally transmitted is shown over time. To make these quantities comparable, we normalise each one for its size.
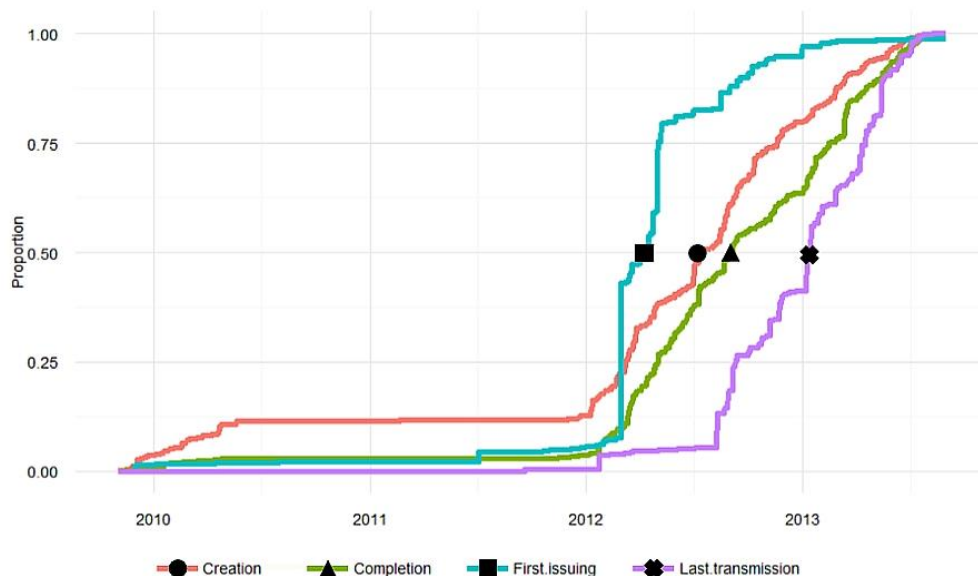

Figure 2. Proportion of different actions performed on documents over time. The graph shows the evolution of documents' creation (red), completion (green), first issues (blue), and last transmission (purple).

What we see is that until August 2010, up to 12% of the total documents are created and only a small percentage of these are completed and issued. Then, after the iterations with the client and the approval of the project, we can see a rise in all types of actions (January-February 2012). By March 2012, people created 25% of the documents and completed around 12% of them. Seventy five percent of documents issued received their first issuing within May 2012. Creation and completion show similar progressions, but also patterns of complementarity: An increase in the creation rate often corresponds with a decrease in the completion rate and vice versa. The evolution of the last transmission date shows that roughly 75% of the coordination iteration cycles are completed in the last 12 months, which is equal to 25% of the total time.

4.2 Zooming in on the type of documents: Showing temporal evolution of iterations and phase transition in the design process

Whilst section 4.1 provides a good overview of the global unfolding of the design process over time, we will now dig deeper into the story that the metadata of documents can tell us. We want to understand what happened during this design process as it progressed. In particular, we want to understand which documents people worked on and what happened during the 'negotiation period'. Because the majority of documents are completed within one month from their creation, we can compare the proportion of documents created and completed each month using, again, a temporal heat map (Figure 3).
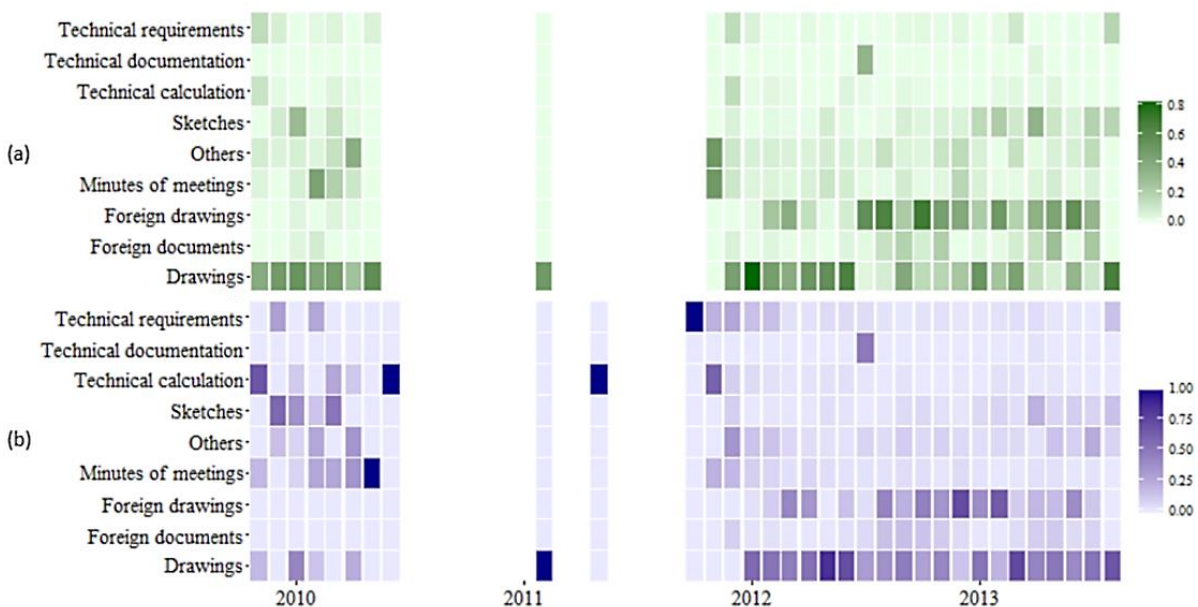

Figure 3. Proportion of type of documents over time. Documents created in green and on top (a) and documents completed in blue and at the bottom (b). White spaces represent no data logging due to a 'negotiation period'.

From November 2009 to May 2010, we see that people created mostly drawings, with some technical requirements, technical calculations and electrical documents. During this period, people did not use foreign drawings; we see only very few foreign drawings created and none completed.

This is consistent with and deepens further the results found in section 4.1. In the early stages of this design process, it is important to communicate and iterate with the client. Once the client's iterations are addressed, the company can use 'foreign drawings' (company terminology) to communicate and iterate with external providers. In the same period, people completed only a small fraction of drawings, focusing on sketches, electrical documents, and technical calculations. Iterations between those types of documents suggest an incremental development approach. These iterations in the early stages of a design process may suggest exploration activity of the solution space.

During the 'negotiation period', people completed some technical calculations they created previously (June 2010 and May 2011). This is a sign of reworking or incremental iterations: people work on previous documents to include more specifics or to correct issues. In October 2011, people worked on and completed previous technical requirements, without creating new ones. This is also a pattern of rework, but it can also mean that, during negotiations, the company and the client agreed to change

previous requirements. In November 2011, we see the creation of new functional specifications in the category 'Others' and rework on technical requirements and technical calculations.

The 'negotiation period' is now clearer: the work of the company addressed issues in technical requirements, calculations, functional specifications, and some new drawings. The intermittent work over time can indicate the necessary time to take decisions and receive approvals. Thus, there is probably more behind-the-stage work, e.g. from sales people, marketing, project managers, and decision makers, than our log contains.

Looking at the association between documents and activities, we found that the work during the 'negotiation period' focused mainly on three parts of the power plant: combustion systems, boiler, and pressure parts.

From January 2012 onward, we see that technical requirements and technical calculations involve very few new creations or rework. During this period, we observe an increase in relevance of electrical documents and process flow diagrams (category 'Others'). Following the 'negotiation period', we observe that foreign drawings (documents that involve external suppliers) come into play, marking iterations between the company and suppliers. Foreign and internal drawings show alternating dynamics: periods where the focus is more on internal drawings follow periods with more focus on foreign drawings, and vice versa.

We also see a clear phase transition from January 2012. The rhythm of the design process changed and experienced a speeding-up, but also the focus of the work switched. Before January 2012, we observe that people created and completed sketches, specifications, requirements, technical calculations and other conceptual representation. After January 2012, we see that people worked on drawings with the goal of incrementing the design of the biomass power plant. Consistent with this phase transition, we observe a shift in the type of iterations: before January 2012, we encounter "coordination iterations" with the client; after January 2012, we encounter incremental completion as a form of "progression iterations" (Wynn and Eckert, 2016) with other companies (suppliers). If we were to give those two periods a label, we would say "conceptual design" for the period before January 2012, and "detailed design" for the period after January 2012.

4.3 Understanding how people influence iterations during document editing

Having gained an understanding of how people used the documents in this design process, we can begin to understand how people interact and influence the document editing process. In their interactions, designers may iterate documents to communicate and to reach a consensus (Bucciarelli, 1994; Goldschmidt and Porter, 2004). Thus, we conceptualise documents as carriers of information. We use network analysis in order to understand how people can influence the iterations during a document-editing process. To account for the lack of full revision history and to understand people in connection with activities and the components of the biomass power plant, we consider relationships between functional units. As each document has a creator and a last modifier, we can infer a directed link (information flow) from a functional unit to another based on the proportion of documents they worked on together. In this kind of network, the last modifier has an influence on the creator as the modifier can decide whether the document is satisfactory. If the document is not satisfactory, then it goes back to the creator for new revisions (thus, new iterations).

We can also think of it as a trust network (Agreste et al., 2015) where trust is implicit and represents the fact that each functional unit trusts the experience or the skills of other functional units that have to complete or revise their work. With such a network, we could investigate the influence that each functional unit has in this network. We can have two types of influential nodes: units that facilitate the work because they create many documents that other units complete and units that are authoritative because they review many documents. We could get a first insight about these two roles by simply counting the number of incoming links (to estimate how authoritative a node is) and the number of outgoing links (to estimate how much of a facilitator role a node takes). Such method, however, would not take into consideration the possible flows that information can follow in the network, giving only a rough estimate of influence from and to direct neighbours. For these reasons, we can use the results of (Agreste et al., 2015) to evaluate how influential people are in this network using the algorithm HITS (Kleinberg, 1999). HITS provides two centrality measures: a 'hub', which formalises the intuition that a node is important if it points to many other important nodes (high outgoing flow), and 'authority', which formalises the intuition that a node is important if it is pointed to by many important nodes (high ingoing flow). In our network from the case, such metrics show evidence for the intuition that a functional unit

is authoritative in the editing process if it receives documents from many other influential units (as 'authority'), and that a functional unit is a facilitator if it sends documents to many other influential units (as 'hub'). The higher the 'authority' score the more authoritative a unit is and the higher the 'hub' score the more facilitator a unit is.

Figure 4 shows a network diagram of the information flows between the functional units. We can see that 'Boiler design' is isolated. This happens because, for all the documents created and completed by this functional unit, both the creator and the last modifier belong to 'Boiler design'. Even though in this design process the boiler is an autonomous sub-system and the unit edits a small amount of documents, this does not mean that 'Boiler design' does not communicate with other units.

Legend
BOD = Boiler design
CMB = Combustion
ELD = Electrical design
EXT = External consultants
MED = Mechanical design
PLD = Plant design
PMJ = Project management
PPD = Pressure parts design
QAC = Quality assessment and control
RES = Retrofit service
SIS = Site service
STM = Structural mechanics

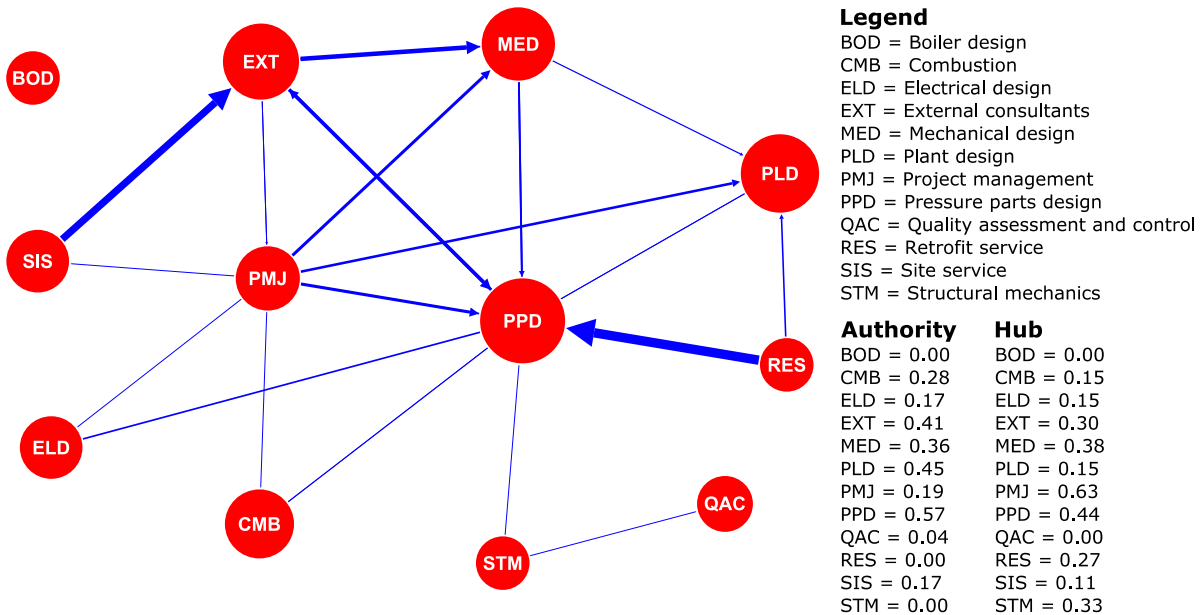| Authority	Hub
BOD = 0.00	BOD = 0.00
CMB = 0.28	CMB = 0.15
ELD = 0.17	ELD = 0.15
EXT = 0.41	EXT = 0.30
MED = 0.36	MED = 0.38
PLD = 0.45	PLD = 0.15
PMJ = 0.19	PMJ = 0.63
PPD = 0.57	PPD = 0.44
QAC = 0.04	QAC = 0.00
RES = 0.00	RES = 0.27
SIS = 0.17	SIS = 0.11
STM = 0.00	STM = 0.33

Figure 4. Network representation of information flows between functional units. Nodes are sized by their in-degree (number of ingoing links). Links are sized proportionally to the percentage of documents flowing from one functional unit to another.

'Quality assessment', being a function of control to certain degree independent from the others, has neither an authoritative nor a facilitator role, as indicated by 'authority' and 'hub'.

'Combustion', 'Structural mechanics', 'Electrical design', 'Site service', and 'Retrofit service' appear not to receive documents from other functional units and as the 'authority' score shows, they appear to have very little or no influence on iterations. For 'Site service' and 'Retrofit service', we note that these functional units focus mainly on maintenance and repair. 'Retrofit service' has also a small role as facilitator as they provide documents for 'Pressure parts design' and 'Plant design'.

The three functional units that show the highest authority scores are 'Pressure parts design', 'Plant design', and 'External consultants'. The three functional units that show the highest hub scores are 'Project management', 'Pressure part design', and 'Mechanical design'. 'Project management' has a clear role as facilitator as it sends documents to many functional units, especially to 'authorities', which is in line with their coordination and scheduling functions. 'External consultants' have a role as 'authority' as this unit can influence 'Pressure part design' and has a moderate role as 'facilitator' as the unit sends documents to 'Project management' and 'Mechanical design'. This balance between the two roles is in line with the function of consultants hired to solve issues. 'Mechanical design' shows a balance between the roles of 'authority' and 'facilitator', acting as an intermediary between 'External consultants', 'Pressure parts design', and 'Plant design'. 'Plant design' has a strong role as 'authority' and a weak role as 'facilitator', which means that it can influence the editing process of other functional units without being able to facilitate the communication in the network. 'Pressure part design' instead shows high scores and thus a strong role as both 'authority' and 'facilitator'.

5 DISCUSSION

By studying editing actions on documents, we showed global patterns of the temporal evolution of the design process. We highlighted a period when the design process was on hold, with intermittent work due to negotiations with the client. These negotiations involved the creation and editing of documents related to combustion system and pressure parts (piping system included). Changes made during these negotiations are likely to include both economic and safety reasons. Such intermittent work marks iterations with the client. Furthermore, we observed how document creation and completion are complimentary; with periods focused more on creation of new documents alternating with periods focused more on completion of previous documents.

Digging deeper into the types of documents created and completed over time, we identified a phase-transition in the design process from conceptual design to detailed design. Marking this phase transition, we observed that people progressed from using mainly documents such as technical specifications, requirements, and sketches what we may term conceptual representations, to mainly working on documents such as internal and foreign drawings, what we may term detailed representations. Such a shift marks a difference in the goals of the two design stages: during conceptual design, people explore different possibilities to formulate a 'plan', while during the detailed design, people progress toward the completion of their work according to the 'plan' decided on during the previous stage. Coherently with this phase transition, we observe how the iterations switch from being focused to the client during the conceptual design, to being focused to external suppliers and functional units during the detailed design. The perspective on types of documents showed the overall signature of a systems engineering approach (INCOSE, 2015) (e.g., the phase transition and the requirements addressed early in the process).

These findings provide empirical evidence of how the design process can follow a logical evolution despite its inherent iterative nature, suggesting that it is possible to plan process milestones as well as iterations.

Furthermore, our findings show the value of the metadata of documents and the importance of tracing the document editing process and more generally, the evolution of the design process. We believe that obtaining the full document revision history could enable even deeper analyses to make sense of iterations on a more granular-level directly relatable to process performance.

The network perspective lets us identify two different roles of functional units in relation with iterations. A unit can facilitate iterations and communication by sending information to other units or can act as reviewer when receiving information from other units. Even though the reviewer could increase the number of iterations, its function assures the right information to progress with the design, thus both roles are necessary. However, we can identify two possibly problematic positions: 1) a unit that has to act as reviewer but not as facilitator can become a 'cul-de-sac' for other units, delaying the progression; 2) a unit that has to act too much both as a reviewer and as facilitator can easily become overloaded by information. The former is the case of 'Plant design', and the latter is the case of 'Pressure parts design'. We know from previous work that most of the problems happened at interfaces with activities related to pressure parts and external piping (see fig. 4 from Parraguez et al., 2016). Supported by our findings, we can hypothesise that their role in the communication network may have had an influence on those interface problems.

Our data-driven multi-level approach from a global to a zoomed-in view on documents plus a network analysis considering iterations between people shows that it is possible and beneficial for process understanding and understanding the role of iterations, to consider iterations from a multi-level perspective, thus adding to the taxonomy of Wynn and Eckert (2016).

6 CONCLUSIONS AND OUTLOOK

This paper focused on understanding iterations in a real design process purely from a breadcrumb trail of data traces left by documents used during the design process. We showed that the temporal evolution and iterations during the design process are reflected in the metadata of the documents. Our results advance state-of-the-art by providing empirical evidence that iterations, negotiations, and design phase-transitions can co-occur in a successful design process. We also showed how the type of iterations changes in correspondence with a design phase-transition. Findings in this paper open a way for process planners and managers to plan the process as a logical progression while still accounting for the uncertainty generated by iterations and negotiations, by making iterations explicit in process and business plans. Furthermore, by using network analysis, we provided a way to understand how people

can influence iterations in the design process. We showed how the process insights obtained through such analysis may be related to performance and interface problems that occurred throughout the design process. Thus, we provide insights on how to structure communication between functional units and how to assess the roles of functional units in terms of the degrees of documents received or sent for editing. Our analysis methodology is easy to implement in analytics software and Enterprise Resource Planners (ERPs) and can scale to very large datasets. Furthermore, although the process analysed in this paper shares some resemblance with the Systems Engineering process model (V-model), our methodology is model-agnostic; thus, it can be applied to other design processes.

We plan to refine and validate our findings by analysing email exchanges using both text mining and temporal network analysis, to gain a better view on the temporal unfolding of the design process, and to understand how the diffusion of information changes over time. We also plan to build a statistical model of the number of revisions of each document to find factors affecting iterations during a design process, thus validating the insights from our network analysis presented in this paper. Finally, it'd be interesting to see how patterns found in our case compare with design processes from other real-world projects.

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ACKNOWLEDGMENTS