Research in Engineering Design (2020) 31:83–102
https://doi.org/10.1007/s00163-019-00322-8

ORIGINAL PAPER

Process models: plans, predictions, proclamations or prophecies?

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Received: 24 September 2017 / Revised: 5 September 2019 / Accepted: 7 September 2019 / Published online: 24 September 2019

Abstract

Design process models have a complex and changing relationship to the processes they model, and mean different things to different people in different situations. Participants in design processes need to understand each other's perspectives and agree on what the models mean. The paper draws on philosophy of science to argue that understanding a design process model can be seen as an imagination game governed by agreed rules, to envisage what would be true about the world if the model were correct. The rules depend on the syntax and content of the model, on the task the model is used for, and on what the users see the model as *being*. The paper outlines twelve alternative conceptualizations of design process models—*frames*, *pathways*, *positions*, *proclamations*, *projections*, *predictions*, *propositions*, *prophecies*, *requests*, *demands*, *proposals*, *promises*—and discusses when they fit situations that stakeholders in design processes can be in. Articulating how process models are conceptualised can both help to understand how process management works and help to resolve communication problems in industrial practice.

Keywords Engineering design · Design process models · Process management · Philosophy of technology · Make-believe theory

1 Introduction: process models direct actions

What is a design process model telling you to do? What is it telling you to expect? What is it telling you about how to reach agreement with your colleagues? What does it mean, in this context?

Designers and design managers talk about processes and processes models all the time without being aware that both the terms and the intentions behind process models are ambiguous. Managers often complain that processes do not get followed or that designers do not carry out tasks or activities in the right way, the right order or at the right time. Designers on the other hand complain about processes being too abstract or that processes are difficult to apply to their day-to-day activities, are missing important aspects, or do not depict the reality that they experience (Eckert and Stacey 2010). This points to a lack of shared understanding about what processes are and what process models tell them. Many factors can contribute to this lack of shared understanding, like different expertise, perspectives, priorities or time horizons. However, this paper focuses on the roles models and how people understand them can play in these divergent interpretations of what to do, as process models are manifestation of processes that are shared—often without explanation—amongst groups.

Models of design processes can be created for many different purposes. But the intended purpose is only part of the story; models are frequently repurposed, and they can be interpreted as having different meanings by different people. The relationship between a model and its target is extrinsic to the model—something not always appreciated by the people who use them—and it can shift during the course of designing without the model itself changing. Our work is motivated by wanting to understand how plans and process models can function to coordinate and manage different groups and individuals in complex processes when their relationship to what is actually done is often fluid and unreliable, and people understand them in different ways, as well as understand how the coordination can go wrong. This paper aims to elucidate the richness of potential ways to

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think about process models (and other, less structured information about processes) in terms of the range of different roles they play in guiding activities. These roles correspond to different ways of conceptualising what process models are; we put forward a set of twelve alternative conceptualizations that might be appropriate in different situations. Considering these roles gives researchers a theoretical framework for looking at the coordination of design processes, and working engineers a set of ideas for making sense of and resolving conflicts.

Engineering companies put considerable effort into developing processes both in terms of high-level process models, such as gateway processes, and in terms of process plans for specific projects to plan, manage, control and record processes (Browning and Ramasesh 2007). These are represented in a variety of different ways from informal hand-drawn sketches of models to formal models generated according to specific modelling conventions, often in specific modelling tools. Processes and their models used in industry can be both formal and informal. High-level prescriptive processes and carefully generated process plans do play an important role, but are only part of the picture (Eckert and Clarkson 2010).

Academic research on design process models has largely focused on prescriptive models from the point of view of how a process should be carried out (see Wynn and Clarkson 2017 for a review) or on the development of tools and methods to generate process plans (Browning and Ramasesh 2007; Karniel and Reich 2011). By contrast, this paper focuses on design processes as seen from the point of view of people in industry, who create models and act based on process models. This paper builds on an empirical case study conducted in an automotive company, where we interviewed 18 engineering managers and engineers about how they plan their processes (Eckert and Clarkson 2010) and other empirical studies of process planning (Flanagan 2006) and process modelling (Wynn 2007) that the second author participated in.

This is a theoretical paper which provides a framework for conceptualising process models to help designers and design research to make sense of diverse interpretations of models. It builds on two philosophical theories: *make-believe theory* (also known as pretence theory and prop theory) and *speech act theory*. Understanding what models *are* and what models *do* is central to our enterprise. For this, we draw on recent work in philosophy of science (primarily by Toon 2012; and Frigg 2010a, b, c) that views scientific models as defining games in which we imagine what the world would be like if the models were accurate. This in turn draws on Kendall Walton's theory of mimesis as make-believe, according to which works of art such as novels and paintings define hypothetical worlds, in conjunction with more general principles of interpretation; by playing a game of make-believe, we can reason and agree about what is fictionally true in these imagined worlds. This paper argues that what people think a model implies is true about the design process depends not just on the model, but on what they conceive of the model as *being*. To explain the difference in interpretations, we draw on speech act theory (Austin 1962; Searle 1969) to argue that the appropriate reasoning principles for thinking about design processes in particular situations are influenced by the *attitudes* to the models people have and convey to others, which depend on what they think of the models as *being* and thus what roles they think the models play in determining the design process itself.

Section 2 begins by framing our discussion of how models of design processes are understood in the context of how design process models are used in industry. In Sect. 3, we sketch out the huge range of kinds of process models by discussing surveys of process model research that have classified models according to intended purpose and the types of activities they are intended for. In Sect. 4, we introduce the philosophical idea of rule-governed imagination games, in which models act as props; and apply this to design process models in Sect. 5. Section 6 explores a variety of ways in which participants in design processes can see design process models as *being* different things that have different implications for the imagination games they can play with them. Section 7 shows how our characterisations of what models can be for the people who use them cuts across the range of purposes they were intended for. Section 8 draws some conclusions for design research and the practice of engineering design.

2 Models in design processes

In this paper we are chiefly concerned with what people draw from design process models. Frequently, and almost always in large-scale engineering, explicit models of processes play crucial roles. However, much process-relevant information used to plan and manage design processes is not systematised in models but comprises assertions of plan elements and requirements and constraints that are not composed into a coherent structure. While this paper talks about process models, most of what we have to say about how models are *used* also encompasses this less coherent process information, though only some of the ways of thinking about models we discuss fit unconnected process elements.

The question of whether social processes like product development, and social structures like a design team or a company have any objective existence, and if so what sort, has generated an enormous amount of debate in philosophy (see Miller 2011) and the social sciences (notably in the seminal contribution of Berger and Luckmann 1966). What if people disagree about what the structures and processes are? This is recognised as a key issue for information systems research on how to support collaborative activities (Checkland 1981). For the purpose of our paper, we can skip over this while taking a pragmatic middle position: Different participants have different and equally legitimate views of what the structure and processes are, but treat their beliefs as being objective facts about objectively existing structures. Where people manage to agree on them well enough to get work done together harmoniously, we can treat the intersubjectively agreed structures as real as a working approximation (note that Checkland 1981, strongly disagrees). Models to some extent reflect the perspectives of the modellers. In situations where conflicts of perspective matter the alternative views need to be respected.

2.1 Terminology for engineering design processes

The term 'design process' is used all the time by people who see no need to define it. It has two distinct meanings that are sometimes confused: (1) the officially prescribed set of steps or stages that product development ought to go through, according to a plan or methodology or company policy; and (2) the set of activities that are actually carried out in the course of developing a plan for an artefact.

In engineering, the sets of activities this covers are often referred to as 'design and development' processes (DDP), or 'product development' processes (PD), or 'new product development' processes (NPD). Browning and Ramasesh (2007) point out that "Product development (PD) comprises the myriad of multifunctional activities conducted by a firm between 'defining a technological or market opportunity' and 'starting production' of a unique product or service". These activities make up the design process and are expressed in terms of process models, as the processes themselves are intangible.

2.2 Interpreting process models as a problem in industry

In our previous work, we have observed a lack of a shared understanding amongst the participants of design processes. Contributing factors included: (a) a plethora of different and often overlapping models were used in the same process (Eckert and Clarkson 2010); (b) information related to one activity was expressed in different ways in multiple models; and (c) a lack of common interpretation of process models (Eckert and Stacey 2010).

2.2.1 A plethora of co-existing models

In the automotive company reported in Eckert and Clarkson (2010), different people in the organisation used a great variety of information artefacts as plans (as illustrated in Fig. 1)

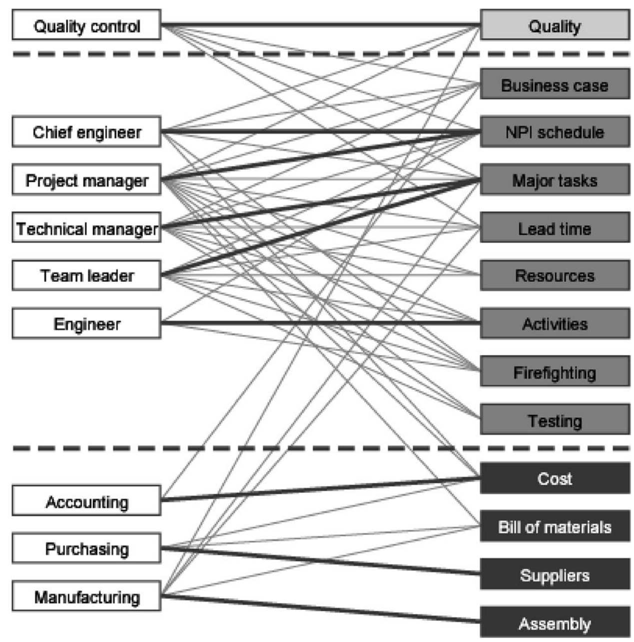

Fig. 1 Stakeholders (left) and the representations they use for planning processes (right). Key: Thick solid lines indicate the main models used by each stakeholder. Thin solid lines indicate additional plans considered. Dashed lines and box shadings indicate the distinction between models in terms of quality plans, process plans and product plans. Figure from Eckert and Clarkson (2010)

rather than having one coherent master plan. Individuals reasoned about multiple models and linked them in their minds. For example, the company generated a business case to bid for a new project, which included a high-level process plan. The project manager used a plan for when particular information or results were required by teams outside the design process, such as slots on testing rigs or handover of information to manufacturing. The individual design teams then generated their own plans to deliver their components and systems, which were largely driven by the lead times of externally sourced components; and the individual designers planned their own activities partly through to-do lists. When a crisis arose, a plan, listing and scheduling tasks, was created to deal with the firefighting (see also Repenning et al. 2001). While the engineers used mainly activity models or time-based models, their colleagues in such business functions as accounting, purchasing and manufacturing used product models to guide and monitor the progress of the process; for example, this particular process was partly controlled by the number of components in a bill of materials that were already signed off.

The business case was developed before the project started and not touched again. The company's high-level NPI (new product introduction) process and the Quality process were predefined, but the dates for the milestones and key activities were adjusted. Lead times were largely set through the needs of the suppliers. Testing tasks were set early in the process through the need to book test equipment. The tasks in the major task plan remained roughly the same, even though the timings changed. Research plans and activity plans were highly dynamic and focused on particular parts of the process. The firefighting plans were local and ephemeral. The cost estimations and the bill of materials were constantly changing as components were finalised and then adjusted to keep the target cost relatively constant.

Large organisations sometimes attempt to capture detailed prescriptions of processes with detailed descriptions of individual steps as part of knowledge capture activities (see Bergsjö et al. 2019); however, they find it challenging to implement these in practice (Riege 2005).

2.2.2 Different aspects of some activities are captured in multiple models

For example, lead time schedules specify the dates when the specifications for components or systems need to be handed over to the supplier to assure timely delivery of the parts. In the case study company, the airbags were major long-lead-time items. The time was negotiated with the supplier based on the preliminary specification in the business case. The designers planned their activities and ordered their decision to be able to specify the airbag on time. The major task plan considers the lead times. Individual designers generate their own activity plans around the lead time plan. Firefighting will occur if lead times could be missed. The signing off of components is monitored in the bill of materials, which is used to track the process. The likely component costs are incorporated into the cost model and other components need to be changed to make them cheaper to meet the overall target cost.

2.2.3 Different perspectives on the same model

The perspective on a process is different between those who are participants in a process and those who interact with a process without helping to carry it out, for example suppliers or test engineers. Inside the process, individuals can affect the process on a local level and might even engage in defining the process; however, in large organisations they might have limited say on the overall processes that they are engaged in or the prescriptive processes the organisation uses. They are allocated tasks with deadlines and have to work towards them, even though many managers make a huge effort to consult and engage designers in the planning. Those outside the process include other groups within the organisation, like finance, manufacturing or sales, and outside suppliers or consultants interacting with the process. In both categories, there are people who need to be concerned with how the process operates and those who are interested in the results produced by parts of the process.

The interpretation of the models is also different between those who generate a process model and those who interpret it. The case study company wanted to avoid everybody putting a time buffer on their time estimates, and therefore issued a statement that the product did not include innovation and so this process would include no iteration. In practice, the vehicle architect had planned in considerable buffer into the time of the 'NPI schedule' (the company's stage gate plan with timings for the gateways), but had not marked this as iteration. While everybody knew that avoiding repetition of steps was unlikely, they kept their buffers to a minimum trusting the project buffer that the vehicle architect had planned in for resolving problems—what one of his colleagues referred to as "emergency innovation" (Eckert et al. 2011).

The planning behaviour in the company was highly dynamic and complex, and the designers and managers needed to cope with a high degree of uncertainty about both the product and the process, yet the company delivers successful products and manages to coordinate a large number of individuals to achieve a common goal. This paper is partly motivated by our observations of the company's process management.

3 Research on design process modelling

The engineering design and process management community has taken a pragmatic approach and largely looked at design process from three different angles. One is developing generic models that aim to identify general patterns across all design process or across some classes of design processes. A second approach concentrates on tool development and specific ways to model and analyse design processes in particular modelling frameworks, which researchers or practitioners can apply to modelling design processes, such as DSMs (Browning 2001), Petri nets (for instance, Kusiak and Yang 1993); Applied Signposting (Wynn et al. 2006; Wynn 2007) or OPM (Dori and Reinhartz-Berger 2003; see Dori 2002). A third strand investigates the behaviour of models developed using one of the model frameworks, and the inferences that can be drawn from the models, for example simulations of process behaviour in Applied Signposting (Wynn 2007).

3.1 Generic models of processes

Generic process models are generated independently of specific projects. In their comprehensive review of design process models in engineering, Wynn and Clarkson (2017) carried out a comprehensive study of the research literature

Table 1 Wynn and Clarkson's organising framework for design process models. It comprises two dimensions, each with several categories. Redrawn from Wynn and Clarkson (2017)

Dimension	Category	Models in this category
Scope	Micro-level	Focus on individual process steps and their immediate contexts; procedures
	Meso-level	Focus on end-to-end flows of tasks as the design is progressed
	Macro-level	Focus on project structures and/or the design process in context
Type	Procedural	Convey recommendations of best practice
	Analytical	Provide ways to model specific situations for analysis/improvement/support
	Abstract	Convey theories and conceptual insights into the design and development process
	MS/OR	Develop insights by mathematical/computational analysis of representative cases

on design process models and classified them by scope and by purpose or type, according to the purpose stated by the authors of the papers, see Table 1. They divided the purpose of processes thus: *Procedural* models are for guiding future processes according to best practice. *Analytical* models are constructed to understand and convey insights from a particular past process. *Abstract* models convey theories and conceptual insights. *Management science/operations research* models are used to develop insights from mathematical or computational analysis of specific cases.

According to the level of detail, Wynn and Clarkson further divide processes into *macro-level*, *meso-level* and *micro-level* models. Micro-level models describe individual process steps. Models of particular processes can be very specific and concrete. Meso-level models, which are the focus of this paper, describe the sequences of tasks and/or flow of information through the process; while macro-level models focus on the overall structure of the process. Meso-level models vary in their level of abstraction (see Maier 2017; Maier et al. 2017). Many generic high level models of design that span different industries have been proposed (see Wynn and Clarkson 2017, for a comprehensive review), as have models of designing in a particular sector such as shipbuilding (e.g., Evans 1959). These are necessarily more abstract. Many of the models that are problematic in practice are procedural and analytical models at a meso-level.

Another dimension on which the models vary is whether they are descriptive or prescriptive models, though the distinction can be blurred (see Eckert and Stacey 2010). Abstract models are frequently used in education and research or to provide a vocabulary to think about specific processes. The remaining categories largely aim at supporting the planning and management of processes. Some of the abstract macro-level models are descriptive in that they describe common elements of many or all design processes. Whereas, procedural models tend to be prescriptive. Analytical and MS/OR models can be either, as some start with the description of current processes from which procedural models for future processes can be derived.

3.2 Purposes of models in industry

Browning and Ramasesh (2007) conducted a survey of 200 research papers and theses on activity-network-based process modelling aimed at supporting process management, thus focusing on what Wynn and Clarkson (2017) term procedural models. They classified the purposes of PD process models into the following categories:

- *Project visualisation* to display actions, interactions and commitments in a current or previous process, for instance using a large process flow map as a focal point for group discussion.
- *Project planning* to identify activities to be done, structure the process, identify sources of uncertainty and risk, allocate resources, and estimate and improve key project variable.
- *Project control* to monitor the state of the project and whether commitments to deliver information and interim results are being kept, and determine the best direction to go and how to dynamically re-plan the project.
- *Project development* for continuous improvement of working practices, organisational learning and knowledge management, and training.

While Browning and Ramasesh analysed research literature, Eckert and Clarkson (2010) observed that the plans in their case study organisation served three distinct purposes:

- *Prescriptive plans* tell designers what they should do and how they should do it, enforcing the order or the timing of plans—these plans are specific and forward looking.
- *Goal and monitoring plans* tell designers what state they must reach at what point in the design process.
- *Recording plans* are used to record what has happened during a project—such plans are sometimes adjusted retrospectively to capture the actual development of the project.

The prescriptive plans map closely to Browning and Ramasesh's project planning and the goal and monitoring plans to the control function of plans. The recording plans could be seen as a special case of project deployment plans; however, in the Eckert and Clarkson (2010) case study, the same models were frequently used to carry out all three of these purposes, while others were updated. Other companies treat the process model as a "living document", which changes all the time. In this case, the original planned timings and activities might be lost.

It is worth highlighting the project coordination function of process models, where models serve to coordinate the work of teams and individual participants within a project, across the projects within a company, and across a supply chain. In design, one of the well-recognised purposes of models is to act as *boundary objects* (Star and Griesemer 1989; see for instance Carlile 2002; Subrahmanian et al. 2003). They serve as channels of communication between people who have different knowledge and expertise, different ways of thinking about designs and problems, and different concerns—what Bucciarelli (1994, 2002) terms different *object worlds*—and can thus draw different inferences from them.

Karniel and Reich (2013) see the goal of process modelling in "obtaining insight into the process to manage it more effectively". They argue that as uncertainties are resolved and the design of the product changes, a process model needs to be updated during the process, incorporating the additional product knowledge, such as new activities or new relations (Karniel and Reich 2011). In Karniel and Reich (2007), they differentiate between pre-defined processes (P-process), current plan processes (C-process), and run-time process (RT-process). In Karniel and Reich (2011), they refine C-processes and RT-processes into 5 classes of dynamic models: iterative models with a constant scheme, i.e. where a given task sequence is repeated; models with exception handing where another predefined path is followed in an iteration; ad hoc models that are changed manually as required; dynamic changes to the scheme, where tasks are added or removed; and changes to the project logic.

4 Models

Designers and other participants in complicated design processes interact with these processes partly through models, and the models play significant roles in shaping what they do. We are interested in how this works, and what people do with their process models, and whether this is different in different situations. This requires us to look at what models *are*, and what their relationships are to whatever they are models of, and how models enable people to make inferences about the targets of the models. Such questions have been of great concern to the philosophy of science community (see Frigg and Hartmann 2012 for an introduction) and more recently also to the philosophy of technology community (for instance, Poznic 2016a). One problem is that the word 'model' is used quite loosely in design as it is in the sciences; how to define the term and what exactly constitutes a model is a controversial issue in philosophy of science. It is nearly impossible to say anything uncontroversial about scientific models; the question of what models in design are models *of* raises more complicated issues (Eckert and Hillerbrand 2018), and design process models are more slippery still (Eckert and Stacey 2010). Nonetheless we need a clear position.

4.1 On what models are

We adopt a pragmatic understanding of representation and modelling, seeing use for a purpose as essential to these notions: "There is no representation except in the sense that some things are used, made, or taken, to represent some things as thus or so" (Van Fraasen 2008, 32).

For us, a model is an entity that is employed as a model by an agent for a purpose. A model may be a physical object, or a program, or a mathematical entity, or a purely conceptual structure specified by a description or a diagram, but it has structure, properties or behaviour in its own right. To employ an entity as a model is to assert that a correspondence of some sort exists between the structure, properties or behaviour of the model and that of the target, and use this correspondence to make inferences about the structure, properties or behaviour of the target.

Scientific models range from material objects such as Watson and Crick's ball and stick physical model of DNA, to numerical models used in computer simulations like the atmospheric models used for weather forecasting, to sets of mathematical equations like those describing the (quantum) harmonic oscillator to model the hydrogen atom. Note that for most philosophers, the equations or the diagrams are not the model—they *describe* the model (Giere 1988; Bailer-Jones 2009; Frigg 2010a, b, c). For instance, Bohr's model of the atom, describing the movements of the electrons around the nucleus as similar to planets around the sun, is an abstract conceptual structure, which can be described verbally, be drawn on paper, or illustrated in a 3D physical model. However, some (notably Toon 2010a, b, 2012) contend that model descriptions are about the targets and that models are not distinct from model descriptions.

There is, however, a consensus that models are ordinarily abstractions of some kind. They can be conscious idealizations or simplifications, or make assumptions contradicting accepted knowledge (cf. Chakravartty 2010). For the purpose of this paper, we treat a model as an abstraction of reality by an agent for a certain purpose: features of the target are disregarded in the mapping or included only as symbols standing for complex characteristics, in the expectation, or hope, either that the excluded features are unimportant for the current purpose or that the influence of the characteristics included in the model can be understood in isolation.

4.2 On the relationships between models and their targets

Though there is no consensus on the exact role of models in science, for many philosophers of science it is central that models *represent* certain aspects of reality, their target systems. Models represent their targets when they stand for them, depict them or denote them. This depends on shared understanding of modelling conventions that enable us to interpret this use. The representation relationship is complex and is debated by philosophers (for a survey see Frigg and Nguyen 2016). Following the account of Morrison and Morgan (1999), models serve to mediate the relationship between theories and the specific phenomena they account for and the results in particular experimental setups they explain.

In science, the targets of models typically are natural phenomena. The relation between the model and its target is, however, even more problematic in design, as the models bring the target into being and only have a loose relation to the product or process that emerges (see Eckert and Hillerbrand 2018). What the target of a design process model is, is a tricky issue, in that while the model is an abstraction of the messy business of designing that enables people to reason about how designing is organised, the model also helps to shape the process itself.

However, in science models also do not always have straightforward targets in the natural world. Models make use of false or simplified assumptions; nonetheless they are the central building blocks of scientific explanations and drive scientific progress. This raises the question for philosophy of science of how can models be used to infer statements that can be seen as right or wrong. Recent philosophers of science, notably Roman Frigg (2010a, b, c) and Adam Toon (2010a, b, 2012), have argued that models in science serve as sources of components and rules for games of make-believe in which the scientists reason about what the world would be like if the models were accurate. They have focused on the role of imagination in envisaging the meaning and implications of scientific models, drawing on Kendall Walton's (1990) theory of make-believe to see how statements about conjectured states of affairs described by models can be true or false.

While engineering design is a serious business—lives and livelihoods depend on it—the idea of imagination games governed by rules gives us a way to understand what is going on in design activities, and in particular, how the different participants coordinate what they do. It enables us to think about the role of models in designing, and see designing and process planning activities as rational activities leading to rationally justifiable conclusions, without committing to naive or oversimplified views of the relationships between models and their targets.

Models of actual and hypothetical artefacts give us ways to understand and imagine what the artefact is like, or would be like, that are constrained by the models. Our imagination is both channelled by the models and can be checked against the models. Similarly, models of design processes give us ways both to imagine how the design processes will work, and make statements about how the design process will work according to the model. How can models do this? How can we think about how models do this, in ways that will help us use them?

4.3 Rule-governed imagination: games of make-believe

Walton (1990) argued that works of fiction such as novels, as well as films and plays and static artworks like figurative paintings, define fictional worlds in which statements like 'Harry Potter is a wizard' are fictionally true while statements like 'Dudley Dursley is a pupil at Hogwarts' are false. According to Walton, the reader or viewer constructs an understanding of the depicted situation by envisioning what follows from what they are explicitly told. This involves participating in an imagination game, just like a child's game of make-believe, where the rules of the game supplied by the artwork, plus more general principles of interpretation, make some propositions true within the world of the game and others false. Walton's view is open to criticism as a theory of how fiction works; for example, New (1999) pointed out that Walton neglects the role of illusion—that the viewer knows is an illusion but willingly enters into—in the appreciation of art or film. However, it gives philosophers of science a way to think about how statements based on models but about the real world can be true or false—and we can agree on them—when it is not obvious as to how the models actually represent the real-world target. We argue here that it gives us a conceptual lens through which to understand how one can make true or false statements about what is the case according to a design process model, when what the target of the model *is* is a slippery issue.

In this view, informational entities like stories are *props* that serve to define the rules of imagination games as well as playing roles in the games themselves. The term comes from the physical objects used in games of make-believe (a cardboard box on the living room carpet serving as a boat); however, what props *are*, collectively, is the source of the ground fictional facts that are used with more general principles for how to use these sorts of informational entities to form and constrain the imagination game by determining what is the case in the game (fictional, in Walton's terminology)—they 'mandate' what the reader is to imagine. Thus the text of *Harry Potter and the Goblet of Fire* is a prop; so too in our view representations of design information like a CAD model of a turbine blade or a Gantt chart listing designing activities are also props.

The notion of *authorised game* is central to Walton's theory. Authorised games are those with an established and socially shared set of rules that can not be arbitrarily changed by the participants in the game, i.e., the readers. The rules are determined by what the author has written. For example, the Harry Potter books are an authorised game, so that what is "true" and "false" in the imagination game is defined and agreed. Thus a statement *S* is *fictional* in a work *W* if the statement is true in the imaginary world defined by the work. (Walton did not like the idea of 'fictional world' preferring to see this just as what follows from the rules of the game; statements that are fictional are valid in a work W in the sense that they are derivable from it.) This applies both for explicitly stated fictional truths, like 'Draco Malfoy is a member of Slytherin House' and implied fictional truths like 'Harry Potter is a native speaker of English'. Correctly inferring implied facts requires background knowledge. It helps the reader to understand the culture the work of fiction is set in. For example, the structure and agony of exams at Hogwarts closely mirror that of British secondary schools.

The players of the game, i.e., the readers, need to buy into the game by accepting the props and rules of the game when that means suspending some of their usual beliefs about the world; and they need to understand the rules sufficiently well to make sense of the story.

Walton came at the problem from the perspective of the interpretation of works of art or fiction, once they are finished and published. His focus was on how fictional statements can be true or false despite being obviously false in the real world in which Harry Potter does not exist, i.e., they are not true simpliciter, so we are not to view them as true, but our proper attitude is one of make-belief. Walton did not concern himself with the need to change the rules of the game depending on an emerging situation, which is crucial to the practice of design. Nor did Walton engage with how the authors of plays or movie scripts have a different perspective from directors and actors, who need to interpret and add to an authorised game in order to make it work and thereby share in the creation of the game the audience plays. We argue here that similar differences in perspective matter for the different imagination games designers and other stakeholders play with design process models.

4.4 Models as props in science

Philosophers of science like Frigg (2010a, b, c) and Toon (2010a, b, 2012) have adapted Walton's theory of make-believe, to argue that theories and models in science define the rules of imagination games in which we can envisage the behaviour of the aspect of the natural world the theories and models are about, and make objectively correct statements about what the world is like according to the model. Central concerns for them are to nail down what models *are* in philosophical terms, and what it is for a model to represent its target, and see how statements about what would be true about the world if the model were correct can be objectively true, without needing to claim that the phenomenon that is the target of the model exists in any sense, or that the model is more than a mental construct. Philosophers are wary of the word 'true', which comes with two and a half thousand years of argument about how to define truth; whether a statement is a valid inference is a more appropriate and useful concept. This matches engineers' conceptions of models and inferences from them having 'validity' and 'fidelity' rather than truth.

According to this argument, the models scientists construct and use constitute props that are both used in the game and help to define its rules. (In philosophy of science this view is called *fictionalism*. The term *fictionalist* is unfortunate, as Giere (2009) points out: scientific models and theories are intended as accurate accounts of the real world and are not works of fiction.) The props include the diagrams, three-dimensional objects, and so on, that describe the models that scientists reason with and about. Although Frigg and Toon's accounts differ and are both open to criticism (see Poznic 2016b), the approach helps to understand how scientists use models. Scientific reasoning connects scientists' creative thought envisioning the world according to the model to the use of rigorous methods to calculate what follows from the models and to compare this with observations of reality. The notion of fictional truth can help us to see how the products of imagination can be subject to rigorous, scientifically and philosophically defensible statements about the claims models make and whether they are borne out by observations.

5 Engineering process models as props in imagination games

We use Walton's theory of games and make-believe and extend it to elucidate how teams of designers doing imaginative work can operate within a shared framework to achieve a coherent view.

5.1 Reasoning with models of hypothetical systems

The individual cognitive processes of making provisional design choices and envisioning what follows from them can be grounded in an agreed set of facts and requirements, and an agreed set of principles for how to interpret models and other documents. The principles enable designers to talk and agree on what is implied by the models, facts, requirements, and so on. (Of course, misunderstandings occur, and designers need to negotiate a shared understanding; see Minneman 1991; Brereton et al. 1996.) Thinking of design as a game of make-believe allows us to treat inferences drawn from models that do not have clearly defined target systems in the same way as inferences from models that have clearly defined, really existing targets. It enables us to look at how engineers and managers accept a set of assumptions and propositions about a new product, which they combine with their knowledge of engineering to reason about the characteristics of hypothetical products.

Seeing design as comprising imagination games in which the models or model-descriptions serve as props give us a way to see how we can talk about the validity of statements about hypothetical systems: a statement is true of the envisioned system if it is implied by the props describing models of the system. In the terminology of Waltonian fictionalism, such a statement is fictional in the work or game defined by the rules (general knowledge about engineering, physics, software, etc.) and the props (the diagrams, equations, etc., specifying the models).

Understanding what a prop (such as a sketch of a mechanism or a building, or a diagram of a design process) contributes to the imagination game has two levels: what it means, and what can be inferred from it using other knowledge (Walton's direct and indirect 'principles of generation'). Walton and his followers distinguish between 'primary' fictional truths that follow 'immediately' from the props, and 'implied' fictional truths. Similar distinctions have been drawn from studies of designing. For instance Goldschmidt (1991), studying architectural sketching, noted an alternation between seeing a sketch *as* being something, and seeing *that* it implied particular consequences.

5.2 Changing the rules of the game

Hypothetical future artefacts are not fixed and are partly defined by the models created when designing them (see Eckert and Hillerbrand 2018). The requirements the artefacts must meet can change during the design process, while proposals and provisional design decisions harden into commitments; thus what is fixed and what is open to discussion in design can shift. In phases where designers (of models of artefacts or of process models) generate new ideas, the boundaries are fluid between models and other representations that function as props that are given (for the time being) and those that are inferences about possibilities that are conditional on them.

In order for large-scale design projects to succeed, who is allowed to do what, and when, needs to be managed and coordinated. Both the props and the rules in the imagination games may change, but, most of the time, these are *authorised games* in the sense that the rules and props are determined by someone with the authority to do so, and shared and agreed. We can see process models as creating an authorised game or contributing to an authorised game, as they set rules for the process and the implications of the model can be debated by designers, managers and other stakeholders who understand the modelling formalism.

Whether we think of an activity defined by one set of goals, rules and props as a game, or see a project as one game, and decisions making changes to that project as revisions of that game, rather than a new game, is a matter of perspective. We can think of design processes as comprising a network of related subgames. What process models do is specify—to varying levels of detail—what these subgames are. The most appropriate analogies with what are commonly thought of as games come from elaborate computer games that include subgames with distinct tasks and goals, and opportunities to repeat activities in changed circumstances. Many design processes have iteration planned in—activities are repeated with different parameter values or changed assumptions, thus with changed props as well as increased knowledge of how to play the game, to converge to a workable design. Knowing that there will be iteration that is not fully specified can lead to process models being seen as vaguer than they actually are. The process models themselves change, changing the expected set of subgames. Design processes are subject to periodic reviews. Many current process paradigms have planned-in updates to the process plans. Gateway processes are reviewed at the gates and adjustments are made to expected tasks and their timing. Agile processes go through planning for each sprint. At this point, revised models are released, which can be thought of as a new version of the authorised game.

For Walton, authorised games are books or potentially other artworks. The activities of designers and managers in a product development process are more akin to a play, where the original author has provided the original prop, but then a new group of actors and directors interpret the play and the fictional world it defines and set new principles of interpretation and define new props. In a design process, as in a play, this elaboration amounting to co-creation is essential for realising the original author's intentions. These elaborations are largely, but often not completely consistent with the previous prop. As major decisions are taken about the design process and process models are updated, a new—derivative—game of make-believe is entered into.

As processes frequently change, there can be many of these derivative games, taking different parts of the process model as given or as open to change and development.

5.3 Process models as props

As explained in Sect. 2, engineering companies generate process models to plan, monitor and control design processes. At this point, the future process that the models describe does not exist, but is shaped by the models. So the relationship to their target is complicated.

Participants in the process need to accept them—as props—and the principles for interpreting them to coordinate their actions. Designers and managers can imagine the implications of process models of varying specificity, combining information about the problem and situation with information about the model.

Of course, the picture is complicated by the participants' different perspectives on the structure of the organisation, interpersonal relationships, the capabilities, needs and priorities of the participants, and so on (c.f. Checkland 1981). These might lead different people to have different views of the relation between the model and actual or future reality. To put it in Walton's terms: the different participants' principles of generation are not necessarily shared, and may indeed conflict. If a process does not have an objective existence, then it is problematic to claim that it is the target system of a model with a well-defined mapping between them. But a model does not require a target system with any particular ontological status to function as a prop; and the aim of a prop in reasoning about design processes is not to reflect a measurable reality, but to create a shared and coherent view.

However, having a workable process plan for a large design project involves committing to divisions of labour within an implied organisational structure as well as a particular conceptualization of the tasks. The use of particular terms in the process model as well as different methods of constructing and diagramming process models has consequences for how the participants conceptualise processes, for instance whether the dependencies between activities are explicitly imagined in the envisionment of the process and stated in the model, left implicit or vague, or disregarded. Thus, PERT charts, Gantt charts and sprint plans both make different aspects of the structure of the process explicit and embody different assumptions about how the process will operate.

5.4 Planning as an imagination game

'How are we going to do this?' Many process models are explicitly generated as plans, and others get used for planning purposes and for guiding the performance of the process, and so are conceptualised (for these purposes) as plans. The models embody decisions made within the project for reasons that are apparent to the creator of the model. When the time comes to implement the plan, it needs to be taken as given in envisioning what needs to be done to produce particular results by deadlines; before then the plan can be changed but according to rules for what the plan needs to be like.

Project planning involves a dance between tentatively describing the process in a model, envisaging how the project would play out according to the model given the planners' knowledge of constraints on the project and of how the activities listed in the model really work, and criticising and revising the model. If the process model is used to generate a schedule manually (rather than picking from a set of simulated schedules) planning and scheduling can be seen as a forward chaining process of make-believe, where parts of the plan are treated as an artefact to be designed and thus open to debate and inferred using the principles of generation, then accepted as props or retracted.

As explained in Sect. 2, large organisations generate a multitude of process models and individuals reason about multiple models at once to make decisions. These can involve many of the different kinds of models outlined in Table 1. The artefacts used as props in planning can include generic process models for development methodologies and company standard processes, and process models for previous projects, that constrain and provide elements of plans for the current project. They thus serve different roles from (provisional) plans for the current project, and are used according to different rules for how to explore the consequences they have for the current project.

Plans for development projects need to balance and combine the needs and priorities of designers with different responsibilities and expertise, and much project planning is done interactively in meetings. When a process model functions as a boundary object to communicate information between people with different interests and knowledge, it gives them a shared prop to constrain their envisioning of the implications of decisions for their own concerns. Thus they can infer propositions that they can agree are implied by the model (in Waltonian terms, fictional within the game defined by the model). For example, when different teams estimate potential finishing times for their own tasks they can start discussing how to coordinate them.

As planning is in practice rarely done by a single person in a coherent fashion, the multiple models or combinations of models afford different interpretations, which can be seen as contradictory fictional propositions. This poses a potential problem in design processes, as multiple legitimate interpretations can lead to problems. In the Waltonian view, fictional propositions are derived based on the props and the world knowledge which the players bring to the props, thus allowing for multiple interpretations. In a similar way, the engineering process models are interpreted based on the knowledge of the individuals and the activities that have already taken place, and are subject to uncertainties like changes in requirements, resources, timing of activities, etc. (see de Weck et al. 2007 for a classification of uncertainty). However, they are also influenced by the perspectives individuals take on models.

Crucial for a successful project is a sufficient shared understanding of the rules for envisioning implications and changes. This involves understanding the syntax of the diagrams and the requirements for what needs to be included in adequate models, as well as the props that carry the information used in a particular planning activity. By possessing specialist knowledge, different participants get to be custodians of different subsets of the rules of the imagination game played by the whole team. From an individual perspective, the participants are playing different games of make-believe with different principles and sometimes different props; from a group perspective, they are responsible for contributing different inferences from the props to a collective game.

5.5 Scenarios of interactions with process models

A view of engineering as a network of games of make-believe, governed by different principles of generation of inferences as well as different props and different goals, suggests that the participants in the imagination games in design processes can find themselves in different situations in which different principles of generation are appropriate. This gives them a different perspective on how they interpret models based on the role that they assume.

The following factors that characterise different kinds of situations will be used in Sect. 6 to identify situations in which different attitudes and perspectives that people can have on process models, i.e., on the props in the game, are appropriate:

- *Process perspective versus Output perspective* One important difference in perspective is between how a process will *work*, what needs to be done, and what will happen; and what a process or part of it will *deliver*. While this appears related to the view from inside or from outside the process, the correspondence is far from exact: people not directly involved in designing may have reasons to care about how the process unfolds; more significantly, designers are both producers of information for others and consumers of information they need from their colleagues. For imagination games using process models as props, this is primarily an issue of what aspects of the props are important. It is the difference between looking at how the principles of generation establish fictional truths to create a fictional state of affairs, and being concerned with using or establishing specific statements about the fictional word.
- *Creator versus Recipient* How one uses a process model to envisage what will happen in a part of a process crucially depends on whether one is responsible for carrying out an activity and producing particular results, thus the creator of some kind of information artefact; or one is the recipient of the information artefact, not responsible for it but dependent on getting it on time and done sufficiently well. To extend our analogy of actors co-creating the fictional world of a play, this is the difference between an actor needing to flesh out a part beyond what is given by the text in order to play it convincingly to deliver on the author's intentions, versus an actor needing other actors' characterizations to work off. (When the recipients are outside the design process, their role is analogous to the audience participating in the game of understanding the fictional world co-created by author, director and actors.)
- *Enfranchised versus Excluded* Are the *source* of a process model or a decision or a constraint, and the *user* of the model or other information both part of the decision-making process? Or is this communication across the boundary of the team responsible for planning or modelling the process? In large-scale design processes, many of the participants are responsible for implementing the plan but not creating it—a matter of role rather than seniority (for instance, as observed by Eckert and Clarkson 2010). There are degrees of outsideness here according to how much contact and influence on the process planning the participants have; they may have influence on some parts of the process plan and not others. Also, many of the users of design process models are stakeholders with reasons to care about what the models are telling them but are not directly involved in designing, and thus do not participate in either creating or following process plans. Here, we are considering participants in the process, but the influence of exclusion from process decision-making on the rules of the imagination games seems very similar for external stakeholders. Conversely, participants in design process modelling make use of process-model-relevant information from outside the process that they and their colleagues within the process can not directly influence. This corresponds to the ability to change the rules and reinterpret the props and needing to stick to given rules. Thinking of a play as a game of make-believe, this is the difference between the directors and actors who put on the play and make decisions about how to interpret or even alter the text, and the audience who play the game of make-believe but do not share in defining it.
- *Negotiation versus Diktat* Is the design process model or other information provisional or flexible or open to negotiation? Or is it fixed because it has been decided upon or is inherently unalterable? This is equivalent to

the fixedness of the game. Again thinking of this in terms of a play, this is the difference between whether the director and the actors are allowed to change the words or have to stick as faithfully as possible to the original script.

- *Transparent versus Opaque* Can the user of the model or other information see and appreciate the reasons behind a decision, or why the implications of the model are what they are claimed to be, or why other information is as it is? Or does this need to be taken on trust or obedience? This corresponds to how apparent the principles of generation are to the readers of books. Some novels depend on principles of generation that the author assumes the reader to know. Many science fiction stories or novels deliberately make events seem very strange to the reader who must take on trust the existence of a rational explanation that will eventually be revealed.

In the next section we discuss ways to conceptualise process models and the activities that they are used in that fit different combinations of these characteristics. However, we do not think this is an exhaustive list of useful conceptualizations.

5.6 Conclusion: agreeing principles of generation

In a game of make-believe, players assume roles which affect the actions that they carry out. Players of games have goals they want to achieve, and different attitudes to current and potential states of affairs. Thinking of designing as a game of make-believe with models as props highlights the fact that multiple way of playing the game can be equally legitimate based on the same 'fictional' propositions derived from the models.

This shows that different interpretations of the implication of models, in particular the combination of multiple models, are an inherent part of interacting with models. It is not the result of lack of modelling ability by the creator of models or lack of understanding of the user, but an inherent part of designing. In practice, figures of authority in design processes, bosses or managers, can provide an interpretation of the process models. However, they and the designers need to be aware that a different interpretation is possible and therefore an authoritative interpretation is required.

It is important that people thinking about the design process, or talking about it or making decisions based on it, agree on what the rules of the game are or are following rules that their colleagues recognise and understand. For example, a group needs to agree on the features that a functional prototype needs to have to pass a particular gateway and on the activities arising from that. Process models help teams to agree on what the various subgames are that make up the design process by guiding the specification of activities with particular goals or recording decisions about them.

There are two sides to agreeing principles of generation for using a model to reason about a design process. One is understanding what the model itself is saying—thus how the prop constrains and guides the imagination game. For example, whether the main function of a process model is to indicate dependency or the order in which tasks are carried out. For another example, whether in a particular organisation one should submit incomplete information on time to give an indication of progress or whether one should wait until the task is finished. While this kind of context is often communicated orally, misunderstanding can lead to decisions being based on unfinished and unconfirmed information.

The other side is understanding what principles should govern the imagination game through which people draw inferences about the design process from the model. What the user thinks the model *means* depends on what the user thinks the model *is*.

6 Conceptualizations of design process models

What different kinds of meanings can design process models have for their users? In other words, what different kinds of rules might the model users need to follow in thinking about the relationship between the model and the process, and what the user should do in response to the model? In this section, we look at how different ways to conceptualise what process models *are* fit different situations and attitudes to the models, and how they help to form different sets of rules for how to think about models and processes. The set of conceptualizations we present are not an exhaustive classification, and we have only considered the use of models in planning and carrying out current and future processes; however they cover a range of situations that are important in industrial practice. The creators of the models and other stakeholders can actively influence how the models are interpreted but only if they realise they need to do this.

Here Walton's approach does not help any further as he does not detail how the games of make-believe actually work or what unites different games of make-believe. To understand this, we draw on another philosophical theory: *speech act theory*, which explains how utterances lead to actions in different contexts. One of the fundamental divisions between these situations lies between seeing process in terms of outputs to be produced at particular times, or in terms of how the process proceeds (see Sect. 5.5). In Sect. 6.2, we discuss situations and conceptualizations fitting an output perspective; and in Sect. 6.3 we discuss situations and conceptualizations fitting a process perspective.

6.1 Speech act theory

Speech act theory (Austin 1962; Searle 1969) looks at how utterances convey meaning to their recipients. According to speech act theory, an utterance does not just comprise the content of its sentences (its *locution*), but also the meaning it is intended to have in context, that is, how it should influence the hearer's beliefs and intentions (its *illocution*). The meaning it actually conveys to a hearer is termed its *perlocution*.

The illocution of an utterance includes what sort of an utterance it is, such as requesting, stating, proposing, promising or warning. The illocution also includes the speaker's attitude to the content, such as expressing belief, doubt, ironic distance and so on. For instance, designers working in groups use rhetorical devices to modulate degree of commitment to design proposals (Minneman 1991; Brereton et al. 1996).

Process models, as well as information about the constraints on the process and the implications the process models have, are frequently referred to in communication acts. These communication acts convey attitudes to the models as well as explicitly including them or dismissing them as relevant to the current activity and highlighting particular features. And we can also think of individuals' private interactions with models as communication acts with themselves that include their attitudes to the models. Our argument here is that these attitudes help determine the principles people apply—or should apply—to draw the appropriate inferences from models.

The attitudes that designers and other stakeholders *can* have and express towards models is tightly connected to what they think the models *are*—that is, how they conceptualise them.

6.2 Output perspective: models mapping results

Within an output perspective—a focus on what the process or part of it needs to produce—situations differ according to how fixed the process and the information artefacts it requires are, and according to whether the requirements for particular information artefacts at particular times are seen from the perspective of the producer or user (see Fig. 2).

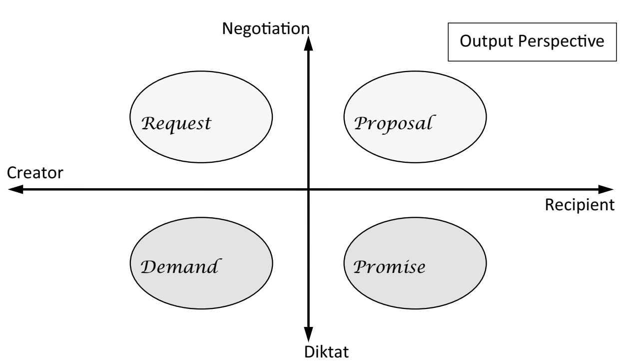

Fig. 2 Conceptualizations of process models, seen from an output perspective

As we have noted, many process models make explicit the need to produce results at particular points in the process. Producing the results gets to be the responsibility of individuals or teams, who have deadlines. How the parts of a process model stating these responsibilities are conceptualised is a matter of perspective. Process models—or portions of them—with these different statuses function as props in imagination games in different ways according to the *goals* of the imagination games. Both creators and recipients need to reason about how to deliver on their own responsibilities: for creators, the models serve to define goals; while for recipients, they serve to define constraints on what they can do.

6.2.1 Models as promises

When part of a process model specifies a result, such as part of a design or some test results, that an individual or a team or the company undertakes to deliver, it can be seen from the perspective of the *recipients* of the information to be produced as a statement of a *promise*. They need to think about whether they can trust the promise and what to do if it is not met, in envisaging how their part of the process will work according to the model.

6.2.2 Models as demands

Conversely, when part of a process model specifies a result to be delivered, it can be seen by the *creators*—the individual or team charged with producing it—as a *demand*. They need to think about how to elaborate their part of the process specified by the model to produce the required result.

6.2.3 Models as proposals

When what is to be delivered and when is not fixed but subject to negotiation, so the model is not settled, what is to be delivered and when is a *proposal* from the perspective of what the individual or team that would be the *recipient* of the suggested output from a part of the process they are not responsible for.

6.2.4 Models as requests

Conversely, when what is to be delivered and when is not fixed, what is to be delivered and when is a *request* from the perspective of what might be asked of an individual or team.

The difference between promises and demands, on the one hand, and proposals and requests, on the other is a matter of both position in the organisation and of time.

6.3 Process perspective: Models mapping activities

Within a process perspective—looking at a design process model in terms of what the activities are and how they are connected—situations differ according to whether the user of the model is involved with making decisions about the process—*enfranchised*—or *excluded* from it; whether the process model is open to *negotiation* or fixed—a *diktat*; and whether the reasoning behind why the process model is as it is is *transparent* or *opaque*. Two positions on three dimensions give us eight types of situations with different characteristics calling for different attitudes to process models (see Fig. 3). Here we describe conceptualizations of process models that fit each of them, without claiming this is a complete list of possible views of process models.

6.3.1 Models as frames

In the activity of constructing a process model, the new model itself, previous or generic models being adapted, and the model element types prescribed by the modelling formalism, function as a *frame*—a structure that specifies categories of things that will be present in the situation and the relationships between them (cf. Schank and Abelson 1977). The frame provides a way to fit the process into slots: to divide up the messiness of a design process into named activities, that belong to particular categories and are clustered and sequenced into particular groups, and define what sorts of information the activities need and produce. This serves to reduce the complexity of what needs to be thought about, by imposing one prespecified structure on something that could be conceptualised and divided up in different ways. However, employing a modelling formalism as a frame is a two-way process of seeing how the categories in the model make sense of elements of the process, and how well what needs to be done and the requirements and constraints on the process fit the categories and sequences. When models are used for planning, this has direct consequences for how later participants in the process will understand it, and how it will be carried out.

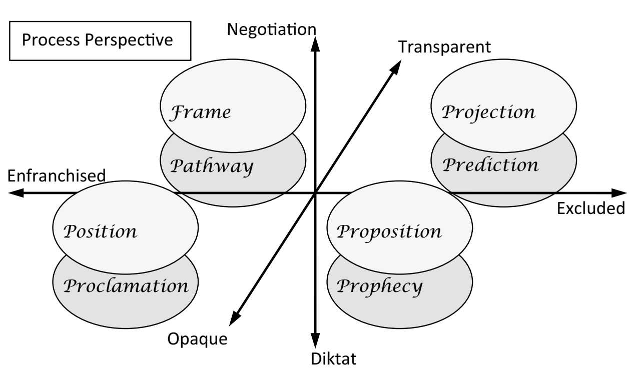

Fig. 3 Conceptualizations of process models, seen from a process perspective. The negotiation-diktat dimension is indicated by the shading

In the imagination game of constructing a model using methodological expectations and a modelling formalism to identify and characterise activities and outputs that will need to be there, and envisioning how the process will work according to the model, the boundaries can blur between props—artefacts that are given—and principles—the knowledge people use to interpret the props—and artefacts produced in the activity.

Note that in this discussion, we argue that the process model acts as a frame for understanding the process. However, the modelling technique acts as a frame for the process model. For example, DSMs treat processes as sequences of tasks, whereas flowchart style models make decisions and alternative paths explicit. Using a process modelling formalism as a frame involves participants in the modelling making decisions for visible reasons about how the process model should fit the process, and negotiation both between participants in the modelling and between the model and the actual or putative process itself.

6.3.2 Models as pathways

When a design process plan is being implemented, the models describing the plan and possibly other models are conceptualised by the participants as a *pathway*: a route to follow with milestones to reach and actions to perform at different places, as well as information and physical artefacts provided by others to be found and problems of particular kinds to be resolved at particular locations. In these situations, the actors are participants in the process who see the decisions embodied in the model as having transparent rational justifications, or at least accept them as justified, and who take the process model as given as a guide to action. The task of the imagination game is to work out, from the model and the detailed information about the state of the design, what to do to reach the next step.

6.3.3 Models as proclamations

Decisions about processes embodied in process models where the rationales for the decisions are opaque can function like proclamations by an absolutist ruler in situations where the people affected by them cannot point out problems and argue for their own concerns. While it is necessary to make decisions to carry out design processes, management decisions made without consultation and consideration of positions are demotivating; they are often unavoidable but the necessity needs to be justified. In very complex processes, there is inevitably an element of proclamation, because not all participants can be consulted and rationales cannot be given in a succinct enough way that people can engage with them. For example, projects often have to work around free slots on testing rigs, which might not be available at ideal times; similarly experts might only be available from a certain point. Thus some statements about processes, perhaps encapsulated in models, can function as fixed points to be reasoned from but not reasoned about, in the game of envisaging how the project will play out.

Models or process constraints embodying seemingly arbitrary decisions are seen as needing to be fought or worked around in ways that are likely to be detrimental to a smooth running project. In extreme cases, they create imagination games where the goal is to find ways to mitigate the consequences of the arbitrary decisions about part of the plan, and achieve goals that are not part of the official plan, thus to create an unofficial plan in opposition to the official plan.

6.3.4 Models as positions

In situations where process planning is subject to discussion between interested parties, models or elements of models, as well as requirements and constraints, may be put forward by the participants. These may have rationales that appear clear to their proposers but appear opaque or overstated or insufficiently well justified to others. These others may push for other priorities or need to ensure that the proposals are compatible with their own concerns. The models may thus serve as positions in negotiations to be accepted, rejected, clarified, elaborated and so on. These negotiations involve the imagination game of envisaging what follows from a model, assessing advantages, disadvantages and costs, envisaging what would follow from variations of the model, assessing what is and is not acceptable, and gauging degrees of need for changes in the model.

For example, design managers often request time estimates from their team members for particular tasks. These are often accompanied by informal process models, to justify the times and steps assigned to them. The team members take these positions as a starting point and negotiate a plan that works for all.

This is particularly an issue when working across a supply chain, for example when selecting between suppliers with alternative processes.

6.3.5 Models as propositions

Process models look different to people who are outside the process, so neither involved in planning the process nor in implementing it. Other stakeholders within the organisation or in other companies need to make use of models of design processes and information derived from them for their own planning and decision-making. Sometimes the model can function as a *proposition*: the actor is outside the decision-making process and so cannot alter the model, and the rationales behind the decisions it embodies are opaque, but the model and its consequences constitute an offer that can be accepted or rejected. Again, this might be the case when working with powerful suppliers, who leave the company no choice but to take an offer. Deciding about a proposition again involves the imagination game of envisaging what follows from a model, and assessing advantages, disadvantages and costs; but the next step is assessing whether these are acceptable in the absence of alternatives.

6.3.6 Models as predictions

In cases where people within the design process or outside it are affected by what will happen and depend on understanding the consequences of how the process will unfold, the process model functions as a *prediction*. The task of the imagination game is using the process model to envision how the expected behaviour of the process—rationally understood but not to be influenced—will affect their own concerns. The predictive nature of modelling plays a very important role in time and resource planning.

In science, predictions are often made based on the understanding of the causal relations in the target system leading to the predicted event. These relations may be deterministic or probabilistic, yielding deterministic or probabilistic predictions, respectively. In other cases, scientific predictions are based on correlations. In science the interest is largely in the output of processes. In design outputs are described/defined by product models, and process models are used to describe the process by which this output is created. We have analysed this relationship in Eckert and Hillerbrand (2018). In sciences such as physics or chemistry, the predictions usually do not affect the event itself. However, in systems that depend on human behaviour, predictions can have an influence on the behaviour of the human agents and therefore on the outcome. For example economic predictions influence human behaviour and thereby the outcome; climate change prediction might affect policy making which in turn might affect behaviour. However, these models do usually not include predictions about how they affect the outcome and do not prescribe how the outcome is generated. Process models do just that: they prescribe and influence the process.

6.3.7 Models as projections

In climate science, a distinction is often made between *predictions* and *projections*, that is directly applicable to understanding the import of design process models. A prediction describes what *will* happen according to the model, and how likely the anticipated outcomes are. By contrast, projections, for instance of future states of the world in climate science, include an element of fiction, by applying the model to conjectured scenarios. According to Poznic and Hillerbrand (2017), the correct epistemological attitude to a prediction is belief (conditional on confidence in the model), whereas the correct epistemological attitude to a projection is make-belief (conditional on the acceptance of the scenario, as well as the model).

Design process models may be based on scenarios for what *might* happen. In some cases they may be parameterized in some way, often in terms of time or resources, so that alternative events or choices can be plugged in. They thus yield (or become) projections that depend on accepting the scenarios. For example, alternative scenarios may need to be considered for what would happen if the project misses test rig slots, or fails to get components from suppliers on time, or the design fails to hit performance targets. People outside the project are enabled to see what would be the consequences for their interests in different scenarios, and to form preferences. Projections are particularly important when companies need to plan based on assumptions about whether or not they obtain particular orders.

6.3.8 Models as prophecies

What happens in a design process is contingent on both the models and the events that unfold in the process. The process model provides a guide to what is to come but how it does so and how far it should be trusted may be obscure to outsiders who depend on what they are told for their own work.

What happens according to a process model depends on other elements being true and on the explicit or implicit logical connections between them. However in actual design processes, unlike in logical contingency, not all the factors that are important are known, nor are the causal relationships fully understood; and what becomes important depends very much on circumstances. This brings us to our last conceptualization of design process models—*prophecy*. The design process model foretells how the design process will unfold and what its consequences will be, but when its justifications and internal workings are obscure it needs to be taken on trust and believed through faith in the knowledge and competence of its originators.

Prophecy is largely a religious concept, which assumes that a prophet receives a divine insight into events that will happen in the future. Some prophets have revealed an inexorable doom, while others have issued warnings about choices the hearers can still make. (Prophecies have posed many questions about the free will of the agents that the prophecies are about, discussed by philosophers through the ages.) This is an oddly appropriate metaphor for design processes as the designers do control the process to a large extent, but are bound by external conditions that they can not be fully aware of and by the laws of nature. Prophecies differ conceptually from predictions in that predictions gain credence from fallible but traceable human reasoning from evidence, while prophecies gain credence from faith in authority—in design, the authority of the manager or the methodology.

7 Discussion: types of model and types of interpretation

We discuss twelve possible conceptualizations, as summarised in Fig. 4. Following basic ideas from speech act theory, we have argued that the attitudes to process models people take in thinking about and discussing processes are crucial, but the attitudes that people *can* take towards process models depend on what they think the process models *are*.

This classification of models cuts across the classification of models by Wynn and Clarkson (2017), which is presented in Table 1, since it addresses the implicit and perceived status of the information the models convey and the roles the models play in decision-making and coordinating design processes, rather than their intended information content or their level of detail or the type of activities the models are intended to be used in. The issues we consider in this paper are the subject of tacit assumptions in most process modelling research. The models reviewed by Wynn and Clarkson largely assume a process perspective—they guide thinking about processes as sets of activities. How specific models fall under different categories varies with the individual models; however some general trends might be seen. Procedural models are transparent at least by intention; whether the user is involved in implementing the procedures determines whether they function as *pathways* or *proclamations*—"we will do it this way"—or as *projections* or *predictions*—"this is what is going to happen". Abstract models often function as *frames* for conceptualising the elements of processes and how they are connected together." Analysis and MS/OR models are intended to generate *projections* and *predictions*, but can in practice be opaque and be seen as *prophecies*. Both descriptive and prescriptive models aim to be transparent. Prescriptive models by their nature are diktats, so that they can be seen as *predictions* or *pathways*; however some development methods explicitly allow for customization to meet the needs of particular projects. Descriptive models are usually constructed through discussion with the participants. As descriptive models look backwards rather than forwards, how they can be interpreted depends on the use to which descriptive models are put.

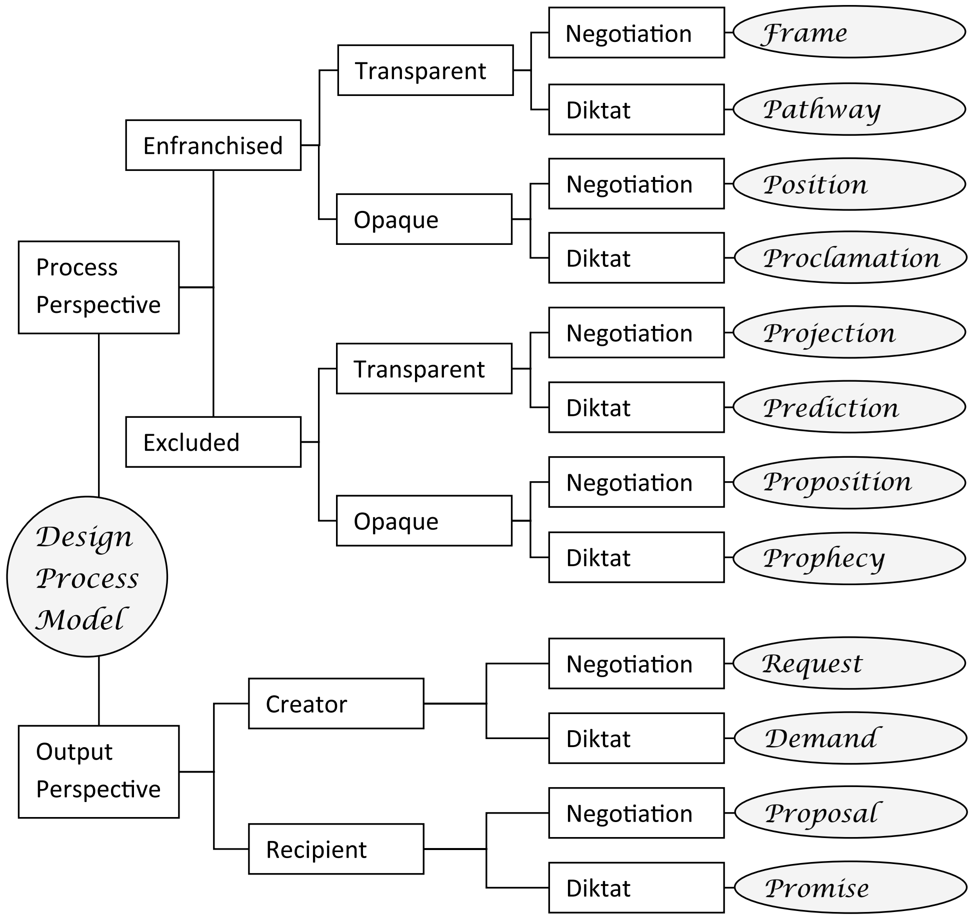

Fig. 4 Twelve conceptualizations of process models

Similarly this classification is also orthogonal to that of Browning and Ramasesh (2007), which covered most of the well-known process modelling frameworks, such as DSMs (Browning 2001) and Applied Signposting (Wynn 2007). These modelling frameworks do not determine how designers use the models or how they communicate through them. However, most modelling frameworks share the common goal of making processes more transparent. They also aim to pull information together that otherwise would be held in several unconnected models. Software engineering methodologies such as the Unified Process (Jacobson et al. 1999), SSADM (see for instance Goodland with Slater 1995) and OPM (Dori 2002) explicitly link product documentation to process steps. This reduces the space of alternative interpretations that are compatible with the models. By analogy, they are the model equivalent of books with better drawn characters and more complete world descriptions, that the readers might enjoy more and create fan communities around.

For the designers in Eckert and Clarkson's (2010) automotive industry study, the multiple process models largely felt like something from which they were excluded and which was opaque to them. The designers created their own models which they understood and saw largely as *requests*, i.e., something that helped others to understand what was required from them and which they were willing to discuss. They did not see most of the models generated by others as *proposals*, but as *demands* that they had to comply with. Through the combination of models that they understood and could influence to varying extents overall the designers felt excluded; and experienced the landscape of different models as opaque and as a diktat. Which make the models collectively a form of *prophecy*.

8 Conclusion: lenses for looking at process models

The analysis presented in this paper has different implications for each of its intended audiences, who will find different aspects of what we have to say new and informative, or familiar and obvious. For engineering designers and managers, we aim to offer some insight into problems with communicating about design processes and ways to discuss what process models mean. For academic design researchers, we put forward a conceptual framework for analysing communication about design processes with and through models, and a different and complementary perspective on the very wide range of design process models put forward by researchers and working engineers. For philosophers of science, the paper offers a contribution to the ongoing project of understanding what models are and what they do, and how they relate to their targets, which needs to encompass models in design as well as models in science.

In this paper, we have argued that analysing how designers, design managers and other stakeholders make sense of what process models are and what they can do with them is important for understanding design planning and understanding what happens in development projects. Process models are used in different ways for different purposes by different people at different stages in the development process. The same process model can be used for different purposes and seen in different ways, and designers can switch between them fluidly. Moreover, many process models are generated before the process unfolds. Therefore the relationship between a process model and its target system is far from uncomplicated. Hence, any statement of the form ‘a design process model is an X’ is likely to be wrong.

Our work has been motivated by the question “How can the process models function to coordinate and manage different groups and individuals when the plans are so fluid and unreliable?” We argue here that looking at designing as a network of rule-governed imagination games provides a useful lens for making sense of what designers, managers and other stakeholders do with design process models. Drawing on ideas in philosophy of science (notably from Frigg 2010a, b, c; Toon 2010a, b, 2012) which themselves drew on Kendall Walton’s (1990) work in philosophy of literature, we see a model as a prop, akin to a book, that governs what people are allowed to imagine in a game of make-believe, in which they envisage the implications of the model. Agreeing on what the props are and on the rules of the game enables multiple stakeholders to draw the same inferences and decide what are valid assertions and reasonable expectations given those rules. What the rules of the game are depends on the relationship between the model and its target. We have argued here that design process models can have a variety of different relationships to past or future design processes, and that the models appear different to people depending on the situations that they find themselves in. Creators of the models see them differently from outsiders. We have argued that people can have a number of different conceptualization of process models depending on their situations.

Figure 4 provides a new classification of ways of thinking about process models to answer the question “How can process models be conceptualised to allow for the different roles that they play?” This is not an exhaustive classification, and we have only considered the use of process models in planning and carrying out current or future design processes; however it covers a lot of situations that are important in industrial practice. Our argument is that the conceptualizations we have presented are what people see design process models as *being*, not what design process models are *like*. Thus they are not metaphors. However, our set of conceptualizations could be used as consciously articulated metaphors for conveying their intended status. We therefore conclude that each process model affords a range of legitimate characterizations and therefore affords different interpretations of the implications of its content. These need to be actively managed to avoid misunderstandings. The implication is that designers and design managers need to put effort into helping their colleagues to interpret the models in the intended way.

In future work, we would like to investigate in more detail the implications of the different conceptualizations in terms of how process models help with envisaging the future. In presenting a set of alternative conceptualizations of design process models, we have drawn on work in philosophy of science on the role of models in forecasting climate change (Poznic and Hillerbrand 2017) to make distinctions between *predictions* and *projections*. A prediction is a rationally grounded calculation of what is most likely to happen according to the model; a projection has an element of fiction in that it is a calculation of what is most likely to happen given both the model and a conjectured scenario. However, process models frequently function as *prophecies*. They foretell the future, but why the model says what it says is obscure to the user, who must rely on trust in the authority and higher knowledge of the prophet or the prophet’s sources of wisdom.

Processes are not gods, but through process models, plans and tacit expectations they direct and control behaviour. Although design processes are social constructs seen differently by the different participants (cf Checkland 1981), they structure how the participants think of what they are doing, creating shared assumptions that certain events will occur. While they afford freedom for the designers in carrying out the activities they demand, they can also be inescapable.

Acknowledgements Claudia Eckert and Martin Stacey were visiting researchers at ITAS, Karlsruhe Institute of Technology, in summer 2017. Our work has benefited from conversations on the nature of models in science with Dr Michael Poznic of KIT.

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