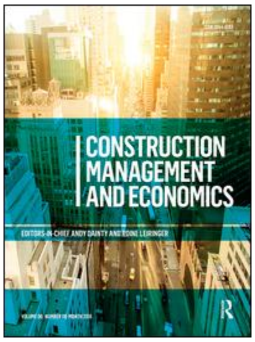

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Causality and interpretation: a new design model inspired by the Aristotelian legacy

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ABSTRACT

Building design and design management practices are beset by many problems to which satisfactory solutions have not yet emerged. The recognition of the Aristotelian legacy on design theorization has given rise to the proposition that the development of a new design concept that integrates the technical and social aspects of design might provide a general solution. This study aims to chart the intellectual history of the design discipline, clarify core design terms, concepts, and relationships, and propose a design model that integrates technical and social phenomena. An integrative literature review is a basis for the assessment and synthesis of representative literature and the construction of the new design model. The new design model, presenting the integrated design process structure for technical and social design activities, is the main contribution of this study. The model was constructed based on the identification of design theory core elements and relationships and the ancient design theories (the method of analysis and rhetoric).

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Building design; design theory; method of analysis; rhetoric; design model; design management

Introduction

This study can be considered a further development of the ideas of Dr. Glenn Ballard and his colleagues on design conceptualization and is presented as a contribution to the Construction Management and Economics (CME) Festschrift in his honour. Ballard and Koskela (2013) argued that design should be conceptualized not only as a technical activity but also as a social one. They also argued that the method of analysis and rhetoric form the "two pillars of design theory" (Koskela and Ballard 2013). The following discussion is on design in general, but construction-related examples are used in its presentation.

Contemporary research on design methodology and methods had its start in the early 1960s (Bayazit 2004). To the present day, theoretical ideas on design have been developed in both academia and practice using "models" (Wynn and Clarkson 2018). In the construction industry, we can point, for example, to generic models (e.g. the "V-model" (Forsberg *et al.* 2005), the design structure matrix (Eppinger and Browning 2012), and work breakdown structures (Koskela 2000)) and construction-specific models (e.g. the RIBA Plan of Work in the UK (RIBA 2020) and the level of development (Uusitalo *et al.* 2019)).

Building projects, however, often fail. According to Love and Li (2000) and Love *et al.* (2008), poor designs are the primary "contributor to building and infrastructure failures as well as project time and cost overruns". Studies in different geographic regions have reported that around 50% of all construction project failures could be attributed to design faults (Agarwal *et al.* 2012, Nicholas and Patrick 2014). Design errors and omissions decrease productivity at the site (Kärnä and Junnonen 2017) and the life-cycle value of built assets (Fischer *et al.* 2017). Design failures also contribute to fatal accidents and injuries on the construction site and during the operation of the buildings (Behm 2005, Sacks *et al.* 2015).

Such design failures suggest that the models underlying building design are either fundamentally flawed or poorly adhered to. This paper's central argument is that building design models fail because they

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are based on a time-honoured but partial theory of design that assumes design is essentially an activity involving causality (Cross 2001a). Another partial conceptualization of design, equally time-honoured, views it as an activity involving interpretation (Buchanan 1985, Stumpf and McDonnell 2002, Snodgrass and Coyne 2013). In design theories and models focussing on causality, the social aspects are abstracted away (explicitly or implicitly) (Love 2002, 2003), as they are not considered the core matter. In design theories and models focussing on interpretation (argumentation, rhetoric, etc.), the causal aspects are abstracted away (Melles 2008), the assumption being that these are accomplished anyway.

These two partial design theories are also known, respectively, as the technical (Buchanan 2009) and social conceptualizations (Love 2003) of design activity. Distinguishing between and separating the technical and social aspects is not new. For example, Schofield (2016) and Barrett *et al.* (1999) related building design project failures to technical and social aspects. This dichotomization has also been addressed in other contexts, for example, in the field of information systems research (Iivari *et al.* 1998). Partly due to this fragmentation, Dilnot (2018) argued that "we still do not have an adequate intellectual comprehension of design in the fullest sense of the term. We do not, in many ways, yet have design knowledge".

The contention here is that a more comprehensive design conceptualization demands the integration of the technical and social aspects of design activity. Integration is required because "the study of design is both a study of a complex human ability, but also one that involves agency beyond the human – in methods, representations, computers, and of course designs" (Lloyd 2019). To this end, Aristotelian design theorization can provide a general solution. Though contemporary design scholars have not been interested in or have failed to embrace the discipline's historical roots (Koskela and Ballard 2013), in science, earlier seminal work must be taken as a starting point to pinpoint gaps or identify elements of lasting value.

This study aims to delineate the design discipline's intellectual history, clarify core design constructs and relationships, and propose a new design model that integrates the technical and social aspects. The integrative literature review method (Torraco 2005) is the basis for the assessment and synthesis of representative literature on design theories. Only the central design theories in the relevant literature are addressed in detail. The objective is "to challenge and extend existing" (Whetten 1989) conceptualizations of design activity and to develop a new understanding and model of designing. Although there is no standardized structure for literature reviews, it has been advised to use a temporal (chronological), methodological, or conceptual (thematic) structure (Torraco 2016). Here, the literature review is organized conceptually into five major sections: (1) design history and the motivation behind the research; (2) design theory requirements and philosophical framing; (3) core design theories; (4) development of a new design model; and (5) discussion. This organization reflects the generally accepted staging of design processes (Andreasen *et al.* 2015): identify the gap; establish goals, requirements, and starting conditions; define the architecture of the conceptual system; develop the artefact; evaluate the artefact.

The first section of the paper addresses the recent history of design theorization and the motivation behind the development of a new integrated design theory. The second section establishes requirements for and the philosophical framing of design theory development. The third section addresses core design theories, including the two pillars of design theory: the method of analysis and rhetoric. In the fourth section, the new model is developed on the basis of the philosophical framework, the method of analysis, and the main elements of rhetoric. This development progresses gradually from the general to the specific in two phases: first, the philosophical framework is constructed, and second, the new model is built upon core design theories and the philosophical framework. In the last section, the three primary outcomes or contributions to design knowledge are discussed; the model is evaluated through comparison with other well-known design theories and models; and finally, future research is considered.

Design history and research motivation

Recent history of design research

Cross (2001a) argued that in contemporary design research, the relationship between design and science changed significantly in the 1920s and 1960s. In the 1920s, the focus shifted to the application of scientific knowledge to product design. In the 1960s, research focussed on how to make design methods more scientific. The present study will not look closely at the first period. Suffice it to say that its key proponents included Theo van Doesburg and Le Corbusier (Buchanan 2009).

The beginning of the second period, the design methods movement, was marked by a conference in

Table 1. Overview of the technical, social, and integrated conceptualizations of design.

Author	Theory/model	Coverage of causal/technical	Coverage of interpretation/social	Coverage of the integration of the technical and the social
Simon (1969)	The Science of the Artificial (Design Science)	Design activity as technical problem-solving	Mentioned in the context of urban planning but not seen as most important (Huppatz 2015)	Not discussed
Rittel (1980, 1987)	Design Argumentation	Mentioned but not seen as the most important	Main focus: conceptualization of design communication as argumentation	Not discussed
Buchanan (1985)	Design Rhetoric	Technological reasoning considered a part of design argumentation	Main focus; conceptualization of design communication as argumentation	Addressed to a limited extent
Bucciarelli and Bucciarelli (1994)	Design as a Social Process	Considered as background knowledge in the social processes of design	Main focus: conceptualization of design as a social process (collective activity)	Addressed to a limited extent
Suh (2001)	Axiomatic Design	Main focus: the conceptualization of design as a technical process	Not discussed	Not discussed
Gero and Kannengiesser (2004)	Function–Behaviour–Structure Model	Focus on conceptualizing technical design activities	Social activities are oversimplified	Not discussed
Åman *et al.* (2017)	Integrating Technical and Human-Centered Design Knowledge	Technical design knowledge	Human-centered design knowledge	Focussed on the integration of technical and social design knowledge
Piccolo *et al.* (2019)	Iterations are a Result of Social and Technical Factors	Design activities and artefacts (documents, models, etc.)	Conceptualized as participants and relationships between activities	Conceptualized design processes as a system of social structures and technical systems

London in 1962 on design methods (Bayazit 2004). This movement sought to base design processes and products on rationality and objectivity – the technical aspects of designing. The movement was mainly concerned with the sequence, phases, principles, heuristics, and goals of design (Evbuomwan *et al.* 1996). Systems theory, operations research, and decision-making techniques were the primary sources of inspiration (Bayazit 2004). The 1960s culminated with the work of Herbert Simon, who defined "the science of the artificial" (design science) (Simon 1969). Although not directly related, Simon's work was aligned with the design methods movement (Huppatz 2015), "particularly the latter's foundations in systems analysis, quantitative methods, and use of computers to aid the design process".

In the 1970s, however, the first design methods movement was criticized by its early pioneers, including Alexander (1971) and Jones (1977), and Simon's development of design science was criticized by Churchman (1970). Opposition arose because there was little evidence of success in applying scientific methods. Rittel and Webber (1973) took a different tack, adopting a constructivist approach, which distinguished design activity from rational methods. They argued that design tasks are subject to "wicked problems" (Lloyd 2019): subject to the diversity of perspectives, values, and objectives of different stakeholders. Since then, several new related design theories and models based on the social conceptualization of the design activity have been introduced (Buchanan 1985, Bucciarelli 2002, Margolin and Margolin 2002), including user-centered design (Norman 1988), participatory design (co-design; Sanders and Stappers 2008), and human-centered design (Giacomin 2014).

This distinction and separation of design's technical and social aspects have continued to the present day (Love 2002, Buchanan 2009, Lloyd 2019). Much contemporary design research, however, is still aligned with Simon's broader agenda of scientizing design activity, "particularly in its definition of design as 'scientific' problem solving" (Huppatz 2015). Christensen and Ball (2019), for example, have noted the focus on technology and engineering in the *Journal of Design Studies* over the last four decades.

Technical and social dichotomy in design research

The technical and social views of design are examples of "disintegrated mutually inconsistent design theories" (Galle 2008). Poor integration of design's technical and social aspects may be one of the main reasons for the difficulties that arise in the organizing and coordinating of design activities, impeding the flow of information in a timely manner (Browning 2002). For example, social aspects are often neglected in building design projects, due to a failure to recognize the need for intrinsically joint design tasks (Çıdık and Boyd 2020).

Design scholars have thus been interested in developing a unified theory of design and designing (Simon 1969, Bucciarelli and Bucciarelli 1994) and integrating the social and technical aspects of design (Åman *et al.* 2017, Piccolo *et al.* 2019). In Table 1, a summary of the technical, social, and integrated conceptualizations of design is presented chronologically. Most scholars, however, have not gone beyond the boundaries of either the technical (Suh 2001, Gero and Kannengiesser 2004) or social views of design (Rittel 1980, Buchanan 1985). Attempts to synthesize the technical and social aspects of the design have tended to be partial, focussing on knowledge integration, the causes of iteration, social objectives, etc.

Design theory: philosophical framing and requirements

Philosophical framing of design

Design scholars have emphasized the importance of philosophy in the clarification of underlying assumptions and beliefs, the framing of the development of new theories, and the evaluation of existing ones (Love 2000). The neglect of philosophical issues has been considered one of the main reasons why the academic community has not yet developed an integrated design theory and design model. Philosophical disciplines relevant to design theorization include metaphysics, ontology, and epistemology (Love 2000, Stumpf and McDonnell 2002).

Metaphysics of design

Since the pre-Socratic period of philosophy, metaphysics has dealt with the question of what is more fundamental, things or processes, structures or change (Roochnik 2004). In "thing metaphysics", the world is assumed to be made of things (with time-independent identities). The focus is on objectivity and the discovery of universals or what is necessary (Roochnik 2004). In "process metaphysics", the world consists of temporal (time-dependent) processes. The focus is on change and the discovery of relations between processes and things (van Inwagen 2019).

Whether the underlying metaphysics is thing metaphysics or process metaphysics will set the focus of design conceptualization. For example, the science of the artificial (Simon 1969), design science (Hubka and Eder 2012), and axiomatic design theory (Suh 2001) make the time-independent elements of design, including the structure of the design object and design activity, the primary focus of design theorization. These scholars have subscribed, knowingly or not, to the view of thing metaphysics, focussing on rationality, universality, and objectivity.

Far fewer design scholars have taken approaches that may be interpreted as proceeding from the premises of process metaphysics. Among those, Love (2002) argued that design should be seen as the human intellectual activity embodied within a designer's situated mental and external actions (Love 2002). Bedny and Meister (2014) and Cash *et al.* (2015), who adapted general activity theory to conceptualize design activity, maintained that human design activity consists of object and subject-oriented activities with the following features (Bedny and Meister 2014, Cash *et al.* 2015): design activities take place in time and place, are influenced by the personal and contextual situation, and have a person assigned.

Ontology of design

Ontology is a branch of metaphysics dealing with categories of being and their relationships (van Inwagen 2019). Of relevance to design research are the categorization of processes and things into objective (observer-independent) and subjective (observer-dependent) realities. Design ontologies are used to categorize representations (mental and conceptual models and material/target systems) (Johnson and Henderson 2011, Gentner and Stevens 2014) or processes/activities (internal or external, object- and subject-oriented) (Bedny and Meister 2014, Cash *et al.* 2015) and consider whether the representations or processes in the mental and physical realities are the same things (monism), two different kinds of things (dualism), or many kinds of things (pluralism) (Van Gelder 1998).

According to McKeon (1968, 1998)[1], in their original meaning[2], analysis and synthesis are metaphysical and epistemological concepts in human inquiry related to the processes of things (i.e. information and material things). Based on this view of analysis and synthesis, human processes can be categorized into the subjective-analytical and subjective-synthetic methods of inquiry and the objective-synthetic processes of things. Furthermore, situated mental and external object-oriented activities involving causality can be divided into three categories (Stevens 1974, Hestenes 2006): deliberation, mental and symbolic representations/simulations, and actions in the world. Situated mental and external subject-oriented activities involving interpretation can be divided into the following: conceptions, perceptions, and sensory experiences (Stevens 1974, Snodgrass and Coyne 2013).

Epistemology of design

Closely related to metaphysics and ontology is epistemology, which is concerned with the nature of knowledge (subjective and objective), the relation between theory, observation, and practice, and the manner in which knowledge is acquired (Creswell and Creswell 2017). Plato and Aristotle laid the groundwork for the opposition in Western philosophy between rationalism and empiricism, two schools of thought in epistemology (Losee 2001).

Plato developed the theory of ideas or forms. He believed that true knowledge is created and held in the mind and proved or demonstrated through deduction (Losee 2001). For Plato, mathematics, especially geometry, was central to the development of his epistemology and the deductive method (Menn 2002). In contrast, Aristotle believed that knowledge (causal explanations) could be extracted inductively from the world and then proved and demonstrated through deduction. That is, Plato placed ideas over matter, while Aristotle considered the interaction between the idea and matter, theory and observation, theory and practice (Losee 2001).

Both Platonic and Aristotelian epistemologies have come to underlie much of design research and practice (Booth 1996). Platonic epistemology has dominated design since the beginning of the Renaissance. It entered the design domain through several well-known architects and engineers (Lefèvre and Buchwald 2004, Murphy 2017). Booth (1996) argued that Leon Battista Alberti, influenced by Platonic epistemology, assigned mathematics (geometry and numbers) "a central role in architectural design". The first engineering schools in Europe (Channell 2009) and the engineering science by Rankine (1872) had been founded on the recognition that different disciplines (military and civil) had their basis in the principle that engineering solutions are deduced from scientific knowledge (Koskela *et al.* 2019).

Aristotelian epistemology has also found its way into the design and engineering domain (Booth 1996, Codinhoto 2013, Koskela *et al.* 2019). Kranakis, who studied the bridge engineering practices of the 19th century in France and America (Kranakis 1997), found that bridge engineering in France was theory-laden, mainly employing deductive methods, while American bridge engineering was empirical, integrating theory, engineering design, and experience. Tenkasi and Hay (2007) named this interactive view involving theory, observation, and practice the second legacy of Aristotle: "one where […] the integration of universals (theory), with the particulars (experience and practice) of a situation [is] the basis of true knowledge and understanding".

Research paradigms: positivism, constructivism and pragmatism

Metaphysical, ontological, and epistemological suppositions have been packaged into contemporary positivist (de Figueiredo and da Cunha 2007), constructivist (Snodgrass and Coyne 2013), and pragmatist (Melles 2008) research paradigms. In positivism, it is assumed that reality (natural phenomena) is independent of the observer (mind), knowable, and explainable by immutable (causal) laws (de Figueiredo and da Cunha 2007). Epistemologically, scientific inquiry is a discovery of truths (universals) about reality (entities, properties, and interrelationships of natural phenomena), and deductive quantitative and statistical methods are used to evaluate the reliability and validity of a theory (Losee 2001). The process of scientific inquiry is expected to be objective and detached from human interpretation (Creswell and Creswell 2017).

Constructivism has its roots in the social sciences. In constructivism, it is assumed that reality is "socially constructed", observer-dependent (de Figueiredo 2017). Constructivism seeks through systematic interpretation to determine the essential properties and structures of "the world of human experiences" (de Figueiredo 2017). Constructivists use the grounded theory method to "generate or inductively develop a theory or pattern of meanings" and rely mostly on qualitative research methods (although quantitative methods may be used too) (Creswell and Creswell 2017).

In pragmatism, no one system of philosophy or view of reality is favoured; thus, it supports a pluralist ontology (Creswell and Creswell 2017). In this view, theories should be linked to experience and practice, that is, the interaction and integration of theory, practice, and experience (Murphy 2017). Pragmatism subscribes to process metaphysics, as continuity and change are the guiding principles of human inquiry. Epistemologically, the human exploration begins with experience, and new knowledge is acquired through experimentation (Rylander 2012). At the core of pragmatist inquiry is abduction, a type of inference used to discover new ideas (explanations) (Murphy 2017).

These paradigms have had a significant influence on the development of design research (Booth 1996). It is contended here that due to the metaphysical, ontological, and epistemological assumptions of positivism and constructivism and their corresponding design research paradigms (Love 2003, Melles 2008, Buchanan 2009, Snodgrass and Coyne 2013), two separate and incompatible design paradigms (Love 2000, 2002, 2003) have evolved: design as a technical activity and design as a social activity. The technical and social views of design are, however, not mutually exclusive. Pragmatism has proven to be a promising philosophical framing of design, as it allows the unification of the two views. According to Melles (2008), "pragmatism in both instrumental and critical forms is a robust epistemological and methodological terrain for design research, which architecture and built environment disciplines have explored as a basis for their methodological pluralism".

Design theory requirements and models

Philosophical framing helps to clarify underlying assumptions and beliefs and thus evaluate existing theories and develop new ones (Love 2000). To operationalize the philosophical framing in later sections, design theory requirements and the functions of models and modelling in design research are addressed.

Requirements for design theory

According to Badke-Schaub and Eris (2013), sound design theory is "[…] a body of knowledge which provides an understanding of the principles, practices, and procedures of design". The term "understanding" in their definition of design theory indicates a focus on describing, explaining, and predicting the behaviour of phenomena. Sound design theory should, however, also provide actionable knowledge for design activity (Argyris 1996, Stumpf and McDonnell 2002). That is, design theories must have practical relevance, bridging theory and practice.

Different frameworks for theory building in science (Dubin 1978) and the design research domains (Jones and Gregor 2007) have been proposed. Regarding the scope of design theory, Whetten (1989) argued that in general, theories consist of four elements and answer six questions: (1) constructs of phenomena (what), (2) relationships between "what" factors (how), (3) justificatory theories and explanations (why), and (4) scope (who/where/when).

In answer to the first, Love (2002) argued that in design, "humans", "contexts", "objects" and "relationships" form the classes of constructs in design theory. In answer to the second, research on design processes is concerned with the study of "relationships" ("stages", "strategies" ("iterations") and "activities") between the three other constructs. The intended changes in "humans" and "objects" are created or brought about by situated activities (Argyris 1996, Cash *et al.* 2015, Dixon 2019). These activities operate ontologically in the problem and solution "contexts" (the artefact's environment and artefact system, respectively) (Simon 1969), and epistemologically in the mental, conceptual, and material "contexts" (Greca and Moreira 2000, Johnson and Henderson 2011, Gentner and Stevens 2014).

Models in science and design

Models and modelling are often used in design and research. A distinction between "models in design" and "models of design[3]" is typically made (Chakrabarti and Blessing 2014). The focus here is on the latter, on how design researchers use models and modelling to represent the design process (target system) or design theory (Vermaas 2014). The intent here is to clarify central ideas and concepts rather than to solve issues related to the academic study of models and modelling.

Scientific design models should provide "[…] an interpretative description of a phenomenon that facilitates access to that phenomenon" (Bailer-Jones 2002). Models are simplifications and partial descriptions (typically focussing on either technical or social dimensions) of phenomena (products, processes, or both in design) and selective in what they represent or not (Frigg and Hartmann 2006). Models range from scale models to theoretical and abstract entities, such as analogous, analogical, or metaphorical models. Models are expressed in concrete and/or abstract forms (Bailer-Jones 2002, Frigg and Hartmann 2006).

Models play an important epistemological role in science and design (Gero 1990, Frigg and Hartmann 2006, Chakrabarti and Blessing 2014). Models support and aid several cognitive functions (Frigg and Hartmann 2006): learning (about models and target systems), explanation, understanding, and prediction. Models also support communication and interpretation among parties and in this way, are useful, for example, in design management (Engwall *et al.* 2005, Maier *et al.* 2014).

Design models should also incorporate descriptive and prescriptive functions (Zeiler and Savanovic 2009). Descriptive models would aim to answer the question "What is the essential structure of designing?", while prescriptive models would answer the question "How should the design process be approached to make it effective and efficient?" (Roozenburg and Eekels 1995). Descriptive models help us to understand and explain what takes place in design and designing, and prescriptive models aim to develop and validate methodical procedures regarding what ought to take place. Prescriptive models are based on descriptive models (Stumpf and McDonnell 2002), which ought to be flexible and tailored to a specific-use situation (Wynn and Clarkson 2018). For example, prescriptive models guide the delivery of projects or the performance of design activities (such as the collaborative making of design decisions).

As the subjects of design research are the mental and external activities of the designer, validation and verification[4] of design models can be challenging (Kroll and Weisbrod 2020). Experimental protocol studies have, for example, been used in design research, but it has been argued that protocol analysis may not reflect a designer's actual thought processes (Cross 2001b). The fragmentation of design theorizations shows that "design research does not yet have the means to test and refute design theories and models" (Vermaas 2014). Koskela (2000) argued that the validation of production (design and construction) theories should be considered "in relative terms, in relation to the purposes at hand".

Design theories and models

Some well-known and generally accepted design theories incorporating models and addressing the nature of the design process include the function–behaviour–structure model (FBS) (Gero and Kannengiesser 2004), axiomatic design (AD) (Suh 2001), the concept-knowledge theory (C-K) (Hatchuel and Weil 2003), parameter analysis (PA) (Kroll and Koskela 2016), the "V-model" (Forsberg *et al.* 2005), and human-centered design (HCD) (Giacomin 2014).

These theories and models address design creativity, complexity, iterations, communication, and social phenomena (Wynn and Clarkson 2018). For example, the C-K theory formalizes design creativity by modelling the movement between concept and knowledge spaces (Hatchuel and Weil 2003). The FBS model, the AD theory, PA, and the V-model address the complexity of designing by explicitly addressing design stages, activities, sequences, and iterations. The V-model and HCD explicitly specify design stages and activities related to the social aspects of designing (Forsberg *et al.* 2005, Giacomin 2014).

These different design theories and models have certain limitations. The AD and C-K theories and the V-model fall short when describing the different modes and types of mental and external activities. The FBS model, AD, PA, and the C-K theory focus on the description of the design and designing with some prescription regarding practice (Wynn and Clarkson 2018). Finally, besides the V-model (although not explicitly), no other design theory or model considers analysis and synthesis to be the underlying methods of human inquiry and information and material processes (Kroll and Koskela 2016).

Except for the V-model, design theories and models subscribe to either the technical or social view of design. The V-model explicitly specifies design stages and activities related to both aspects of designing. The FBS model, the AD theory, the C-K theory, and PA either neglect or oversimplify the social aspects. The HCD is limited to the social view, abstracting away the causal aspects (Melles 2008).

Summary of philosophical framing and requirements for design

Design scholars have emphasized the importance of learning from the philosophy of science; the neglect of philosophical issues has been considered one of the main reasons for broken design theory development (Love 2000, Vermaas 2014). It has been argued here that the dichotomization of design into the technical and the social could be due to the different metaphysical, ontological, and epistemological assumptions of positivism and constructivism, which, respectively, underlie these two designs research paradigms. Pragmatism was proposed as a philosophical framing of design that could bring about the integration of the technical and social aspects of design.

Requirements for developing a design theory and the design process model based on it were also identified. Design theories should cover four elements and answer six questions: (1) constructs (what), (2) relationships (how), (3) justificatory theories and explanations (why), and (4) scope (who/where/when). In design, "humans", "contexts" and "objects" are the constructs, and the "stages", "strategies" ("iterations") and "activities", the relationships. Design theories and models have explanatory and descriptive functions that should guide and support design practice in fulfilment of the prescriptive function. The validity of design theories and models could be assessed in relative terms.

Many design theories and models already exist. However, the design theories and models addressed above subscribe to either the technical or social view or have oversimplified the causal or interpretive aspects of design. The theories and models considered fall short in describing the different modes and types of activities, except the V-model, which explicitly considers and integrates both the technical and social aspects of design.

Core design theories

Core concepts of design activity: causality and interpretation

As discussed above, contemporary design theories are based on partial conceptualizations of design. These include design as solely a technical or social activity (Love 2000, 2003); in other words, an object- or subject-oriented activity. Technical object-oriented activities involve causality (Cross 2001a), and social subject-oriented activities involve interpretation (Snodgrass and Coyne 2013).

Western philosophers and scientists have long accepted the centrality of the concept of causality, which was discovered through studies of geometry and then generalized to other contexts (Niiniluoto 1999, Netz 2003). Albert Einstein argued that the "development of Western science is based on two great achievements: the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility to find out causal relationships by systematic experiment (during the Renaissance)" (Cohen 1994).

Other scholars have used ancient rhetoric to study and define the meaning of interpretation (Ormiston and Schrift 1990). Heidegger (1996) described interpretation as a process of anticipation and revision of meaning, the progressive transformation of tacit understanding into more explicit forms. In the context of design, this has been treated as design rhetoric (Buchanan 1985), design argumentation (Stumpf and McDonnell 2002), the social design process (Bucciarelli 2002), design communication (Crilly *et al.* 2008), and design collaboration (Kleinsmann *et al.* 2012).

Object-oriented design activity is concerned with the causality of the object (as in, for example, the theory of technical systems (Hubka and Eder 2012)) and the design activity (as in, for example, systematic design methodology and methods (Jones 1992, Suh 2001)). Cross (2001a), for example, argued that "design science refers to an explicitly organized, rational and wholly systematic approach to design; not just the utilization of scientific knowledge of artefacts, but design in some sense a scientific activity itself". Subject-oriented activity is concerned with the

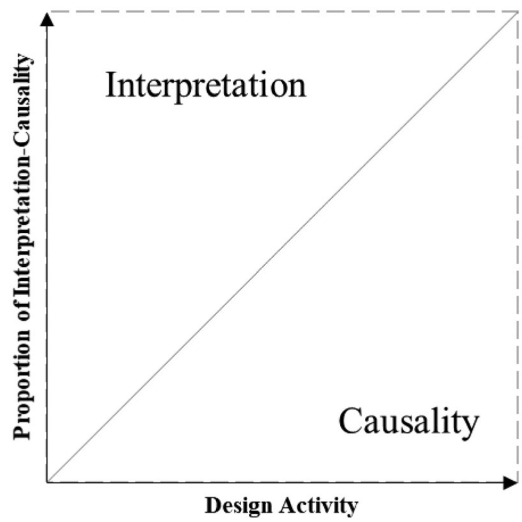

Figure 1. Design activity involves varying degrees of interpretation and causality.

interpretation (meaning-making) (Snodgrass and Coyne 2013) of human purposes (as in, for example, user-centered design (Norman 1988)) and interactions (when considering, for example, design as a social process (Bucciarelli 2002)).

Traditionally, technical and social, that is, object- and subject-oriented, design activities have been considered separate and mutually incompatible, partly due to the philosophical framing of design theories and models. In this study, it is argued that design activities contain varying degrees of causality and interpretation. In the earlier stages of design, there are more design activities with a higher proportion of interpretation, and in the later stages, more design activities with a higher proportion of causality. That is, design activity is the interaction between the causality and interpretation phenomena manifested in object and subject-oriented human activities (see Figure 1).

This new understanding of design has implications for design and design management in construction, as illustrated by the following examples:

1. Design involves aspects and activities arising from designing for and with humans (Bucciarelli 2002, Love 2003, Giacomin 2014) and aspects and activities related to designing to function and designing with methods (Jones 1992, Suh 2001, Hubka and Eder 2012). Although technical aspects need to be considered (Barrett *et al.* 1999), the early design stages emphasize the interpretation of the values, needs, and requirements of stakeholders. Although the social aspects still need to be considered, as the design is a collaborative effort, the

later design stages will emphasize the conversion of requirements to design solutions (Ballard 2012).

2. There is a qualitative difference between verification and validation in the design, making, and operation stages of building project delivery. That is, processes ensuring the actual "fitness for purpose" of a building require interpretation, and "compliance with specifications" means that requirements have been met.
3. Design management should consider the technical and social views of design, as design involves situated object- and subject-oriented design activities. As Çıdık and Boyd (2020) argue, design management should, for example, allocate resources and time to allow the iterative completion of coupled design tasks that require the social coordination of design activities and technical coordination of building systems.
4. Building design and design management education should provide the technical and social competencies needed to manage design projects effectively (Eynon 2013). Building engineering design and design management education, however, tend to focus on the technical aspects, in line with Platonic epistemology (Koskela *et al.* 2019).

Of course, several methodologies and methods, such as the Last Planner System (Ballard 2000), Choosing by Advantages (Arroyo 2014), Target Value Design (Ballard 2012, Zimina *et al.* 2012), and the integral morphological C-K approach (Zeiler and Savanovic 2009), already assume that production (design and making) phenomena include both the technical and social aspects.[5] However, these methodologies and methods would benefit from a theory of design that explicitly supports this assumption.

Aristotelian productive sciences and contemporary design conceptualizations

Since the times of Plato and Aristotle, geometry has provided a model for necessary reasoning, and rhetoric, a model for plausible reasoning (McKeon 1968). The method of analysis and rhetoric played an essential role in Plato's development of the dialectical method and Aristotle's development of the productive sciences (Asano 1997, Parry 2003).

The use of the method of analysis to solve geometric problems was already sophisticated and well-defined in Plato's and Aristotle's time (Hintikka and Remes 1974, Netz 2003). In *Nicomachean Ethics*, Aristotle wrote, "For the person who deliberates[6] seems to investigate and analyze in the way described as though he were analyzing a geometrical construction" (Aristotle 2009). For Aristotle, there was an affinity between the method of analysis and productive sciences (Parry 2003, Koskela *et al.* 2014).

Aristotle (2012) also provided a thorough description of the art of rhetoric, "another form of productive science" (Shields 2016). Rhetoric as a discipline emerged in ancient Greece in connection with the need of citizens to speak for themselves and be persuasive in law courts (Herrick 2017). For Aristotle, rhetoric was "the faculty (*dunamis*: capacity, power) of observing in any given case the available means of persuasion" (Aristotle 2012). From early on, ideas from rhetoric have been applied in design disciplines, that is, architecture, music, sculpture, etc. (Herrick 2017).

Most design scholars have, however, either neglected or overlooked the works of the ancient Greeks. Although Simon (1969) and Buchanan (2009) acknowledged that the roots of the strategies of change (design) could be traced back to Aristotle's four causes, they did not link design to the Aristotelian concept of productive sciences, the conceptualization of which was influenced by the method of analysis and rhetoric[7]. This means that seminal design research in the 1960s showed an incomplete understanding of the history of design theorizing and unawareness that much had already been achieved in design theory (Koskela *et al.* 2014).

The proposition that the method of analysis and rhetoric independently underlie technical and social design conceptualizations, respectively, is not new to the design community (Buchanan 1985, Codinhoto 2013, Koskela *et al.* 2014, Kroll and Koskela 2016, Halstrøm 2017). Only one scholarly contribution has, however, attempted to synthesize the two strategies of inquiry (Koskela and Ballard 2013). The failure to recognize the method of analysis and rhetoric as complementary theories of design might explain the unsatisfactory progress made in the development of design science.

Ancient strategies of design inquiry: the method of analysis and rhetoric

The intent here is not to provide a complete presentation of the method of analysis and rhetoric but to evaluate whether they could be used to develop a new design conceptualization. As strategies of human inquiry, both the method of analysis and rhetoric are, by definition, design theories. The method of analysis introduces basic ideas, principles, factors, and processes to solve or discover solutions for geometric problems, and rhetoric develops and studies persuasive communication (Koskela and Ballard 2013). The main elements of the method of analysis and rhetoric are presented below in line with Whetten's (1989) theory framework and Love's (2002) design theory constructs.

Scope (who/where/when)

The method of analysis is for solving geometrical problems and the discovery of geometric solutions (Hintikka and Remes 1974, Netz 2003). Two kinds of analysis have been distinguished (Hintikka and Remes 1974): theoretical analysis (proving theorems) and problematical analysis (demonstrating geometric constructions). Rhetoric is the development of persuasive communication and the study of such communication (Herrick 2017). Three rhetorical genres have been distinguished based on rhetorical situations (Buchanan 1985, Aristotle 2012): the judicial, deliberative, and epideictic.

Constructs (what)

Constructs are organized into three categories, including "contexts", "humans", and "objects" (Love 2002). In the method of analysis, contexts include the states of geometrical problems and solutions, and objects include definitions, postulates, causalities (cause and effect), and relationships (wholes to parts) of geometrical figures (Hintikka and Remes 1974). In rhetoric, contexts include given situations and common ground; humans include the rhetor and the audience; and objects include arguments, enthymemes (different patterns of arguments), and the medium (Herrick 2017).

Relationships (how)

Relationships are organized into stages, strategies, and types of activities (Cash *et al.* 2015, Wynn and Clarkson 2018). In the method of analysis, stages include problem clarification, the analysis proper, and resolution in the analysis and construction, demonstration, and conclusion in the synthesis (Hintikka and Remes 1974). In rhetoric, the stages include invention, arrangement, style (implementation), memory (representation), and delivery (Herrick 2017). Strategies in the method of analysis are heuristic and iterative in the analysis and determined in the synthesis (Codinhoto 2013); the strategy in rhetoric is iterative (Buchanan 1985). Types of reasoning in the method of analysis include transformation, regression, and decomposition in the analysis and composition, deduction, and induction in the synthesis (Codinhoto 2013), which may be creative (abductive) or non-creative (Koskela and Kroll 2020). In rhetoric, the types of reasoning include induction, deduction (Herrick 2017), and abduction (Bybee 1991). External activities in the method of analysis include assembly, testing, and verification (Forsberg *et al.* 2005), while in rhetoric, they include implementation, delivery, and judgement by the audience (Buchanan 1985).

Justification and explanatory knowledge (why)

In the method of analysis, testable propositions on theorems and constructions are generated in the analysis and demonstrated/proven in the synthesis (Netz 2003). In rhetoric, topics, arrangements, and expressions of arguments are developed, tested, and judged by the rhetor and audience (Buchanan 1985). In the method of analysis, knowledge of existing, proven theorems and constructions of geometry and logic is used to justify and explain things (Netz 2003). In rhetoric, common ground (*endoxa*: shared values, beliefs, and presumptions) and knowledge of the rules of logical argumentation act as the starting point for the development of persuasive communication (Ballard and Koskela 2013, Herrick 2017).

Summary of core concepts to construct a new design model

In this section, the intent is to investigate the fundamental concepts of design, justify the importance of the method of analysis and rhetoric in design theorizing, and take a close look at the central concepts and principles of the method of analysis and rhetoric.

Aristotle relied on the method of analysis and rhetoric as established strategies of human inquiry in the development of the productive sciences – the designing and making of beautiful and valuable objects. Most contemporary design scholars have, however, either neglected or failed to connect the two ancient strategies of inquiry. The method of analysis supports the operationalization of the causal theory of design activity, and rhetoric supports the interpretation theory of design activity. The method of analysis has descriptive and prescriptive functions, rhetoric, prescriptive functions. The outcome of this section (shown in Table 2) is a conceptual framework for constructing a new design model.

Table 2. Comparison of the method of analysis and rhetoric according to design theory elements.

Elements of (design) theory	Method of analysis	Rhetoric
Scope (boundaries)	Strategy for solving and discovering solutions for geometric problems (two kinds of problems: theoretical and problematical)	Strategy for persuasive communication and studying communication (three kinds of rhetoric: judicial, deliberative, and epideictic)
Constructs (factors)	*Contexts:* States of geometrical problems and solutions (what is given and sought, solution principles, and means of construction in the analysis; assembly, proof, and decision in the synthesis) *Objects:* Definitions, postulates, causalities (cause and effect), and relationships (wholes and parts)	*Contexts:* Given situation, common ground *Humans:* Rhetor (intention and character) and audience (effects and emotions) *Objects:* Arguments (subject to character [*ethos*], logic [*logos*], emotion [*pathos*]), enthymemes, and medium (form, content, logic)
Relationships	*Stages:* Problem clarification, analysis proper, and resolution in the analysis; construction, demonstration, and conclusion in the synthesis *Strategies:* Heuristic, iterative, and determined *Activities:* Types of reasoning include transformation, regression (creative [abductive] and non-creative), and decomposition in the analysis; composition, deduction, and induction in the synthesis; external activities include assembly, testing, and verification	*Stages:* Invention, arrangement, style (implementation), memory (representation), and delivery *Strategies:* Iterative *Activities:* Types of reasoning include induction and deduction in logos; external activities include implementation and delivery by the rhetor and judgement by the audience
Justification and explanatory knowledge	Proven theorems, constructions of geometry, and logic	Common ground (*endoxa*: values, beliefs, and presumptions) and rules of logical argumentation

Construction of a new design model

This section will describe the design model that can be developed on the basis of the philosophical framing and elements of the method of analysis and rhetoric.

Construction of a philosophical framework

The main elements of the philosophical framework are presented in Figure 2, and they are explained here in terms of metaphysics, ontology, and epistemology. Metaphysically, design is viewed as a human intellectual activity (Bedny and Meister 2014, Cash *et al.* 2015). Ontologically, design is divided into a situated internal and external object- (solution domain) and subject-oriented (problem domain) activities (Cash *et al.* 2015) involving causality and interpretation (Snodgrass and Coyne 2013), respectively. Object-oriented activities are further divided into deliberation, mental and external (conceptual) simulation, and action (Hestenes 2006). Subject-oriented activities are divided into sensory experiences, perception, and conception (Stevens 1974). Although the arrangement of different activities in Figure 2 might seem structured and linear, in reality, they occur in an intertwined manner.

Epistemologically, design is concerned with creating, applying, and justifying design knowledge (Galle 2008). The horizontal division in Figure 2 addresses the difference between subjective and objective knowledge. The movement between subjective and objective knowledge represents the relationship between the designer (the knower) and the design artefact (the known) (Eastman 2001). Designers use models and simulations as epistemic instruments (e.g. building information models) to extend their capacity to reason (Gero 1990, Maier *et al.* 2014). Object- and subject-oriented activities operate in the context of mental models, conceptual models, and material systems (Greca and Moreira 2000, Gentner and Stevens 2014). In Figure 2, the conceptual model and material system contexts are combined to simplify the framework.

A new design model

The new design model shown in Figure 3 was constructed on the basis of the philosophical framework in Figure 2 and the two strategies of human inquiry in Table 2. What follows is a description of the elements and relationships of the new design model.

The new model is a configuration of ideas and concepts related to designing contexts, design objects (the causal structure of the design), design stages, design strategies (iterations), and modes and types of mental and external activities. As the method of analysis and rhetoric are designed theories, the construction of the model follows the logic of geometric problem solving and aligns with the development of persuasive communication.

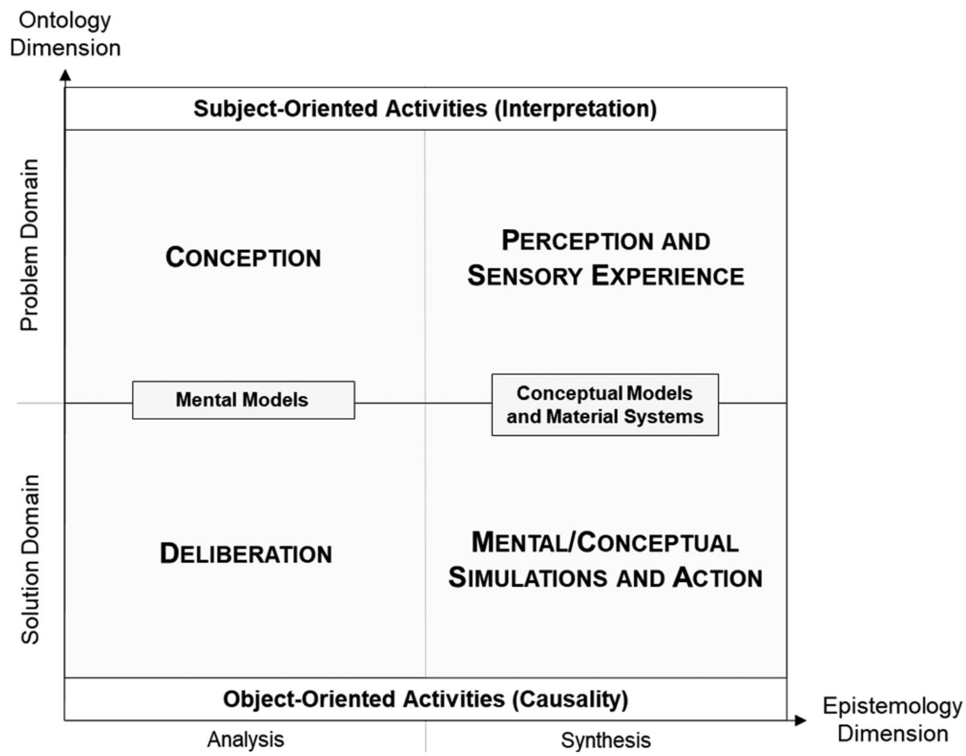

Figure 2. The philosophical framework constructed for design conceptualization.

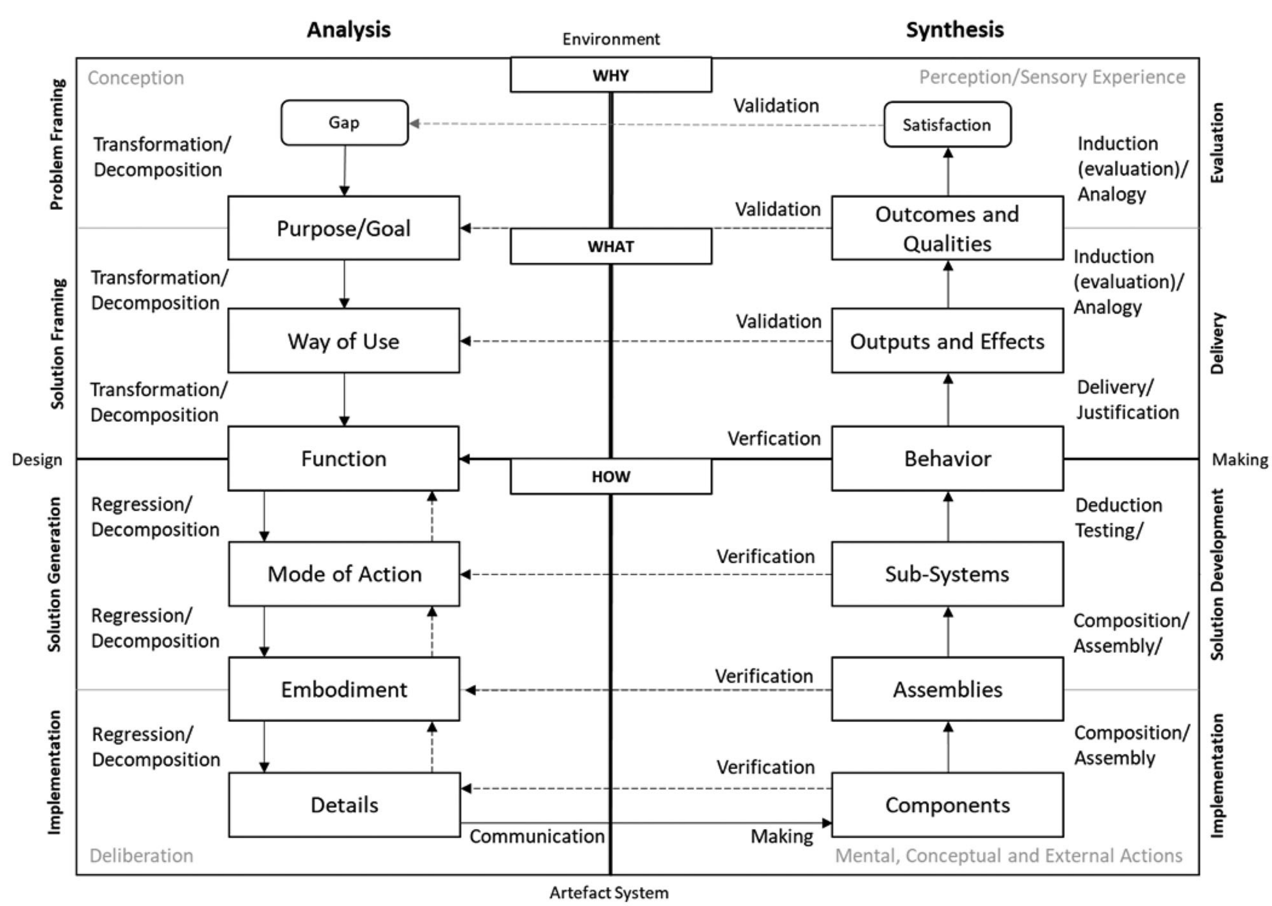

Figure 3. The new design process model integrates causality and interpretation phenomena with object- and subject-oriented activities.

In Figure 3, in the conception quadrant, the problem and solution framing stages (Haase and Laursen 2019) carry the design process from the gap to the goal (purpose), way of use, and finally, function (Vermaas 2013). The gap and goal are considered from the perspective of the "systems we design within" ("WHY"), and the way of use and function, from the perspective of the "system we design for" ("WHAT") (Lurås 2016). The movement between states in the problem domain is mediated by two different types of mental actions, transformation ([re-]interpretation) and decomposition (Kroll and Koskela 2016).

The solution-generation stage in the deliberation quadrant belongs to the solution domain (Simon 1969) and considers the "system of design" ("HOW") (Lurås 2016). The design process moves from requirements (function) to design concept (mode of action), design embodiments, and finally, details (Codinhoto 2013, Kroll and Koskela 2016). These movements are mediated by regression and decomposition, which can be creative (abductive) or non-creative (Koskela and Kroll 2020). When the problem and solution are novel to a designer, deliberation can be heuristic, leading to progressive iterations (Wynn and Eckert 2017). When the mapping between ends and means and between functions and structure is well-established in routine design tasks, deliberation in the analysis is sidestepped. Design continues according to a determined strategy in the synthesis (Codinhoto 2013, Koskela *et al.* 2014).

The implementation stage bridges the analytical and synthetic modes of design and human inquiry. This has two possible meanings, depending on the context. In a design context, it refers to the translation of the designer's ideas into representations (Taura and Nagai 2017) – the "modelling of models" (Maier *et al.* 2014). In the context of the realization of a design, it refers to the making (i.e. fabrication) of components (Koskela 2000).

The solution development stage involves synthetic inquiry and belongs to the mental, conceptual, and external actions quadrant. This stage encompasses the movement from assemblies to sub-systems and from sub-systems to system behaviour. The principal mental activities are composition and deduction (Kroll and Koskela 2016), and the principal external activities are assembly and testing (Forsberg *et al.* 2005). As in the "V-model" (Forsberg *et al.* 2005), these steps in the synthesis mirror the steps in the analysis (Codinhoto 2013). The formal procedure for ensuring the alignment of the analytic and synthetic processes with the design and making processes is known as verification (Forsberg *et al.* 2005).

Steps in the perception/sensory experiences quadrant, forming the delivery and evaluation stages, encompass the movement from behaviour to outputs and effects, outcomes and qualities (values), and finally, satisfaction or gap (Halstrøm 2017). The main types of activities include induction (evaluation) and analogical reasoning as mental activities and delivery and justification as external activities (Kroll and Koskela 2016). At every step, the validation process ensures alignment with customer/client and user goals and needs (Forsberg *et al.* 2005).

Summary of the construction of the new design model

The new design model proposes a design process structure based on design contexts (general, user, and artefact contexts), design objects (the causal structure of the design), and relationships (design stages, design strategies (iterations), and modes and types of mental and external activities). The model integrates technical object- and social subject-oriented activities, which involve causality and interpretation, respectively.

A salient feature of the new design model is that it considers design inquiry methods (modes and types of resolution and composition) and processes of things (what happens to information and material) inherently analytic or synthetic. That is, analysis and synthesis are not merely stages, as often assumed in design research (Kroll and Koskela 2016), but are also indicative of the metaphysical and epistemological theories underlying the conceptualization of design activity.

As can be said of all models, the new design model is, however, a simplification of the actual process. First, designing is not a linear process and does not always follow an established sequence. Further, while specific modes and types of mental and external actions and operations are dominant in different stages and steps, the types involved may, in practice, also include ones not addressed in this study.

Discussion: contributions, evaluation and validity

The starting point of this study was the proposition that a new design theory and model could be developed on the basis of Aristotelian design theorization – the method of analysis and rhetoric. In all, three contributions to the body of design knowledge have

Table 3. Comparison of different design theories and models.

Aspects	Characteristics	FBS	AD	C-K	PA	V-model	HCD	New Model
Focus	Creativity			+				
	Complexity	+	+		+	+		+
	Iteration	+	+		+	+	+	+
	Social					+	+	+
Process scope	Macro (project)					+		
	Meso (phase)					+	+	+
	Micro (individual)	+	+	+	+			+
Analysis	Process focussed	+			+	+	+	+
	Product focussed	+	+			+	+	+
Synthesis	Process focussed				+	+	+	+
	Product focussed					+	+	+
Analysis and synthesis	Mirroring	+/−		+/−	+/−	+	+/−	+
	Interpretation					+	+	+
	Causality	+	+		+	+		+
Stages	Specifies stages/phases					+		+
Iterations	Progressive	+		+	+	+	+	+
	Corrective	+		+	+	+	+	+
	Managerial					+	+	+
Causal structure	Specifies causal structure	+	+	+	+	+		+
Activities	Mental	+/−			+			+
	External				+			+

been made: elucidation of the intellectual history of the design discipline; the clarification of core terms, concepts, and their relationships in the context of design; and the formalization of a new design process model that integrates the technical and social aspects of design.

Although contemporary design scholars have paid some heed to Aristotelian design theorizations (including the method of analysis and rhetoric), the majority have been relatively incognisant of design theorizing history. Furthermore, although philosophy has provided a rich source of inspiration (Love 2000, Galle 2008, Buchanan 2009, Vermaas 2014), design scholars have also neglected philosophical issues when framing design theories and models. These failures could partly explain the unsatisfactory progress made in the development of design science.

Core terms, concepts, and relationships of design have been clarified as follows. Key elements include "humans", "contexts" and "objects", which constitute design theory constructs, and "stages", "strategies" ("iterations") and "activities", which represent the relationships. These elements of the method of analysis and rhetoric were mapped to design theory scope, constructs, relationships, and justificatory and explanatory knowledge. The historical fact that analysis and synthesis are not just design stages but metaphysical and epistemological concepts was also clarified. Finally, the importance of causality and interpretation to Western philosophers and scientists and their interrelationship in design was addressed. Technical object- and social subject-oriented activities in design embody varying degrees of causality and interpretation.

The new design process model proposed in this study is the principal contribution. The new model integrates and aligns different ideas and concepts related to design inquiry: analysis and synthesis, causality and interpretation aspects of design, and situated object- and subject-oriented activities. It was argued that technical and social design activities could be integrated when design is considered from the perspective of process metaphysics and pragmatism.

The function–behaviour–structure (FBS) model (Gero and Kannengiesser 2004), axiomatic design (AD) (Suh 2001), the concept–knowledge (C-K) theory (Hatchuel and Weil 2003), parameter analysis (PA) (Kroll and Koskela 2016), the "V-model" (Forsberg *et al.* 2005), and human-centered design (HCD) (Giacomin 2014) were also critically reviewed. In Table 3, these design theories and models are compared with the new design model. Though it must be acknowledged that these different models also contain aspects not present in the new model (e.g. two axioms in the AD theory), it becomes evident that the new design model is more comprehensive and at a higher level of generality. This is often the case with unifying theories, which lean towards breadth over depth (Deutsch 1997), and thus, they will generally not include all the aspects of different specialized theories.

The initial validity of the model needs to be considered. While it is impossible to validate the new model directly, as it addresses the most fundamental concepts and aspects of designing (e.g. the meaning of analysis and synthesis), the initial validity of the new design model can be demonstrated indirectly in four different ways.

First, external validity is assured by the use of well-known and accepted strategies of human inquiry, the method of analysis and rhetoric, which fulfil descriptive and prescriptive functions, to develop the new design theory and model. Second, there is some historical justification. It was shown that the technical and social conceptualizations of design have contributed independently to design theory. There are also grounds to believe, given the attempts of other scholars to integrate the technical and social aspects, that this integration would bring about a new understanding of design and thus improvements in design practice. Thirdly, a comparison of the new design model with other design theories and models has shown it to be more comprehensive than the others (see Table 3), even if it does not include all the elements of the other theories and models. Fourthly, although no practical study was carried out here to evaluate initial practical utility, it was carried out elsewhere as part of a broader research project[8].

Admittedly, even if the initial validity of the new theory and design model is accepted, its full validity is yet to be confirmed. Further research is required to refine and test the theory and model. It should also be investigated how the new conceptualization of the design process and the new design model support the development of a new understanding and lead to improved performance in design projects.

Conclusions

Building design projects fail all too often, giving rise to the hypothesis that their underlying models fall short. It was argued that this shortcoming in building design models arises from the fact that they are based on time-honored but partial design theories, involving solely either causality or interpretation. It was demonstrated that a more comprehensive design model that integrates the technical and social conceptualizations of design activity can be achieved when adopting a philosophical framing that draws from process metaphysics and pragmatism. The new design model presents a design process structure based on design contexts, design objects, design stages, design strategies (iterations), and modes and types of mental and external activities. The new model is expected to support the development of a better understanding of the design process and improve design and design management practices. It would be of benefit to existing design and design management methodologies, methods, and tools, and would support the development of new ones with explicit theory. However, further research is required to test and refine the proposed design model.

Notes

1. The significance and importance of McKeon's work has been emphasized by seminal and still-living philosophers. An overview of his life and impact are provided by Plochmann (1990) and Garver and Buchanan (2000).
2. The terms analysis and synthesis already existed in ancient Greek and had a precise technical meaning in the ancient method of analysis (Niiniluoto 1999). According to Hintikka and Remes (1974), analysis and synthesis referred to particular kinds of separation and composition. See also (Codinhoto 2013) and (Koskela *et al.* 2014) for clarification of both the original meaning and current meaning in design.
3. "Models in design" are models used in designing, including, for example, building information models (BIM), 2D computer aided drawings, sketches, etc; and "models of design" are models used in research to describe or prescribe how design is or should be carried out (Chakrabarti and Blessing 2014).
4. "Validation refers to checking fitness against an external goal, and verification deals with the correspondence between an [artefact] and its specification" (Kroll and Weisbrod 2020).
5. Due to space limitations, it is not possible here to broaden the discussion to different planning theories, design methodologies, and their underlying assumptions related to the technical and social aspects. This area remains an important topic for future study.
6. Koskela *et al.* (2014) interpreted deliberation to cover planning and design.
7. For a detailed analysis and comparison of the method of analysis and rhetoric to contemporary design theories, models and concepts, see Pikas (2019).
8. For a tentative evaluation of a practical utility, readers are encouraged to read Pikas *et al.* (2020).

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