ValueD: a model of cognitive value determination in design

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ABSTRACT

In spite of the increasing importance placed on the creation and delivery of value, it is unclear what value is and how it is determined in design. In this paper, the first descriptive model of value determination (ValueD) is presented to clarify the key elements and mechanisms involved. ValueD describes value determination as a cognitive process that is situated and dependent on an agent's knowledge. The variables involved are: an entity interpreted by an agent; a situation of an agent; knowledge of an agent; a criteria prioritisation activity; a criteria selection activity; and a criteria judgement activity. The output of the value determination process is a value statement. Value is shown to refer to *a judgement on the extent an interpreted entity satisfies an agent's criteria*. The ValueD model is evaluated through comparison against seven axioms of value and a protocol analysis of an engineering design episode. The article concludes with a discussion of strengths, limitations, and future work on ValueD, and its relationship with key value concepts such as added value, exchange and perceived value, benefit, and need.

Introduction

Organisations continually strive to find ways to increase economic value in terms of higher revenue and/or profit margin. Chief executive officers confirm value as an important parameter for business navigation (Hug 2003). Authors claim that management should focus on value creation (Copeland, Koller, and Murrin 2000) and that companies need to shift from a traditional view of seeing business as a set of functional activities to an externally-oriented view, concerned with seeing business as a form of value delivery (Bower and Garda 1985).

A notable body of work on value exists in different contexts, including axiology (e.g. Holbrook 1994; Lamont 1956; Rescher 1982), economics (e.g. Allingham 1982; Bailey 1967; Borja de Mozota 2006; Smith 1904), psychology (e.g. Brentano 1968; Maslow 1943; Rescher 1982; Schwartz 2006), and sociology (e.g. Allport 1961; Feather 1975; Kluckhohn 1951; Kohlberg 1983; Neumann 1986; Pauls 1990; Rokeach 1973; Schwartz and Bilsky 1987). However, there are inherent differences in the interpretation of value (Seni 2007). There is a lack of agreement on the concept of value *per se*, and on a conceptual framework from which research can be conducted (Hutcheon 1972). Similarly, different interpretations of value

exist in the context of design. For instance, Borja de Mozota (2006) states that value happens by achieving a result superior to that of the competitor. Daniels (2006) suggests evaluating the money a design saves in product cost over the previous design and other value metrics such as innovation, differentiation, and simplification. Desbarats (2006) suggests the use of market share as a metric to measure how designs add value. The three descriptions point to knowledge gaps on value in design: when does value appear; what is an appropriate metric for value in design; and how can value be added in design?

It appears that in spite of the increasing importance placed on the creation and delivery of value, it is still difficult for designers to design a 'valuable' product, and difficult for customers to distinguish valuable from non-valuable. In short, it remains unclear (i) what value is, and (ii) how it is determined (i.e. interpreted and ascertained through cognitive processing) in the context of design. We have addressed (i) in previous work by identifying key characteristics of value in the form of axioms (Reber, Duffy, and Hay 2019). To address (ii), this paper presents the results of inductive research providing a novel model that formally describes the value determination process in design. The resulting Value Determination model (ValueD) clarifies the elements and mechanisms involved in value determination, and provides, for the first time, a consistent basis for further investigations on the role of value determination in the delivery of value in design.

To provide a basis for modelling value determination, literature on the general characteristics of value is briefly presented in Section 2. The ValueD model is then introduced in Section 3. In Section 4, an epistemological evaluation of ValueD is conducted through comparison against seven value axioms (Reber, Duffy, and Hay 2019). The results of a protocol analysis carried out to explore empirical support for ValueD in design practice are also presented. The model and its relationship to general concepts of value is discussed in Section 5, and the paper concludes with a summary of the work in Section 6.

Value in design

Over the decades, perspectives on value in design have changed following changes in the corporate competitive environment for product development. These perspectives are characterised by: global competition and purchasing, where customers have greater choice and therefore products must exhibit greater differentiation; rising energy, material, and labour costs increasing the need for products and processes to increase efficiency; and rapid technological change shortening product lifecycles and increasing product variety, which leads to a paradigm shift from high volume and low variety to agile and lean production and product development processes. Consequently, early interpretations of value in design based on product worth and cost (Miles 1966) from a manufacturer's perspective have evolved and encompass the customer's perspective in terms of benefit, need, quality, utility, and value of services as outlined in Table 1.

Two different value approaches are inherent to the value interpretations in design, i.e. value as an outcome in return for an input, or value as an outcome *per se*. Value as an outcome in return for an input (Ashworth and Hogg 2000; British Standards Institution 2000; Chase 2001; Dell'Isola 1997; Fowler 1990; Miles 1966; Hamilton 1996; Miles 1972; Thomson et al. 2003; SAVE 2007; Yvars and Duhau 2012; Bertoni et al. 2020; Colombo et al. 2020) refers to an input in terms of cost, price, product consumption, or more generally as something exchanged. Value interpreted as an outcome *per se* (Borja de Mozota 2006; Daniels 2006;

Table 1. Value interpretations in design from the literature on product development.

Date	Interpretations	Reference
2020	Value is a balance between performance, cost, schedule, and other important stakeholder measures to produce the best outcome.	Bertoni et al. (2020)
2020	Value is the ratio of benefits to price.	Colombo et al. (2020)
2017	Value is how beneficial something is perceived to be.	Gill, Summers, and Turner (2017)
2017	Value for organisations and products can be grounded in economic theory.	Heskett (2017)
2015	Value is the extent that a design is perceived as useful by society.	Grace et al. (2015)
2012	Value is the ratio of functions to costs.	Yvars and Duhau (2012)
2007	Value is a fair return or equivalent of goods, services, or money for something exchanged.	SAVE (2007)
2006	Value happens by achieving a result superior to that of the competition.	Borja de Mozota (2006)
	Value is determined in terms of product cost reduction and other metrics such as innovation, differentiation, and simplification.	Daniels (2006)
	Value is determined in terms of market share.	Desbarats (2006)
2003	Value is benefits (what you get) divided by sacrifices (what you put in).	Thomson et al. (2003)
2000	Value is a complex entity made of scarcity, utility, costs of production, worth in use, value in exchange, and made by marginal utility. It is influenced by the conditions of supply and demand.	Ashworth and Hogg (2000)
	Value is the relationship between the contribution of the function to the satisfaction of the need and the cost of the function.	British Standards Institution (2000)
1997	Value is function plus quality divided by cost.	Dell'Isola (1997)
1996	Value is the level of importance that is placed upon a function, item or solution. Value can be considered as the ratio of function achieved to its life cycle cost.	Hamilton (1996)
	Value is a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer.	Womack and Jones (1996)
1992	Value is a functional outcome, a goal, purpose, or objective that is served directly through product consumption.	Burns and Woodruff (1992)
1990	Value is a capability provided to the customer at the right time at an appropriate price, as defined in each case by the customer.	Chase (2001)
	Value is a user's initial impression plus satisfaction in use, divided by first cost plus follow-up cost.	Fowler (1990)
1972	Value is the relationship of function cost to actual cost.	Miles (1972)
1966	Value is the relationship of product worth to product cost.	Miles (1966)

Desbarats 2006; Gill, Summers, and Turner 2017; Grace et al. 2015; Hamilton 1996) refers to the metrics of market share, innovation, differentiation, or a result superior to that of the competition. From the value interpretations given in Table 1, it can be concluded that value as an outcome in return for an input (e.g. cost) dominates the literature on value in design.

The discussion on value in design in the literature can be split into four main streams: (1) product and (2) process value management; (3) economic value of design; and (4) human values in design. Product value management has a focus on the analysis and modelling of value in terms of objectives, functions, cost, benefits, user perception, quality, needs, wants, and worth (Bertoni and Bertoni 2019; Boderick 1992; Colombo et al. 2020; Fowler 1990; Kim 2020; Liang et al. 2020; Mudge 1989). Some approaches consider the relationships between different elements involved. For example, the FAST value analysis method considers cost, function, needs, and wants (Bytheway 1965; Yvars and Duhau 2012). Value Sensitive Design relates human values and technical properties (Mok and Hyysalo 2018). Value Driven Design models system value as a function of multiple objectives including performance, cost/profit, quality, brand recognition, and sustainability, and accounts for differences in stakeholder preferences (Bertoni et al. 2020; Bertoni and Bertoni 2019; Papageorgiou, Eres, and Scanlan 2016). However, none of these approaches comprehensively describe the elements fundamentally involved in value and its determination. Design

process value management considers specific techniques to increase design process value in terms of needs, objectives, and success criteria (Ashworth and Hogg 2000; Cather et al. 2001; Faludi, Yiu, and Agogino 2020). Though some of the process value approaches consider the relationship between specific elements (e.g. design techniques to support the identification of business needs), they again only consider part of the elements involved and therefore provide a limited view. Design management literature points to the need to manage the economic value of design (Benton, Miller, and Reid 2018; Borja de Mozota 2006; McNabola 2013; Westcott et al. 2013). However, the terminology applied in this area is ill-defined, and it is unclear how value contributions arise from design as a product and/or process, from management of design, and/or from value management in design. Literature provides different perspectives on human values in design: design that accounts for human values (Alsswey and Al-Samarraie 2021; Friedman, Kahn, and Howe 2000; Kim 2020; Kyng and Mathiassen 1997); human values in the context of decision making processes and ethics (Le Dantec and Do 2009; Marshall and Erlhoff 2008; Mok and Hyysalo 2018); and human values in the context of value alignment in organisations (Hsu 2017; Kotter and Heskett 1992; Liedtka 1989). In the broader literature on value in sociology, consensus on elements related to human values has emerged gradually since the 1950's (Braithwaite and Scott 1991). However, as discussed above, design involves product, process, and economic value in addition to human values. As such, identifying the key elements and mechanisms involved in value in design requires a more fundamental formalism of value as a means to support research across different value types.

Previous work has explored the fundamental characteristics of value, and discussed these in a design context (Reber, Duffy, and Hay 2019). These characteristics are formalised as value axioms. Axioms may be characterised as rules that are objective in their grounding and universal in their applicability (Rescher 1982). The value axioms defined in (Reber, Duffy, and Hay 2019) can be summarised as:

- Axiom 1 – The person axiom - value is people based: Value in the context of design requires a means to reflect the personal characteristics of the value phenomenon. All value definitions refer, in an explicit or implicit manner, to people, e.g. consumer, customer, and human beings, while others utilise an enterprise and organisation that represent humans or groups of humans.
- Axiom 2 - The cognition axiom - value is an output of a cognitive process: People express value in terms of statements such as, 'X is of value'. The statement can be seen as an output of a cognitive process. To formalise a value statement requires value determination, i.e. a cognitive process of establishing value aiming towards a value statement.
- Axiom 3 - The determination axiom - value requires determination: All interpretations refer to value as cognitive concepts, i.e. an effect produced in the mind, belief, desire, level of importance, and criteria by which judgements are made, providing support to the cognition axiom. Holbrook's (1994) interpretation looks at value as a preferential judgement highlighting the determination process of value.
- Axiom 4 – The situation axiom - value is subject to situatedness: Situated cognition research claims that every human thought and action is adapted to the environment where it is situated, because what people perceive, how they conceive their activity, and what they physically do all develop together.

- Axiom 5 – The interpretation axiom - value is subject to interpretation: Value is determined on interpreted entities rather than on entities of the external world *per se*, since people cannot bypass the interpretation process.
- Axiom 6 – The entity axiom - value is entity-connected: 'Valuing' requires 'something' to be valued, e.g. assets, end-states of existence, events, exchanges, functions, items, modes of conduct, objects, products, qualities, solutions, things, and 'what is regarded as desirable'.
- Axiom 7 - The criteria axiom - value is criteria-connected: Value determination incorporates criteria ranging from economic criteria (such as 'low price', 'cost of production', and the 'amount buyers are willing to pay'), to human criteria (such as 'desirability', 'level of importance', and 'personally and socially preferable'). All value definitions utilise at least one criterion suggesting criteria to be a key element of the value phenomenon.

Nonetheless, although the general characteristics of value have been identified, there is still a lack of knowledge on the underlying key elements and mechanisms involved in its determination. As conveyed above, the literature on product, process, and economic value in design, as well as human values, is without any fundamental formalism that describes these aspects. Such a formalism could provide a consistent basis for further investigations to clarify aspects such as: when value appears; appropriate metrics for value in design; how value can be added in design; the management of economic value in design; the integration of human values in design; value alignment in a design context; and the relationship of different value types in design.

Modelling the value determination process

As shown in Section 2, the existing literature on value in design is lacking a fundamental formalism that describes the value determination process. To address this issue, we developed the ValueD model. We adopted an inductive approach to identify the key elements and mechanisms of value determination emerging from the literature, and formalised these using a suitable generic representation. Thus, ValueD is a descriptive model of the value determination process, formalising the phenomenon for the first time. As shown in Section 3.1, ValueD is based on a generic formalism of design activities, i.e. on cognitive activities that process knowledge. In Section 3.2, the activities involved in the process of value determination are discussed. In Section 3.3, the key elements of value determination are summarised, and the ValueD model is introduced.

Value determination activity

It may be seen from the literature that value is inherently people-based (e.g. see axiom 1 on p.4). Thus, a generic design activity concept (Sim and Duffy 2003) can provide a means to model the determination of value. A design activity is defined as an 'action taken by a design agent to achieve a knowledge change of the design and/or its associated processes (i.e. sequence of action), in order to achieve some design goal' (Sim and Duffy 2003, 202). A design agent could be a designer or another stakeholder who has an impact on the design and/or design process. According to Sim and Duffy (2003), the basic elements of a design activity (A_d) consist of:
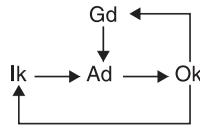
Figure 1. Design activity formalism.

- knowledge that directs the activity, Goals (G_d);
- knowledge presented prior to the activity, Input knowledge (I_k); and
- knowledge presented as a result of the activity, Output knowledge (O_k).

Sim and Duffy (2003) suggested that these basic elements may be related as shown in Figure 1.

In the generic design activity concept, Sim and Duffy (2003) adopt an IDEF0 modelling technique. This modelling technique is particularly suitable to model value determination because: a process can be represented without fixed start and end points; activities can be represented in terms of knowledge processed within it; each activity transforms knowledge input to output and the internal mechanisms of the transformation may not be modelled, i.e. it is not required to know internal mechanisms; and each activity or process can be partitioned to show details on another diagram, ensuring a single diagram does not become too cumbersome. Thus, the generic design activity formalism provides a means to model value determination in terms of a shared understanding of design activities and of abstracting away from the particularities of human behaviour.

Based on the literature, value can be characterised as the output of a cognitive determination activity (e.g. see axioms 2 and 3 on p.4). This activity is introduced here as being an explicit or implicit activity of value determination (A_{vd}) as illustrated in Figure 2.

The model of the activity of value determination applies the following terminology:
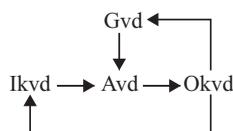
A_{vd} = Activity of value determination
G_{vd} = Goal of value determination
I_{kvd} = Input knowledge to value determination
O_{kvd} = Output knowledge of value determination

The value determination activity (A_{vd}) is a cognitive activity aimed towards determining value (G_{vd}). This activity processes input knowledge (I_{kvd}) into output knowledge (O_{kvd}). The following classes of knowledge are involved:

- Input knowledge (I_{kvd}) refers to the initial knowledge of an agent, i.e. knowledge prior to the value determination activity. The input may be an interpreted entity. The entity may

Figure 2. Activity of value determination.

exist in the agent's external world (e.g. a physical product) or in the agent's interpreted world (e.g. an idea). However, to determine value on external world entities, the entities are interpreted by the agent and therefore become part of the agent's internal world. Thus, no differentiation is required here for value determination on external or internal world entities.

- The goal (G_{vd}) refers to knowledge that directs and constrains the value determination activity. Goal knowledge refers to a future situation, which is perceived by the goal originator to be more desirable than the current situation. Goals in design are almost ubiquitous, although they are often implicit or ill-defined (O'Donnel 2000). The overall goal in value determination is a determined value expressed in terms of an explicit or implicit value statement.
- Output knowledge (O_{kvd}) of value determination is a value statement (e.g. 'An entity is of value.') on the entity under consideration. This value statement may be seen as an increase to the agent's design knowledge and may prompt a new design activity to be invoked and so the design process proceeds.

In abstracting the value determination activity to a knowledge level model, an agent is represented as a knowledge resource. People are generally viewed as the core resources in design (Frankenberger, Badke-Schaub, and Birkhofer 1997), but other resources, such as methods, techniques, and tools are also used and may be categorised among human, material, and informational (Eynard, Girard, and Doumeingts 1999). However, for value determination purposes, all resources may be represented as forms of knowledge that can be utilised within the cognitive process.

In the context of the value determination activity, the term knowledge is applied in a broad sense that includes tacit and explicit knowledge. It should be noted that for the purpose of modelling value determination, this knowledge also includes desires, ethic/moral principles, experiences, goals, implicit theories on how the physical world behaves, inborn qualities, outcome foci, and needs.

While the model of the value determination activity provides a means to derive declarative knowledge on the value phenomenon, it does not provide procedural insights, i.e. knowledge on 'how' value is determined. The model also does not formalise the criteria-connected characteristics of the value phenomenon discussed in the literature (e.g. see axiom 7 on p.5). Therefore, a more detailed analysis of value determination is required. This analysis is provided in Section 3.2, where the major activities involved in the value determination process are outlined.

The value determination process

It is proposed that the value determination process consists of three main activities: criteria selection, judgement, and prioritisation, as presented below.

Criteria selection and judgement activities

The model of the value determination activity in Section 3.1 illustrates that knowledge of an interpreted entity is processed in value determination towards a value statement. In terms of logic, the value statement can be interpreted as a declarative sentence that is either true or false (Strawson 1952). This indicates that a value statement can be seen as the output of

a cognitive judgement. In formulating judgements, a formal process of evaluation applies. This formal process involves a set of criteria that must be satisfied in order for a judgement to be made. Thus, it is argued here that value determination involves a judgement activity.

Criteria in value determination are dependent on the agent's knowledge. This is, for example, because: first, an agent not knowing a criterion is not able to consider this for a judgement; second, dependent on an agent's knowledge, the agent may or may not consider particular criteria; and third, because an agent may judge value based on knowledge, e.g. on standards and roles within a certain community. Criteria applied for value determination are introduced here as value criteria.

In formulating a value statement, agents must select value criteria from their knowledge. In selecting the criteria, the agent must consider knowledge on the interpreted entity. In other words, agents in selecting criteria establish a cognitive link between the interpreted entity and the set of criteria required to formulate the value judgement. Thus, there is a need for a criteria selection activity as the activity of selecting and connecting criteria to interpreted entities. The relationship between a judgement based on criteria and the criteria selection activity is illustrated in Figure 3.

The following terminology is applied in Figure 3:

A_{cs} = Activity of criteria selection
G_{cs} = Goal of criteria selection
I_{kcs} = Input knowledge to criteria selection
O_{kcs} = Output knowledge of criteria selection
A_{cj} = Activity of criteria judgement
G_{cj} = Goal of criteria judgement
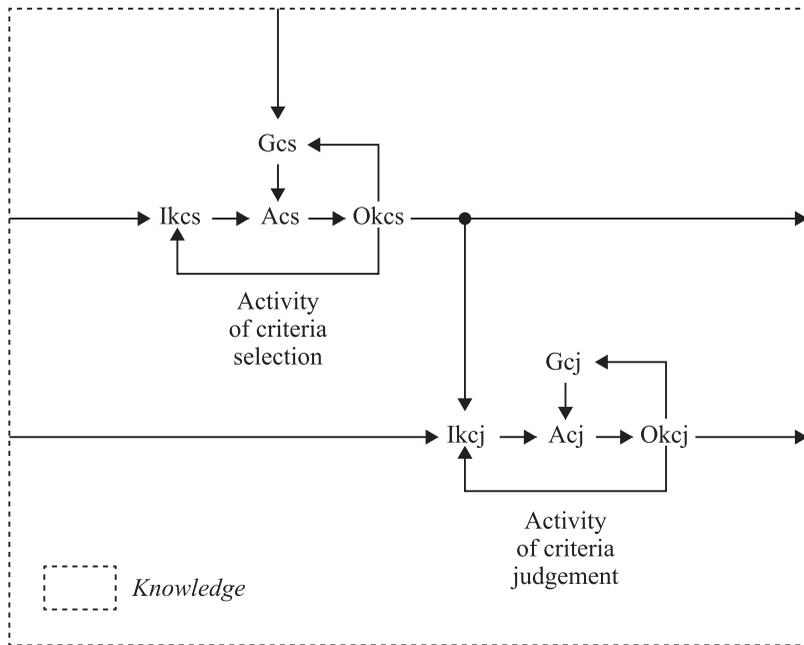
Figure 3. Criteria selection and judgement.

I_{kcj} = Input knowledge to criteria judgement

O_{kcj} = Output knowledge of criteria judgement

The criteria selection activity (A_{cs}) is the cognitive activity of selecting criteria for value determination based on an agent's knowledge. The following classes of knowledge are involved:

- The goal of criteria selection (G_{cs}) may be described in terms of a selected criterion or a set of selected criteria. There are often differing requirements relating to design aspects such as shape, form, function, and behaviour that need to be considered and selected to base value determination upon.
- Input knowledge (I_{kcs}) refers to knowledge on the entity under consideration. This may include knowledge of past designs in a domain, e.g. criteria that can be used in different design cases, and knowledge on criteria from specific past design cases. However, knowledge on the interpreted entity must be included as a basis to select appropriate criteria for judgement.
- Output knowledge (O_{kcs}) is a criterion or a set of criteria that serves as input knowledge (I_{kcj}) to criteria judgement. The selected criteria provide a contribution to the agent's overall knowledge.

The criteria judgment activity (A_{cj}) is a cognitive activity judging to what extent the interpreted entity satisfies criteria. The following classes of knowledge are involved:

- Input knowledge (I_{kcj}) refers to knowledge on the criteria to be applied, i.e. output knowledge (O_{kcs}) from the criteria selection activity (A_{cs}) and knowledge of the interpreted entity.
- The goal of criteria judgement (G_{cj}) is a judgement on the extent criteria are satisfied.
- Output knowledge (O_{kcj}) refers to the knowledge of an overall judgement on the extent individual criteria are satisfied by the interpreted entity. This knowledge is expressed in terms of a value statement and provides a knowledge contribution to the agent.

The criteria selection (A_{cs}) and judgement (A_{cj}) activities terminate if criteria are identified or a value statement is derived. However, the design agent is governed by the Principle of Bounded Rationality (Simon 1996). The Principle of Bounded Rationality states that given a goal, an agent may not possess perfect or complete knowledge of, or be able to economically compute or access, the correct action that will lead to the attainment of the goal. Therefore, no such solutions may be produced; instead new goals result that invoke new design activities.

Overall, the value determination activity (A_{vd}) is modelled here in terms of two sub-activities: criteria selection (A_{cs}), selecting criteria for value determination based on the interpreted entity under investigation; and criteria judgement (A_{cj}), judging the extent individual criteria are satisfied by the interpreted entity. This 'extent of criteria satisfaction' is expressed in terms of a value statement as the output knowledge of value determination.

From the criteria selection (A_{cs}) and judgement (A_{cj}) activities, it can be concluded that criteria represent key elements in value determination. Section 3.2.2 introduces a personal criteria system as a means to provide further insights into this aspect.

Criteria prioritisation activity

Value, as outlined in Section 3.2.1, refers to a judgement on the extent an interpreted entity satisfies criteria. From the criteria selection and judgement activities it can be concluded that criteria are key elements of value determination. In design, criteria vary considerably because different agents may have different criteria and individual or groups of agents may consider a range of different aspects such as cost, flexibility, lead-time, performance, quality, and/or risk. However, it may be argued that expert knowledge of an agent is not the exclusive resource for criteria selection, but rather criteria selection makes use of an agent's knowledge as interpreted in a broad sense, including desires, experiences, needs, etc. as outlined in Section 3.1.

The criteria selection activity (A_{cs}) provides a means for explanations of activities involved in criteria judgement, but does not address 'how' criteria are selected. What is suggested here is that criteria selection involves a judicious use of criteria derived from an agent's personal criteria system, influenced by their desires, needs, etc. This concept provides a means for the value determination activity (A_{vd}) to take into account that designers in practice determine value as experts in their domain, but at the same time inseparable as human beings.

The personal characteristic of value is approached in the value determination activity by an agent's individual knowledge and consequently by individual criteria selected for value determination. The mechanisms involved in this selective use of criteria may be described analogous to mechanisms involved in personal value systems (Rokeach 1973) in terms of an enduring organisation of beliefs concerning preferable modes of conduct or end states of existence along a continuum of relative importance. However, what is suggested here is not to introduce an enduring organisation of beliefs, but rather an enduring organisation of criteria with relative importance, i.e. a personal criteria system for value determination.

It is proposed that agents hold personal criteria systems, i.e. personal and ongoing systems of criteria and their priority. Personal criteria may be shifted on a priority list; new criteria may appear on the list, while other criteria may disappear if they are no longer appropriate. The personal criteria system provides a means to reflect the agent's individual preference of criteria in value determination.

In general terms, personal criteria systems provide a means to support explanations on the personal characteristic of value based on a personal prioritisation of criteria applied in value determination. This can be formalised in terms of a criteria prioritisation activity in the context of criteria selection as outlined in Figure 4.

The following terminology is applied to formalise criteria prioritisation (A_{cp}):
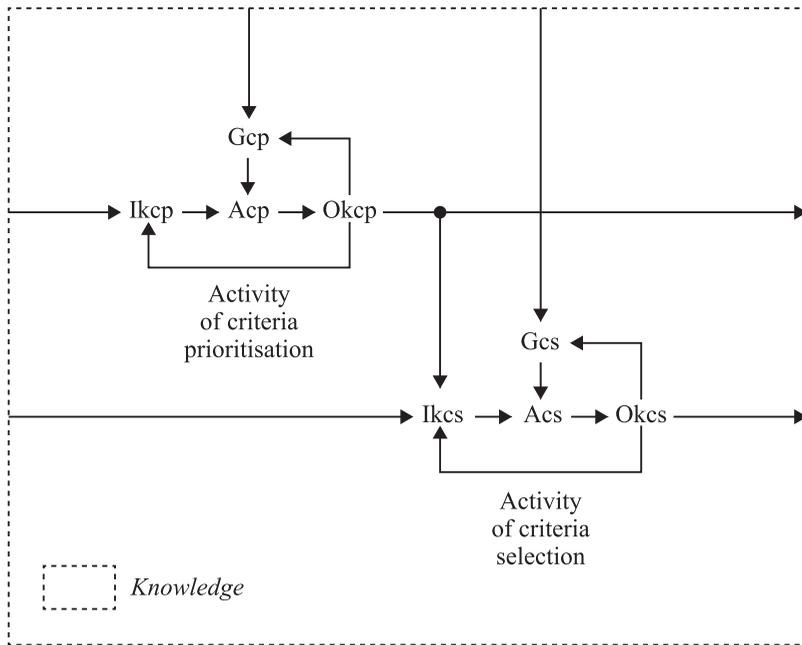
A_{cp} = Activity of criteria prioritisation
G_{cp} = Goal of criteria prioritisation
I_{kcp} = Input knowledge to criteria prioritisation
O_{kcp} = Output knowledge of criteria prioritisation

The criteria prioritisation activity (A_{cp}) is an ongoing cognitive activity varying criteria on a personal criteria priority list, adding new criteria to the list, and removing criteria as appropriate.

- The goal of criteria prioritisation (G_{cp}) is 'up-to-date' prioritised criteria.
- Input knowledge (I_{kcp}) refers to an agent's knowledge in a broad sense.

Figure 4. Criteria prioritisation and selection.

- Output knowledge (O_{kcp}) refers to an up-to-date list of criteria at the moment in time when criteria are required for criteria selection in the context of a specific interpreted entity. Output knowledge (O_{kcp}) is the input knowledge to criteria selection (I_{kcj}).

The criteria selection activity (A_{cs}) is seen as capturing a 'snapshot' of prioritised criteria from the A_{cp} at the time criteria selection is required.

The Value Determination model (ValueD)

Having established the criteria selection (A_{cs}) and judgement (A_{cj}) activities in Section 3.2.1 and the criteria prioritisation activity (A_{cp}) in Section 3.2.2, a model of the value determination process in the context of design, known as the Value Determination model (ValueD), is illustrated in Figure 5 below.

ValueD describes the key elements and mechanisms involved in value determination. Value determination is modelled here in terms of activities aimed towards determining value (G_{vd}) by processing input knowledge (I_{kvd}) of an interpreted entity into output knowledge (O_{kvd}) in terms of a value statement. The process may be described as follows:

Knowledge of an interpreted entity is provided to criteria selection (A_{cs}) as input knowledge (I_{kcs}). To make a selective use of criteria, criteria selection (A_{cs}) prompts criteria prioritisation (A_{cp}) to provide up-to-date and prioritised criteria as input knowledge. Based on knowledge of the interpreted entity and knowledge of up-to-date criteria, criteria selection (A_{cs}) makes a selective use of criteria in the context of the interpreted entity and provides the selected criteria to criteria judgement (A_{cj}) as input knowledge (I_{kcj}). Criteria judgement
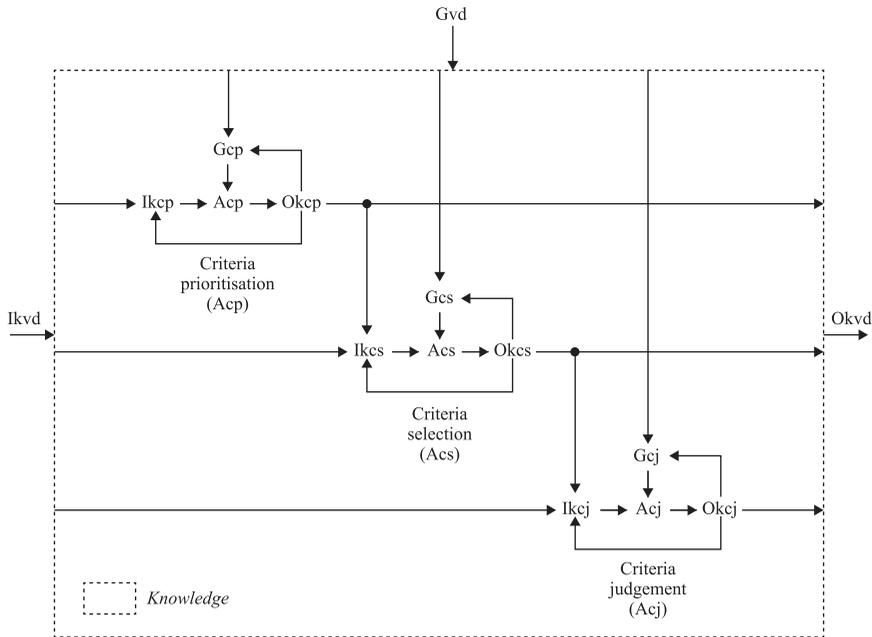
Figure 5. The Value Determination model (ValueD).

investigates the extent criteria are satisfied by the interpreted entity and provides a value statement as the output knowledge (O_{kcj}). Figure 6.

From the above, it can be concluded that value can be defined as:

a judgement[1] on the extent[2] an interpreted[3] entity[4] satisfies an agent's[5] criteria[6].

The fundamental elements of value determination have been elucidated in the ValueD model and captured within the definition of value above. Comparing these elements to value definitions from the literature (see Table 2) demonstrates that none capture the essence of value in all of its parts. The definition provided here is generic, and is therefore applicable to value determination in different contexts beyond just design.

Evaluation of the Value Determination (ValueD) model

In Section 3, ValueD was introduced based on a cognitive value determination process with an interpreted entity as the input and a value statement as the output, whereby criteria prioritisation, selection, and judgement (i.e. a personal criteria system) are involved (Section 3.2). The model is intended to constitute a fundamental formalism that describes value determination in a design context. Thus, there is a need to evaluate: (i) the extent to which ValueD reflects fundamental characteristics of value; and (ii) the extent to which the model is supported empirically in design practice. To this end, ValueD was (i) compared against the value axioms (Reber, Duffy, and Hay 2019) summarised in Section 2, and (ii) explored in a protocol analysis (Ericsson and Simon 1984).
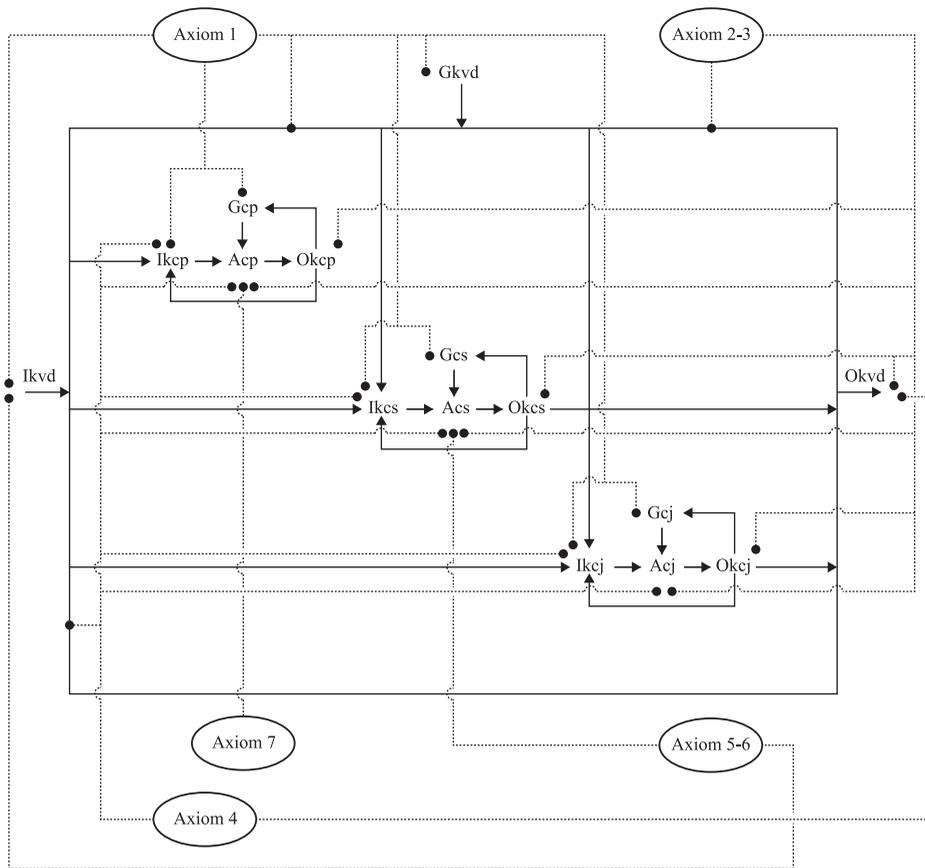
Figure 6. Relationship of value axioms to ValueD constructs.

Epistemological evaluation against value axioms

The value axioms covered in Section 2 convey the fundamental characteristics of value identifiable in the literature (Reber, Duffy, and Hay 2019). They may be viewed as general rules governing the value phenomenon, which are objective in their grounding and universal in their applicability (Rescher 1982). The ValueD model should therefore reflect all of these axioms in order to be considered a coherent fundamental formalism of value determination. To evaluate ValueD in this respect, we compared the model with the values axioms defined in (Reber, Duffy, and Hay 2019). Each of the axioms was found to be reflected within ValueD, and the relations between the axioms and the elements and mechanisms of the model are illustrated using dotted lines in Figure 6. Activity relationships are represented by solid arrows.

- The person axiom (Axiom 1) is considered in ValueD in terms of personal knowledge as a resource of value determination and in particular in terms of input knowledge to value determination (I_{kvd}), criteria prioritisation, (I_{kcp}), selection (I_{kcs}), and judgement (I_{kcj}); and knowledge on the goals of value determination (G_{vd}), criteria prioritisation (G_{cp}), selection (G_{cs}), and judgement (G_{cj}).

Table 2. Comparison of value definitions in the literature to the ValueD definition[a].

Interpretations	1	2	3	4	5	6	Explanation
Value is a balance between performance, cost, schedule, and other important stakeholder measures to produce the best outcome.		✓			✓	✓	• best ≡ extent • performance, cost, schedule, other measures ≡ criteria • stakeholder ≡ agent
Value is the ratio of benefits to price.	✓					✓	• benefits, price ≡ criteria • ratio → judgement
Value is how beneficial something is perceived to be.		✓	✓				• how beneficial ≡ extent • perceived ≡ interpretation
Value for organisations and products can be grounded in economic theory.				✓	✓		• product ≡ entity • organisation ≡ agent
Value is the extent that a design is perceived as useful by society.		✓	✓	✓	✓	✓	• design ≡ entity • extent ≡ extent • perceived ≡ interpretation • society → agent • useful ≡ criteria
Value is the ratio of functions to costs.	✓					✓	• costs, functions ≡ criteria • ratio → judgement
Value is a fair return or equivalent of goods, services, or money for something exchanged.		✓		✓	✓		• fair return and equivalent ≡ extent • goods, services, or money ≡ entity • exchange → agents
Value happens by achieving a result superior to that of the competition.		✓		✓	✓		• superior ≡ extent • result ≡ entity • competition → agents
Value is determined in terms of product cost reduction and other metrics such as innovation, differentiation, and simplification.	✓		✓	✓		✓	• determined ≡ judgement • in terms of → interpretation • entity ≡ product • cost reduction and other metrics ≡ criteria
Value is determined in terms of market share.	✓		✓			✓	• determined ≡ judgement • in terms of → interpretation • market share ≡ criteria
Value is benefits (what you get) divided by sacrifices (what you put in).	✓		✓	✓		✓	• divided by → judgement • x → interpretation • what you get & what you put in → entity • benefits → criteria
Value is a complex entity made of scarcity, utility, costs of production, worth in use, value in exchange, and made by marginal utility. It is influenced by the conditions of supply and demand.		✓		✓		✓	• influenced → extent • marginal utility ≡ entity • scarcity … exchange ≡ criteria

Definition[a]	1	2	3	4	5	6	Elements
Value is the relationship between the contribution of the function to the satisfaction of the need and the cost of the function.	✓	✓		✓		✓	• satisfaction ≡ judgement • contribution → extent • function ≡ entity • need and cost ≡ criteria
Value is function plus quality divided by cost.	✓					✓	• divided → judgement • function, quality, and cost ≡ criteria
Value is the level of importance that is placed upon a function, item or solution.		✓		✓		✓	• level ≡ extent • function, item, or solution ≡ entity • importance ≡ criteria
Value can be considered as the ratio of function achieved to its life cycle cost.	✓	✓				✓	• ratio → judgement • achieved ≡ extent • function and life cycle cost ≡ criteria
Value is a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer.	✓			✓	✓	✓	• defined … by the customer ≡ judgement • capability ≡ entity • customer ≡ agent • right time and appropriate price ≡ criteria
Value is a functional outcome, a goal, purpose, or objective that is served directly through product consumption.				✓	✓	✓	• functional outcome ≡ entity • consumption → agent • goal, purpose, or objective ≡ criteria
Value is a user's initial impression plus satisfaction in use, divided by first cost plus follow-up cost.	✓	✓	✓		✓	✓	• divided → judgement • satisfaction ≡ extent • impression ≡ interpretation • user ≡ agent • use and cost ≡ criteria
Value is the relationship of function cost to actual cost.	✓					✓	• relationship → judgement • cost ≡ criteria
Value is the relationship of product worth to product cost.	✓					✓	• relationship → judgement • worth and cost ≡ criteria

[a]Numbered columns refer to the elements in the definition above (see Page 11).
≡ denotes 'instance of'.
→ denotes 'implies'.

- The cognition axiom (Axiom 2) and determination axiom (Axiom 3) are considered in ValueD in that value is interpreted as the output knowledge (O_{kvd}) of a cognitive value determination process based on the output knowledge (O_{kcp}, O_{kcs}, O_{kcj}) from criteria prioritisation (A_{cp}), selection (A_{cs}), and judgement (A_{cj}).
- The situation axiom (Axiom 4) is considered in ValueD in that value is interpreted as the output knowledge (O_{kvd}) of a cognitive value determination process based on an agent's knowledge and in particular on the input knowledge to value determination (I_{kvd}), criteria prioritisation (I_{kcp}), selection (I_{kcs}), and judgement (I_{kcj}). The personal criteria system in terms of the criteria prioritisation (A_{cp}), selection (A_{cs}), and judgement activities (A_{cj}) represent further elements related to the situated characteristic of value.
- The interpretation axiom (Axiom 5) and entity axiom (Axiom 6) are considered in terms of an entity's interpretation as the input knowledge to value determination (I_{kvd}) and the criteria selection activity (A_{cs}) that establishes a cognitive link between the interpreted entity and the criteria selected for judgement.
- The criteria axiom (Axiom 7) is considered in terms of the criteria prioritisation (A_{cp}), selection (A_{cs}), and judgement activities (A_{cp}). Overall, value according to ValueD refers to the judgement on the extent an interpreted entity satisfies criteria.

Protocol analysis

A concurrent protocol approach was adopted to explore empirical support for ValueD in the design activities of a practising designer. An engineering design protocol established by Kok (2000) was analysed. This protocol consisted of a transcript of an audio/video recording of a single designer at work. The designer recorded was a senior ship designer with more than ten years working experience in a company that provides consultancy services in the design and supervision of high-speed naval craft and warship construction. The protocol took 2 h 45 min. The verbalisation and drawing activities of the senior ship designer were recorded using a digital video camera. AutoCAD was used to record all of the drawings pertaining to the design tasks.

In protocol analysis, the recorded data is segmented into independent parts in order to facilitate the analysis of every segment independently. Protocols are segmented according to the purpose of the analysis (Gero and McNeill 1998; McNeill, Gero, and Warren 1998; Purcell et al. 1996). The purpose of the protocol analysis provided in this paper was to analyse value determination in the context of design activities. As such, the activities that the designer engaged in throughout the protocol were identified first (as segments), on the basis of key words or phrases uttered by the designer suggesting the nature of the activity (as described by Kok (2000)). The key elements of value determination, i.e. value entities, value criteria, and value statements, were then deduced through coding and interpretation of the protocol data in each design activity segment. The results of this analysis are presented in the following paragraphs.

Overall, 102 value statements were identified throughout the design episode. A value statement may be explicit or implicit. That is, a designer may or may not communicate a value statement to the designer's external world. 79% of the value statements identified in the protocol were explicit, and 21% implicit. Table 3 provides examples of each type of value statement identified from the protocol analysis, along with value entities and criteria. Column 2 presents the value statement (V) example from the protocol transcript (highlighted

**Table 3.** Examples of explicit and implicit value statements.

Seg. No. (Time)	Transcript (value statement, V, in bold)	Design activity (A)	Type of value statement	Value entity (E)	Value criterion (C)	Criterion		
						Prioritised	Selected	Judged
36	But the included angle between buttock and the propeller shaft is 8 degrees. In this present configuration that seems very reasonable.	decision making	explicit	concept	angle is 8 degrees	–	✓	✓
3	The vessel has a range of 2,000 nm at 14 knots. These vessels were chosen as the most suitable for the conditions in the area. Shore boats were wanted with long range and good sea-keeping characteristics.	• analysing • decision making	implicit	concept	long range good sea-keeping characteristics	– –	✓ ✓	✓ ✓

in bold text), column 3 indicates the design activity (A), and the remaining columns convey the value entity (E), value criteria (C), and what the designer was observed to do with the criteria:

- In segment No.36, the designer decided (A) that an angle of 8 degrees 'seems very reasonable', i.e. the design concept (E) was considered as valuable based on the criterion of 'an 8 degree angle' (C). The designer's conclusion of 'that seems very reasonable' (V) was interpreted as an explicit value statement.
- While the designer was analysing (A) in segment No.3, the 'range of 2000 nm at 14 knots' was decided (A) to be the most suitable range for sea-keeping conditions in a specific area. Customers wanted, 'shore boats with long range and good sea-keeping characteristics', i.e. the design concept (E), was considered as valuable if it satisfied to a certain extent 'long range' (C) and 'good sea-keeping characteristics' (C). Value was interpreted as judged on the basis of these criteria; however, a value statement (V) was not made explicitly by the designer.

In the design episode investigated, value was primarily determined in the contexts of the activities relating to decision making (40%), prioritising (13%), evaluating (8%), determining (7%), identifying (7%), defining (6%), exploring (5%), analysing (3%) and gathering (3%), as illustrated in Figure 7. Note that these results (along with those presented in Figures 8 – 10) are based on one design protocol only.

8% of the value determinations are related to 'other' design activities. These are approximating, associating, constructing, decomposing, generating, resolving, searching, selecting, standardising, structuring and synthesizing. It can be concluded from Figure 7 that whilst the majority of instances of value determination were found to occur within decision making activities – almost four times more than any other activity – determination
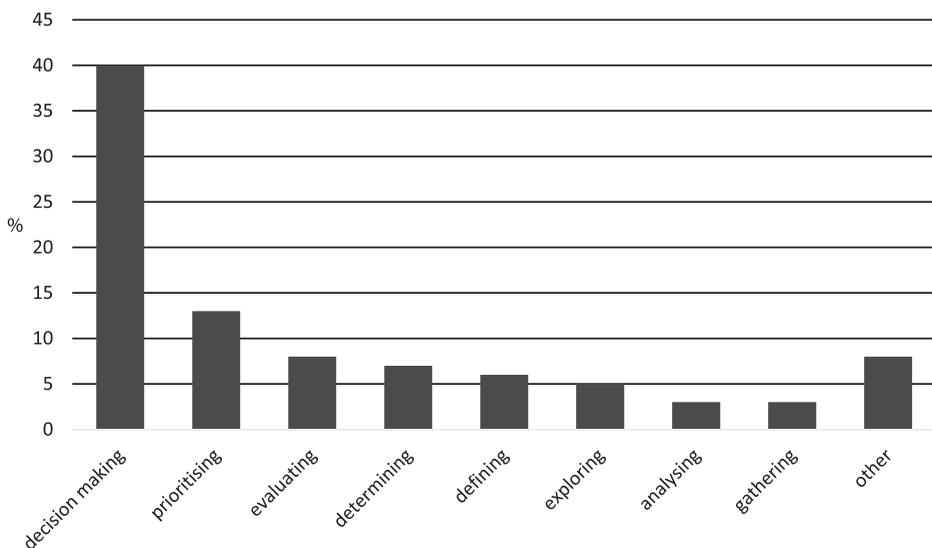
Figure 7. Percentage of value determinations related to design activities.
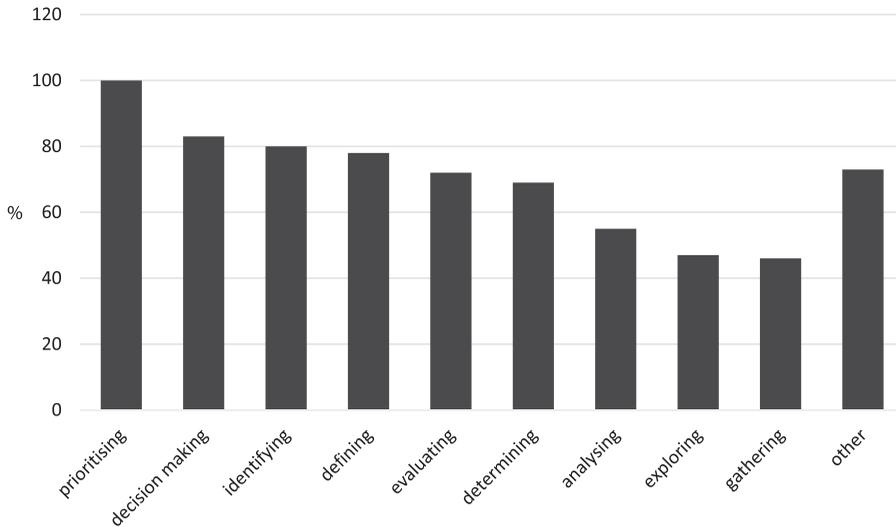
Figure 8. Relative percentage of value determinations to design activities.
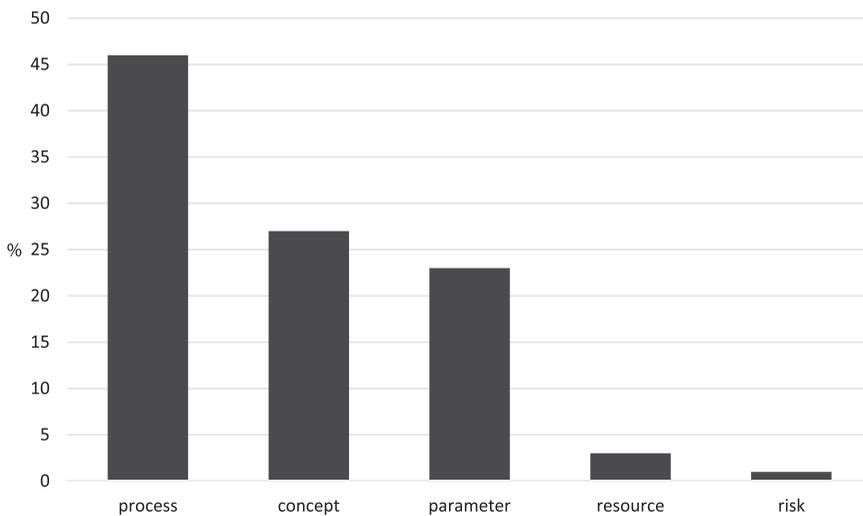
Figure 9. Percentage of value entities identified in the design episode.

was also identified in a substantial number of other activities. Further, an analysis of the ratio between design activities and value determination reveals that 100% of prioritising is related to value determination, as illustrated in Figure 8. Six of the activities encompassed value determination in 70% to just over 80% of instances, and the remaining three in between 40% to 60% of instances.

Analysing value determination against entities reveals that value is determined on the design process (46%) in the context of decision making on the next design step, on the design concept (27%), and on parameters (23%), followed by resources (3%), and risks (1%), as illustrated in Figure 9.

Table 4. Example of values entities identified in the design episode.

Value entity (E)	Segment No.	Transcript	Explanation[b]
process	32	And then from a redundancy consideration, we would like to think about how to put the engines in separate compartments and divide the two compartments with a water-tight bulkhead.	In deciding the next design step, the designer applies the criterion 'consider redundancy' as a value criterion (C) regarding the next step (E). In other words, the next design step is of value to the designer if the design step considers redundancy.
concept	12	We have been advised that the $/kW price of a 4-engine application is prohibitive and that we should concentrate our efforts on the 6-engine application.	In gathering information (A), the designer states they have been advised to concentrate on a 6-engine application. The value determination is on the 6-engine application (E) based on the criterion of the $/kW relation (C).
parameter	113	Right now the requirements with regard to collision bulkheads are such that the bulkheads should be placed not less than 94% of ship's length and not greater than 97%. Something of that nature.	Value determination is on the bulkhead position, i.e. on the parameter of the bulkhead position (E) to be placed not less than 94% of ship's length and not greater than 97% (C).
resource	9	There are a lot of home-made systems that suit the particular requirements. Therefore, we have to look overseas for different suppliers with perhaps some US connections. This will make the selection in certain situations more acceptable to the US government.	The designer makes a decision (A) to 'look overseas for suppliers with US connections'. Value is determined on suppliers (E) based on the value criterion (C) to be acceptable for the US government.
risk	95	We've got to be careful that in the process of moving we do not move it through the bulkhead at the other end. That is some 92 mm in the figure. Move the engine and the gearbox 120 mm.	In evaluating the design concept (A), the designer identifies the risk 'to move through the bulkhead'. The designer makes a decision (A) 'to be careful' (E), which may be of value to the designer in the sense of 'not to move through the bulkhead at the other end' (C).

[b]A = design activity, C = value criterion, E = value entity

Examples of value entities identified in the design episode are provided in Table 4. The transcript excerpts (column 3) can relate to a number of entities, but only those identified in the value entity column (column 1) are highlighted for illustration.

From the protocol, when analysing value determination against value criteria applied, it appears that in 27% of the value determination activities, the criteria are not communicated in the transcript. This result may be interpreted from different perspectives: consciousness and/or unconsciousness; a contradiction to ValueD existing in the empirical data; and/or to what extent the result may be a function of the method applied to identify value criteria:

- From the perspective of consciousness and/or unconsciousness, an interpretation may be that designers tend to apply value criteria in an unconscious manner and/or apply certain criteria in consciousness but do not state criteria explicitly in the design protocol.
- From a human values perspective it may be argued that designers apply value criteria related to human values, i.e. deeply held enduring beliefs but do not express these criteria explicitly in the context of design activities. This interpretation may be seen as supported by the finding that the remaining 73% of value criteria articulated in the context of design activities (with only one exception in terms of 'personal satisfaction'), related to design expert knowledge, e.g. clearance, information, position etc.

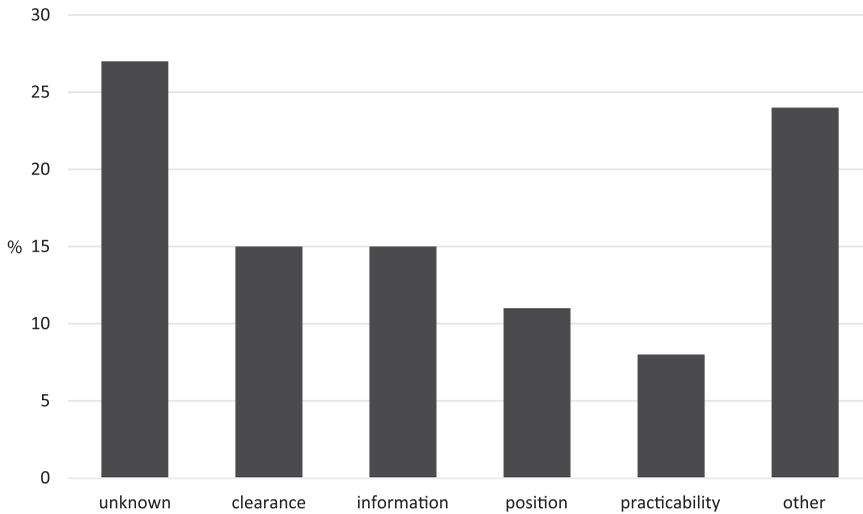**Table 5.** Examples of value criteria identified in the design episode.

Value criterion (C)	Segment No.	Transcript	Explanation[c]
unknown	44	We have the envelope of the engine plus gearbox. What we must check now, is whether the bottom of the gearbox is going to be within the hull envelope.	The designer makes a decision (A) on the next design step (E) in terms of 'what we must check now'. The criteria (C) applied in value determination on the next design step remains unknown.
clearance	16	Notwithstanding these requirements, we have to satisfy sensible routes for the installation and ready removal of equipment that are likely to be replaced or serviced. This adds another driver to where the equipment may or may not be situated.	In analysing (A) the design concept, the designer identifies the need to satisfy sensible routes for the instalment and removal of equipment. Satisfying sensible routes (C) includes considerations on clearance and space and is determined as valuable in the context of the overall design concept (E).
information	78	All we're trying to do at this stage is get some approximate idea of space envelope. How much room do we need to allow for the machinery? Once we have decided that we can then move on to other aspects of the arrangement to see how we can best fit in those needs.	The designer makes a decision (A) on the next design step (E) in terms of 'all we're trying to do at this stage is to get some approximate idea of space envelope', i.e. value is determined on this next design step based on the criterion to 'gain information' (C).
position	34	Where else can we consider putting the engines? In this category, the engines should be placed in such a manner that the propulsion shaft angle with respect to the buttock lines of the vessel in which the shaft line is arranged is 6–12 degrees maximum.	The designer makes the decision (A) that the shaft line is 'arranged 6–12 degrees maximum'. The engine position (E) is valued in terms of 'such a manner that the propulsion shaft angle is arranged 6–12 degrees maximum (C), i.e. based on a position.
practicability	23	These prospects are shown on the screen for your inspection. As you can see, the ability to put 4 engines in a row is just grossly impractical. There is no room for the ship's structure. The engines would have to go in at heights which would make them difficult to maintain and access. It would raise the CG and impact the overall stability of the vessel. So, at a glance we can see that this is not a sensible approach.	The designer makes a decision (A) that '4 engines in a row is just grossly impractical'. The design concept (E) is valued in terms of 'grossly impractical' (C), i.e. this concept is not of value to the designer based on practical considerations.

[c]A = design activity, C = value criterion, E = value entity.

- From a method perspective it should be noted that the criteria have been identified in the context of design activities and then classified in groups of criteria, i.e. unknown, clearance, information, position, practicability, and other. Thus, criteria not related to the design activities investigated were not identified. With respect to the classification of the criteria, e.g. as unknown, related to clearance, information, etc. it should be noted that this classification was based on the researcher's interpretations of the design protocol text and segments. Thus, criteria applied across segments were not identified.

Despite there being no value criteria identified in 27% of design activities, in 73% of the activities value criteria were identified. Examples are provided in Table 5.

The 73% of value determination activities where criteria were identified can be grouped into six different classes of criteria. That is, in 15% of the value determination activities, the criteria are related to clearance, in 15% to expected information, in 11% to absolute or relative positions, in 8% to practicability, and in 24% to other criteria in terms of

Figure 10. Percentage of value criteria identified in the design episode.

acoustics, balance, customer acceptance, comfort, motion, personal satisfaction, progress, and stability, as shown in Figure 10.

Based on the results of the protocol study, it may be concluded that there is empirical support for the ValueD model in design practice. All elements and mechanisms in the model were found to be supported by the protocol data to some extent. Further investigation with additional protocol data is needed to determine the extent to which the model is generally applicable across different design episodes, as well as episodes in different design domains.

Discussion

The previous sections have reviewed the literature on value in design, introduced the ValueD model to formalise the key elements and mechanisms involved in value determination, and presented the results of epistemological and empirical evaluations of the model. The strengths and limitations of ValueD are discussed in Section 5.1, highlighting areas for future work. In Section 5.2, the model is used to clarify and provide insights into key value concepts commonly discussed in the literature.

Reflection on ValueD and future work

ValueD is the first model to formally describe the elements and mechanisms fundamentally involved in value determination. The results of the evaluation (Section 4) support the ValueD model in a design context. The elements and mechanisms of the model reflect the fundamental value axioms identified in (Reber, Duffy, and Hay 2019), and were identified in the protocol analysis of design activities. However, the relationships between value determination and design activities, and between the value criteria and identified entities, may be dependent on the individual designer and the design episode, i.e. they may not be generalisable. Additionally, it is not yet clear whether ValueD is generalisable to other design

agents (e.g. users and customers) who were not investigated during evaluation. Further research applying ValueD to a range of design activities and agents is needed.

Regarding comprehensiveness, some critical issues have to be raised. One is that even if the output of ValueD is correct in terms of corresponding to practice as suggested by the protocol analysis findings, the way the human mind actually acts as opposed to any verbalisation of activities may be different to the process proposed in the model. Another issue regarding ValueD is the question of whether people use several ways to perform any particular cognitive function. If we assume they do, then the model of value determination represents (at best) one proposition of value determination. Another issue was raised by Miller (1994), who questioned consciousness in cognitive science and concluded that we do not know a lot about consciousness and unconsciousness. One may argue that the process of value determination may be the same in both consciousness and unconsciousness, and a differentiation is not required. However, because we do not know a lot about consciousness and unconsciousness, we cannot draw this conclusion. At a minimum, we may expect that the ValueD represents a propositional model of value determination under the condition of consciousness.

In addition to the protocol analysis, ValueD was evaluated from an epistemological perspective against a set of value axioms. The axioms are general rules governing value, identified as fundamental to the phenomenon in a previous inductive investigation of value theory in axiology, economics, psychology, sociology and design (Reber, Duffy, and Hay 2019). ValueD was found to reflect all of these axioms, and can therefore be considered a coherent fundamental formalism of value determination. However, it is possible that there are further value axioms that were not identified through the investigation reported in (Reber, Duffy, and Hay 2019). New axioms may highlight additional aspects of value determination that are not currently described in ValueD, or contradict existing model elements. Thus, the model may evolve as our knowledge about value in design advances through future research.

Knowledge represents a key resource for value determination. The behaviour of this resource was not investigated as part of this research. That is, the areas of desires, experiences, implicit theories on how the physical world behaves, inborn qualities, and outcome foci in relation to the value determination process were not investigated. Further research is required on the value determination process in the context of these areas to generate comprehensive explanations on value in design. A strength in this respect is that ValueD is based on a modelling standard similar to the broadly accepted generic IDEF0 standard, providing a common and consistent basis for investigating value in different contexts.

Value determination was considered in ValueD from a single-agent perspective. However, in the context of design, value may be determined in situations with multiple agents involved, e.g. in the context of a dialogue between a customer and a designer. Although multi-agent environments were considered in the context of the research, ValueD was not tested against multi-agent environments. Further investigations on multi-agent environments based on ValueD may provide a means to support generality of the model.

Concepts of value and ValueD

By clarifying the fundamental elements and mechanisms involved, ValueD provides the basis for further investigations on the role of value determination in the delivery of value in

design. Such investigations could, for instance, contribute to the development of improved and completely new tools and techniques for designers and managers.

More immediately, ValueD can help to clarify key value concepts discussed in the literature. As conveyed in Table 1 in Section 2, value-related phenomena such as added value, exchange, perception, benefit, and need are central to this discourse. However, whilst it is generally agreed that these concepts are not directly equivalent to 'value' *per se*, their nature and relationship to value is not clear. Each concept is discussed through the lens of ValueD below to provide insight into these aspects.

Added value: A change to an agent's knowledge is fundamental to changes in an agent's value statement. Changing an agent's situation, interpretation, and criteria prioritisation, selection, and judgement provide a means for a change in value statements. Although these changes provide an opportunity to influence value statements, by no means is there a guarantee for a value statement change. This is because an agent: may not consider a change as relevant and ignore the change; may consider a change as relevant but not change criteria priority, selection, and judgement; or may change the value criteria but judge the extent of criteria satisfaction as before. In other words, a change that may occur in the value statement lacks management towards an increase in the extent an entity satisfies criteria. This, however, may be seen as related to the terminology of value adding and added value as frequently used in literature. With respect to added value, ValueD demonstrates that in criteria selection (Acs), agents select specific criteria in the context of the interpreted entity. In doing so, agents establish a cognitive link between the interpreted entity and criteria, i.e. agents add criteria cognitively to the entity. The selected criteria are the input to criteria judgement (A_{cj}) and consequently the basis for the value statement. In other words, the selective use of criteria makes a value statement entity specific. In this context, adding value may then be interpreted as the activity of adding criteria to an entity, increasing the degree of satisfaction of criteria and/or replacing added criteria with more satisfactory ones.

Exchange value refers to a specific situation where two entities are involved but the focus of value determination is on the entity's 'exchange' rather than on the entity's value statements *per se*. An agent in the situation to judge value on the exchange of entities (e.g. money against a product) determines the value of these entities, which results in entity specific value statements. The value statements become the input knowledge to value determination on the 'exchange' of entities. However, the entity specific value statements may not be of relevance to the value determination on the exchange of the entities. For value determination on the 'exchange', other criteria may be applied then for value determination on the entities involved. In a situation where e.g. the exchange of a product against money is considered, an agent may come to the conclusion that the product satisfies the agent's criteria to a higher extent than the money. However, in determining value on the exchange of the product against money, the agent may apply a criterion such as 'saving money to reduce risk' and come to the conclusion that the value of the entity's exchange is low. Overall, exchange value refers to the extent an 'exchange of entities' satisfies an agent's criteria. What is exchanged here is not value as such, but rather entities linked to value statements.

Perceived value: Value as the output of a cognitive process is not perceived in the sense of the ability to see, hear, or become aware of something through the senses. However, what may be perceived in value determination is an entity in the agent's external world. That is,

an interpreted entity is the input knowledge to value determination and this entity may be perceived through the senses. Consequently, the terminology of determined value and perceived entity should be used rather than perceived value. It should also be noted that value cannot be received or provided, i.e. one cannot 'transfer' value. Even if there would be a consensus by the agents involved in value determination on the interpreted entity and criteria priority, selection, and judgement, by no means is value transferred from a conceptual point of view.

Value and benefit: There are fundamental differences between value and benefit. A benefit refers to an advantage or profit, while value refers to a value statement, i.e. to the extent an entity satisfies criteria. A benefit with high value to one an agent may be of no value to another, although it is the same benefit. That is, a benefit may be the input knowledge to value determination and judged on the extent the benefit satisfies value determination criteria. An entity providing a benefit by no means must be an entity of value; it is only in the specific case where criteria in value determination are related to the benefit (e.g. an advantage) that a 'beneficial' entity may be of value to an agent.

Value and need: Value is not dependent on need although the concepts have some characteristics in common: they are context dependent, a matter of change, related to satisfaction, and subjective. However, there are also distinctions in that value: is related to motivation only in the specific case where criteria in value determination are related to motivation; cannot be satisfied like needs; and is not objective. Need is considered in ValueD in terms of an agent's knowledge where knowledge on need may, as a driver of motivation, trigger a value determination activity, change priorities and criteria in an agent's personal criteria system, and provide criteria for value determination.

Conclusion

Increasing importance is placed on the creation and delivery of value in design. However, although an extensive body of work exists on value in this context, the literature is lacking a fundamental formalism describing the key elements and mechanisms involved in value determination. In response, this paper has presented the results of inductive research aiming to model the value determination process in design. The resulting Value Determination model (ValueD) provides, for the first time, a consistent basis for further investigations to clarify the role of value determination in the delivery of value in design. Such investigations could, for instance, contribute to the development of improved and completely new tools and techniques for designers and managers.

Value determination, as a cognitive process, is situated and dependent on an agent's knowledge. In ValueD, the value determination process is formalised in terms of a knowledge processing activity generating a value statement as the output from knowledge of an interpreted entity as the input, under the direction of the overall goal of determining value. The variables involved in the value determination process are: an entity interpreted by an agent; a situation of an agent; knowledge of an agent; a criteria prioritisation activity aimed to provide up-to-date and prioritised criteria; a criteria selection activity aimed to make a selective use of criteria in the context of an interpreted entity; and a criteria judgement activity aimed to judge the extent an interpreted entity satisfies criteria. The output of the value determination process is a value statement.

The criteria prioritisation activity can be interpreted in terms of a personal criteria system, i.e. an ongoing cognitive activity shifting criteria on a personal priority list, adding new criteria to the list, and removing criteria from the list as appropriate. In criteria selection, agents make a selective use of criteria based on input knowledge of the interpreted entity and on up-to-date and prioritised criteria. In selecting criteria, agents cognitively connect criteria to the interpretation of an entity under investigation. In criteria judgement, agents judge the extent the interpreted entity satisfies the criteria selected in the criteria selection activity. The 'extent of criteria satisfaction' is expressed in terms of a value statement as the output knowledge of value determination. Thus, value refers to a judgement on the extent an interpreted entity satisfies an agent's criteria.

ValueD was reviewed against seven value axioms (Reber, Duffy, and Hay 2019). The axioms constitute a set of formal rules describing the fundamental characteristics of value, that are objective in their grounding and universal in their applicability (Rescher 1982). ValueD was shown to be consistent with the axioms, which characterise value as connected to people, entities, and criteria; subject to situatedness and interpretation; and the output of a cognitive process. The results of a protocol analysis focusing on the analysis of value determination in the context of engineering design activities were also presented. These results were shown to support ValueD in that value determination was identified in the context of designing. However, the relationships between value determination and design activities and between the value criteria and entities identified may be dependent on the individual designer and the design episode, i.e. they cannot be generalised. Additionally, it is not yet clear whether ValueD is generalisable to other design agents (e.g. users and customers) who were not investigated during evaluation. Further research is required involving multiple design activities and agents to potentially obtain generalisable results.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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