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# Technical Artefact Theories: A Comparative Study and a New Empirical Approach

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## Abstract

Embracing an inter-disciplinary approach grounded on Gärdenfors' theory of conceptual spaces, we introduce a formal framework to analyse and compare selected theories about technical artefacts present in the literature. Our focus is on design-oriented approaches where both designing and manufacturing activities play a crucial role. *Intentional* theories, like Kroes' dual nature thesis, are able to solve disparate problems concerning artefacts but they face both the philosophical challenge of clarifying the *ontological nature* of intentional properties, and the empirical challenge of *testing* the attribution of such intentional properties to artefacts. To avoid these issues, we propose an approach that, by identifying different *modalities* to characterise artefact types, does not commit to intentional qualities and is able to empirically ground compliance tests.

**Keywords** Conceptual spaces · Technical artefacts · Ontology · Product design

## 1 Introduction

The study of artefacts has a long tradition in different fields including archeology (Rouse 1960), philosophy (Kroes 2012; Hilpinen 1993; Lowe 2014; Thomasson 2007; Houkes and Meijers 2006), knowledge engineering (Kassel 2010; Borgo and Vieu 2009; Kitamura and Mizoguchi 2010), psychology and cognitive sciences (Bloom 1996; Malt et al. 1999). In this paper we focus on *technical* artefacts. In particular, we look at technical artefacts from an engineering perspective,

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therefore at products that are designed starting from some *requirements* and are produced following a *make-plan* to match some physical *specifications*.

Despite the heterogeneity of the existing approaches (Borgo et al. 2014) and the difficulty to precisely separate technical artefacts from natural objects, artworks or social artefacts (Kroes 2012), most theories share the idea that technical artefacts "result from intentional production and (...) are essentially characterised in terms that refer to human purposes and activities" (Houkes and Vermaas 2014, p.168). Technical artefacts are therefore material objects *intentionally* designed and produced to match practical purposes. One of the best known representatives of this intentional stance is the theory developed by Kroes and colleagues (Kroes 2012) according to which technical artefacts bear a *dual nature*: on the one hand, they are physical objects which can be studied within the scope of physics; on the other hand, they are fully-fledged intentional objects designed to exhibit *intended* physical capacities (i.e., physical behaviours or input-output relations). In this view two artefacts with the same physical characteristics may be classified under different types because of their intentional features, i.e., because they *are meant* (by designers) to exhibit different physical capacities. In Houkes and Vermaas (2014) the intentional stance is further enriched by *use plans* that individuate other instruments and the way in which technical artefacts must be used to achieve the *goals* they are intended for. Other approaches add the intentional stance also at the level of production processes: technical artefacts are manufactured by *intentionally executed* processes with the *goal* of realising intended physical qualities (Houkes and Vermaas 2014) or capacities (Kitamura and Mizoguchi 2010).

By embracing an intentional stance, some classical problems of artefact theories can be addressed. For instance, natural objects and byproducts are ruled out from the range of technical artefacts because they are neither intentionally produced, nor they bear intentional properties. Also, malfunctioning can be understood as the lack of some of the capacities that artefacts of a given type are intended to exhibit. However, first, note that by becoming mind-dependent, technical artefacts acquire a weak metaphysical status.[1] Second, the relational nature of intentional properties is highly debated in philosophy (Franssen and Kroes 2014b). Third, the classification under artefact types is not only generically dependent on humans but it becomes specifically dependent on the mental states of designers, i.e., on the *private* attributions of qualities. The private dimension of intentionality conflicts with the *empirical* procedures followed in the engineering practices of product design and manufacturing (Eder and Hosnedl 2008; Romero Subirón et al. 2018). In these contexts *compliance tests* are indeed performed by acquiring information on the physical qualities of material products by relying on standardised measuring devices rather than on the psychological analysis of designers' mental states (Groover 2007, ch.40).

To tackle these issues, we discuss a proposal that avoids committing to intentional qualities and identifies different modalities to characterise artefact types. As we will

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[1] There is a hot philosophical debate on whether artefacts are part of the fundamental structure of reality or whether they are the result of how humans conceptualise reality (Lowe 2014; Thomasson 2007; Hilpinen 1993; Franseen et al. 2014a).

see, these modalities allow to make sense of the ways in which artefact types are described in engineering by means of design specifications, requirements, and make plans. Technical artefacts remain purely physical objects whose compliance with artefact types is tested by relying on specific empirical procedures associated with the characterisation modalities.

Theories of technical artefacts commonly ignore also another central aspect of engineering empirical procedures: measuring devices have limited resolutions and engineers cannot always measure all the relevant physical qualities of products. Accordingly, compliance is commonly (quantitatively or qualitatively) evaluated on the basis of imprecise and partial data (possibly corrected, completed, and mediated by experts' background knowledge). Even at the early stages of designing processes, experts may indeed specify *tolerances*, i.e., admitted deviations with respect to the intended product (Sanfilippo et al. 2018). These elements suggest to establish a parallel between *compliance* tests and *categorisation* processes: similarly to the way in which cognitive agents, on the basis of some limited perceptions, categorise objects with some degree of confidence determined on the basis of the *similarity* between the object and the *prototype* (or the *exemplars*) of a certain concept, experts, on the basis of limited measurements, evaluate the compliance of a given manufactured product in terms of its similarity with respect to the designed ideal product. Despite the different focus of interest, the framework we propose is therefore inspired by cognitive theories of categorisation. Interestingly, also in cognitive science no consensus on the nature of artefacts has been reached. It has been shown that an artefact can be categorised on the basis of different kinds of information like form, intended functions, actual capacities, use, etc., but no experimental result has confirmed any of these hypotheses, see Carrara and Mingardo (2013) and Houkes and Vermaas (2013). According to recent studies in epistemology, the clustering of artefacts into types has a contextual nature in the sense that it is the *epistemic context* that "determines which of the myriad properties of things determine kind membership and which are irrelevant in this respect" (Reydon 2014, p.132).

The paper is structured as follows. We first compare multiple theories of technical artefacts to discuss their advantages and disadvantages. In order to do this in a *uniform* way[2], since each theory relies on its own vocabulary and conceptual system, we present a formal framework that adapts the theory of *conceptual spaces* introduced by Gärdenfors (2000). The framework is used to represent types and multiple classification mechanisms in empirical scenarios (cf. Section 2) and to capture the different elements that characterise the design of a product and their interdependencies (cf. Secttion 3). With this framework at hand, we formalise and compare in Section 4 selected theories of technical artefacts ranging from purely physical theories to intentional ones. Section 5 shows how the intentional nature of designed artefacts can be captured by distinguishing different modalities of characterising artefact types and by introducing a new notion of compliance (classification) that is empirically grounded on the measurements of the physical qualities of the products. Section 6 concludes the paper.

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[2] A similar work has been done for functions (Borgo et al. 2011; Garbacz et al. 2011).

## 2 A Basic Framework to Represent Types

We present in this section a formal framework aimed at representing types in a way that is compatible with design and empirical contexts. The proposed framework extends and modifies cognitive theories of categorisation – in particular, the theory of *prototypes* presented in Smith et al. (1988) and the theory of *conceptual spaces* introduced by Gärdenfors (2000) – to account for our empirical engineering stance. The framework is formalised in first order logic (FOL), which is a formalism accessible to a relatively large public that allows to *uniformly* and *precisely* represent several traits of designed artefacts, a fundamental aspect to capture subtle differences among various theories. We adopt the following notational conventions: $(i)$ free variables are implicitly universally quantified; $(ii)$ the $\iota$ (iota) is a definite description operator *à la Russell*, i.e., $\psi(\iota x(\phi(x)))$ is a schema for $\exists x(\phi(x) \wedge \forall y(\phi(y) \rightarrow y = x) \wedge \psi(x))$; $(iii)$ predicates are noted in uppercase `typewriter` type, e.g., `PERSON`; $(iv)$ logical functions and definite descriptions are noted in lowercase **bold** normal type, e.g., **mother_of**; $(v)$ individual constants are noted in lowercase `typewriter` type, e.g., `john`; $(vi)$ the symbol $\triangleq$ introduces syntactic abbreviations (definitions).

### 2.1 Qualities and Types

Following Gärdenfors, we distinguish between *properties* (here called *qualities*) and *concepts* (here called *types*). Qualities – e.g., colours, weights, shapes, lengths, textures, and capacities – are organised into and across *domains* – e.g., colour, taste, shape – by means of *subsumption* and *correlation* relations (cf. Section 2.2).[3] Types have a multi-dimensional nature, i.e., they are intensionally characterised by qualities belonging to several domains. For instance, the Testarossa type is characterised by a given shape, by being 448cm long, 1506kg heavy, etc. We assume that designers share both the domains and their structure. This shared knowledge makes explicit the context at the basis of any engineering designing process, e.g., it includes scientific theories but also cognitive competences or know-how acquired from past experiences.

In FOL, properties are usually represented by *predicates*, individuals by *individual constants*, and classification by *predication*. However, following this approach the subtle interdependencies between the requirements and the specifications involved in the designing process would not be representable (cf. Section 3). Similarly for the distinction between *subsumption* and *correlation* (cf. Section 2.2) and for alternative (possibly non-essentialist) ways of classifying individuals under types (cf. Sections 2.4, 4 and 5).

To cope with these issues, which play a crucial role for technical artefacts, we *reify* qualities and types into the domain of quantification. For example, *being Testarossa* is represented by the individual constant `testarossa` instead of the predicate

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[3] Some qualities may have a complex nature. For instance, colours can be defined in terms of hue, brightness, and saturation. We do not consider this aspect in the paper.

$\mathtt{TESTAROSSA}$, and the fact that John's car ($\mathtt{jcar}$), at time $\mathtt{t}$, is a Testarossa is represented by $\mathtt{CF(testarossa, jcar, t)}$ instead of $\mathtt{TESTAROSSA(jcar, t)}$, where $\mathtt{CF}$ is the relation of classification (cf. Section 2.4).

Qualities are partitioned into a finite number $\eta$ of *domains* $\mathrm{D}_i$, e.g., the domains of colour, shape, and weight, see (d1) and (a1) where $\mathrm{QT}(x)$ stands for "$x$ is a *quality*". For instance, $\mathrm{D}_{\mathrm{colour}}(\mathtt{red})$ states that the quality *being red* belongs to the colour domain. Following the theory of conceptual spaces, qualities in a given domain may be attributed to individuals separately from the attribution of qualities in other domains.[4]

$$\textbf{d1}\quad \mathrm{QT}(x) \triangleq \bigvee\nolimits_{i=1}^{\eta} \mathrm{D}_i(x)$$

$$\textbf{a1}\quad \bigwedge\nolimits_{i \neq j=1}^{\eta} (\mathrm{D}_i(x) \rightarrow \neg \mathrm{D}_j(x))$$

Gärdenfors represents concepts by sets of properties in a number of domains together with $(i)$ an assignment of *salience* weights to the domains, and $(ii)$ information about the *correlations* (holding in the scope of the concept) between the qualities in the considered domains. Following this idea, our types – represented via the $\mathrm{TY}$ predicate – are disjoint from qualities even though they are *characterised* by them. The primitive relation $\mathrm{CH}(x, y, a)$ stands for "the type $x$ is characterised by the quality $y$ with salience $a$".[5]

Types have a multi-dimensional nature, i.e., they are characterised at least by two, but usually by several, qualities (a2). In addition, types' characterisation in a domain is unique (a3). For example, according to (f1),[6] $\mathtt{TESTAROSSA}$ is characterised by the qualities $\mathtt{red}$ (colour) and $\mathtt{1506kg}$ (weight), where colour is more salient than weight ($<$ is an order relation between saliences).

In Section 2.4 we consider the impact of salience on classification.

$$\textbf{a2}\quad \mathrm{TY}(x) \rightarrow \exists yzab(\mathrm{CH}(x, y, a) \wedge \mathrm{CH}(x, z, b) \wedge y \neq z)$$

$$\textbf{a3}\quad \mathrm{CH}(x, y, a) \wedge \mathrm{CH}(x, z, b) \wedge \bigvee\nolimits_{i=1}^{\eta} (\mathrm{D}_i(y) \wedge \mathrm{D}_i(z)) \rightarrow y = z \wedge a = b$$

$$\textbf{f1}\quad \mathtt{CH(testarossa, red, a)} \wedge \mathtt{CH(testarossa, 1506kg, b)} \wedge \mathtt{b} < \mathtt{a}$$

## 2.2 Subsumption and correlation

Qualities can be intensionally interlinked. Taxonomical relations are the most extensively used structural relations. We introduce an intensional *subsumption* relation between qualities: $x \sqsubseteq y$ stands for "the quality $x$ *is intensionally subsumed* by

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[4] *Correlations* can hold between qualities belonging to different domains, cf. Section 2.2.

[5] Gärdenfors assumes that in different contexts the salience of a given property or domain for a concept can change. For simplicity, we do not consider this aspect here.

[6] Formulas prefixed by **f** are used for examples or constraints that are not in our theory.

the quality $y$". Subsumption holds only for qualities in the same domain (a4). For example, `scarlet` can be subsumed by `red` but not by weight-qualities.

$$\textbf{a4}\quad x \sqsubseteq y \rightarrow \bigvee_{i=1}^{\eta} (\mathrm{D}_i(x) \wedge \mathrm{D}_i(y))$$

Intuitively, subsumption represents an abstraction or specification process: the subsumed quality is more specific than the subsuming one.[7]

Formally, $\sqsubseteq$ is a discrete and atomic partial order: it is reflexive, antisymmetric, transitive, discrete, and atomic, i.e., every quality subsumes an *atomic* quality, that is, a quality that does not *properly* subsume any other quality, see (d2) where $x \sqsubset y \triangleq x \sqsubseteq y \wedge \neg y \sqsubseteq x$ (Casati and Varzi 1999). From an epistemological perspective, atomic qualities represent the maximal resolution available for the design specification (that usually corresponds to the maximal resolution of the observational devices one disposes of for compliance-checks). For instance, when the quality `red` is atomic, more specific shades of red, e.g., magenta or scarlet, are irrelevant in the design context at stake.

$$\textbf{d2}\quad \mathrm{AT}_{\mathrm{QT}}(x) \triangleq \mathrm{QT}(x) \wedge \neg\exists y (y \sqsubset x)$$

According to Gärdenfors, quality domains can be further structured by ordering, topological or geometrical relations. For instance, weights and lengths are commonly linearly ordered, whereas colours can be organised according to the colour spindle or the RGB wheel (Gärdenfors 2000). We refrain from introducing additional structural constraints on domains, because they depend on specific application domains.

Subsumption organises quality domains acontextually. Vice versa, correlation concerns intensional dependencies between qualities (belonging to different domains) *in the scope of* a given type.[8] For instance, the way ripeness- and colour-qualities covary can be typical of specific kinds of fruits. In a design perspective, correlations may represent the know-how of experts. For instance, designers may believe that in the context of the design of solid objects, the cutting capacity requires an object to have a sharp shape and to be made of iron.

The predicate $\mathrm{CR}(x, y, z)$ stands for "in the scope of the type $z$, the quality $x$ (in a given domain) constrains the quality in a different domain to $y$", see (a5).[9] Axiom (a6) assures that both the qualities $x$ and $y$ are relevant for $z$, i.e., they are subsumed by qualities characterising $z$.

$$\textbf{a5}\quad \mathrm{CR}(x, y, z) \rightarrow \bigvee_{i \neq j=1}^{\eta} (\mathrm{D}_i(x) \wedge \mathrm{D}_j(y)) \wedge \mathrm{TY}(z)$$

$$\textbf{a6}\quad \mathrm{CR}(x, y, z) \rightarrow \exists uvab(\mathrm{CH}(z, u, a) \wedge \mathrm{CH}(z, v, b) \wedge x \sqsubseteq u \wedge y \sqsubseteq v)$$

To avoid subsumptions clashing with correlations, hence to maintain the general knowledge consistent, we assume (a7) and (a8). The former assures that, in the scope

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[7] Ontologically, subsumption can be intended as a *genus-species* relation or, more specifically, as a *determinable-determinate* relation, see Sanford (2013).

[8] Some correlations can universally hold. For instance, Einstein's mass-energy equivalence links energy and mass through the constant $c^2$, i.e., every individual with a given energy has a given mass and vice versa.

[9] We focus hereby on correlations that link only two different domains.

of a type, the correlate of a quality in a given domain is unique. The latter guarantees that the taxonomical structure is preserved through correlation. Usually, correlations that hold in the context of the type $u$ also hold in the context of all subtypes of $u$ (a9). Finally, correlation can be closed under subsumption as done in (d3).

**a7** $\mathtt{CR}(x, y, u) \wedge \mathtt{CR}(x, z, u) \wedge \bigvee_{i=1}^{\eta} (\mathrm{D}_i(y) \wedge \mathrm{D}_i(z)) \rightarrow y = z$

**a8** $\mathtt{CR}(x, y, u) \wedge \mathtt{CR}(z, w, u) \wedge y \sqsubset w \rightarrow x \sqsubset z$

**a9** $\mathtt{CR}(x, y, u) \wedge v \sqsubseteq u \rightarrow \mathtt{CR}(x, y, v)$

**d3** $\mathtt{CR}^*(x, y, u) \triangleq \exists zw(x \sqsubseteq z \wedge w \sqsubseteq y \wedge \mathtt{CR}(z, w, u))$

Note that subsumption, correlation, and characterisation correspond to different forms of implication. In FOL, by representing properties as predicates, all these relations collapse to material implication. Vice versa, our framework allows to separately manage these relations, which is an important aspect to distinguish different sorts of classification (see Section 2.4). However, by abstracting from the specific kind of implication, the general notion of subsumption between *types* can be introduced as in (d4).

**d4** $x \sqsubseteq_{\mathrm{TY}} \triangleq \mathrm{TY}(y) \wedge$
$\forall za(\mathtt{CH}(y, z, a) \rightarrow \exists u(\mathtt{CH}(x, u, a) \wedge (u \sqsubseteq z \vee \mathtt{CR}^*(u, z, y))))$

By looking at (d4), note that $\sqsubseteq_{\mathrm{TY}}$ allows a type to be subsumed by a lower-dimensional type, e.g., a type characterised in terms of colour and shape can be subsumed by a type characterised only by colour.

## 2.3 Objects and Processes

We distinguish two kinds of individuals: ($i$) *physical objects* (aka *continuants* or *endurants*) – identified by the predicate $\mathtt{OB}$; and ($ii$) *processes* (aka *events*, *occurrents* or *perdurants*) – identified by $\mathtt{PR}$. Despite our focus is on objects, processes are necessary to discuss some views on artefacts (cf. Section 4).

Both objects and processes are in time, see (a10) where $\mathtt{PRE}(x, t)$ stands for "*x is present* at time $t$". However, while objects, e.g., John or the Tour Eiffel, are wholly present at every time they exist, processes, e.g., the life of John or the battle of Waterloo, accumulate temporal parts during their existence (see Casati and Varzi (2015)). The mereological primitive $\mathtt{PART}(x, y)$ stands for "the process $x$ is part of, is a phase of, the process $y$" (see Casati and Varzi (1999) for the formalisation of parthood relations).

For our goals, time is just a set of indexes linearly ordered by the precedence relation $\preceq$. The logical functions **beg** and **end** individuate the time at which an individual comes into existence (d5) or goes out of existence (d6), respectively. To capture manufacturing oriented notions of artefacts (cf. Section 4.1), a relation of causation, hereby assumed as a backward specific existential temporal dependence, is necessary: $\mathtt{PROD}(p, x)$ stands for "the object $x$ has been produced by the process $p$".

The notion of causation is challenging to grasp and formalise (for a philosophical introduction see Mumford and Anjum 2013). We just rely on an intuitive understanding of PROD that is minimally characterised by (a11).

$$\mathbf{a}10 \quad \mathtt{OB}(x) \vee \mathtt{PR}(x) \rightarrow \exists t(\mathtt{PRE}(x,t))$$

$$\mathbf{a}11 \quad \mathtt{PROD}(p,x) \rightarrow \mathtt{PR}(p) \wedge \mathtt{OB}(x) \wedge \mathbf{end}(p) = \mathbf{beg}(x)$$

$$\mathbf{d}5 \quad \mathbf{beg}(u) \triangleq \iota t(\mathtt{PRE}(u,t) \wedge \forall t'(\mathtt{PRE}(u,t') \rightarrow t \preceq t'))$$

$$\mathbf{d}6 \quad \mathbf{end}(u) \triangleq \iota t(\mathtt{PRE}(u,t) \wedge \forall t'(\mathtt{PRE}(u,t') \rightarrow t' \preceq t))$$

## 2.4 Classification

Since qualities and types are in the domain of quantification, the standard FOL predication mechanism cannot be adopted to represent the attribution of qualities and types to individuals. We therefore introduce the new primitive relation of (*direct*) *classification* holding between *qualities* and objects or processes: $\mathtt{CF}(x,u,t)$ stands for "the quality $x$ (directly) classifies the individual *$u$ as it is at time $t$*" (a12).

$$\mathbf{a}12 \quad \mathtt{CF}(x,u,t) \rightarrow \mathtt{QT}(x) \wedge (\mathtt{OB}(u) \vee \mathtt{PR}(u)) \wedge \mathtt{PRE}(u,t)$$

Classification is temporally qualified to grasp the fact that individuals may change through time. For example, even though at time $\mathtt{t}_1$, John's car is red, i.e., $\mathtt{CF}(\mathtt{red},\mathtt{jcar},\mathtt{t}_1)$, John may paint it yellow at time $\mathtt{t}_2 \neq \mathtt{t}_1$, i.e., $\mathtt{CF}(\mathtt{yellow},\mathtt{jcar},\mathtt{t}_2)$. Some qualities of processes, e.g., the length of a match, behave in a different manner since they apply to whole processes rather than to their parts.[10] The relation $\mathtt{CF}(x,u)$ represents the situation where the quality $x$ applies to the whole process $u$.

Our framework is compatible with different perspectives on classification. Ontologically, classification may represent *instantiation*; cognitively, it may represent (human) *categorisation*; empirically, it can stand for *measurement*. As observed in the Introduction, both categorisation and measurement do not require a perfect match with the world.

First, the observational apparatuses designers dispose of have limited resolutions. For instance, it is possible to have data about the redness of John's car without any empirical evidence of the exact shade of red.

In our approach, we represent this situation by allowing individuals to be directly classified under non-atomic qualities , e.g., $\mathtt{CF}(\mathtt{red},\mathtt{jcar},\mathtt{t})$ . This is a first departure from the theory of conceptual spaces (see Masolo and Porello 2016).

Second, perceptive apparatuses and measurement devices may generate poor or noisy data because of malfunctioning, misuse, or wrong design. For instance, suppose that the weight of John's car is measured by using two scales which output different results. The inclusion of the statements $\mathtt{CF}(\mathtt{1506kg},\mathtt{jcar},\mathtt{t})$ and

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[10] We do not discuss quality domains characterising processes. The reader can refer to Masolo et al. (2003) for an ontological proposal that distinguishes the qualities of processes from the ones of objects, and to Warglien et al. (2012) and Gärdenfors (2014) for the representation of events and actions in conceptual spaces.

`CF(1507kg, jcar, t)` in a framework where cars have a unique weight and where `1506kg` and `1507kg` represent disjoint qualities produces an inconsistency.

However, in empirical contexts, discordant data are common. To avoid inconsistency and allow for classification statements like the previous ones, $(i)$ we assume that `CF` represents *raw* empirical data, i.e., it registers the outputs of observational devices without any further restriction; and $(ii)$ we rule out disjointness axioms between qualities together with axioms that allow to infer *direct* classification statements (still correlation and subsumption allow to infer *indirect* classifications under types, see (d9)).[11]

We discuss now the classification under types. In Gärdenfors (2000), the salience assigned to the domains in the definition of a concept is central for classification. Gärdenfors discusses alternative ways in which salience can impact classification, but he mainly focuses on metric approaches where salience weights shape the metric of the Cartesian product of the domains involved in the definition of a concept. Intuitively, the distance in a high-salient domain weighs more than the distance in a low-salient domain. This purely quantitative approach is difficult to be captured in FOL and is oriented towards the explanation of categorisation phenomena. Given our design perspective and FOL setting, we adopt a qualitative approach and discuss a few alternatives aimed at illustrating the general mechanism behind the notion of salience-dependent classification (under a type).

The first notion we consider discards salience information, see (d7). It captures a classical *essentialist* view on types by which all the qualities characterising a type express necessary and sufficient conditions for an individual to be classified under the type. Looking at (d7), note that all these qualities must *synchronically* apply to the individual $u$.

$$\textbf{d7}\quad \mathtt{CF}_{\mathtt{TY}}(x,u,t) \triangleq \mathtt{TY}(x) \wedge \forall ya(\mathtt{CH}(x,y,a) \rightarrow \mathtt{CF}(y,u,t))$$

The second notion represents a first step towards a salience-sensitive definition. By relying on the order relation $<$ between saliences, (d8) distinguishes *primal* (necessary) qualities, namely, the ones with salience greater than a given threshold $\bar{\mathrm{a}}$, from *optional* (peripheral) ones. Cognitively, the latter qualities may be used to quickly identify potential instances of a type whose essence is however based on primal qualities. In a design scenario, one can separate strict from soft requirements to indicate different desired qualities (Eder and Hosnedl 2008).

$$\textbf{d8}\quad \mathtt{CF}_{\mathtt{TY}}(x,u,t) \triangleq \mathtt{TY}(x) \wedge \forall ya(\mathtt{CH}(x,y,a) \wedge \bar{\mathrm{a}} < a \rightarrow \mathtt{CF}(y,u,t))$$

The third alternative goes in the direction of a non-essentialist definition by avoiding to pre-determinate a set of necessary qualities. It requires that the sum of the saliences of the qualities (considered in the definition of a type) that an object satisfies is higher than a certain threshold, i.e., classification is based on the matching features between types and objects.[12]

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[11] It is possible to take into account procedures to transform the chaotic collection of raw data into a dataset consistent with the knowledge at stake (Masolo et al. 2018).

[12] We refrain from introducing a formal definition for this notion of classification, which is possible in FOL but requires several additional primitives.

Note that in the theory of *prototypes* originally introduced by Rosch (1978), a prototype is usually intended as “a prestored representation of the usual properties associated with the concept’s instances” (Smith et al. 1988, p.487). In a design context, one can look at types as prototypes characterised by *ideal* or *intended* (rather than usual) qualities where classification (like *similarity*) is based on the matching of the qualities of manufactured objects with the ones of designed ideal products.[13]

Classification relations inspired by more elaborated definitions of similarity, e.g., the contrast rule introduced by Tversky (1977), could be adopted as well. Also, one could better account for the variability of the instances of a given type (concept). For instance, Smith et al. (1988) add *typicality* information to prototypes. In this view, although, e.g., the concept of apple allows for green, brown, and red colours, the most typical apple is red. This would be useful for capturing tolerances. For instance, a specification like $1kg \pm 20g$ makes explicit the fact that designers accept some deviations from their goal of having a product with a $1kg$ weight, but the qualities in the range $[980g, 1020g]$ are ordered by a preference relation. These extensions, which can be (partially) represented in FOL, are left for future work.

As we will see in the next sections, the decoupling between characterisation and classification allows to clearly separate the grounding of the intensional dimension of artefact types from the grounding of their extensional dimension. Intensionally, artefacts types are grounded on designing processes while extensionally they are grounded on the compliance tests performed by engineers. Different theories can be thus compared on the basis of their design and testing commitments. In Gärdenfors’s conceptual spaces these two dimensions are not explicitly separated. Classification is just membership: the point in a space that represents the object must belong to the region that represents the concept.[14] This region encapsulates a complex categorisation mechanism, since it is usually obtained by applying a tessellation procedure starting from a prototype or a set of exemplars of the concept (and the salience of the domains). In this approach characterisation is therefore ‘made extensional’ through the tessellation procedure.

Each $\mathtt{CF_{TY}}$-alternative can be closed under $\sqsubseteq_{\mathrm{TY}}$ into $\mathtt{CF}^*_{\mathrm{TY}}$, see (d9) and (t1). The difference between $\mathtt{CF_{TY}}$ and $\mathtt{CF}^*_{\mathrm{TY}}$ is *epistemologically* grounded: $\mathtt{CF}^*_{\mathrm{TY}}$ (but not $\mathtt{CF_{TY}}$) relies on knowledge concerning the taxonomical and correlation structures of the domains involved in the definition of the type. $\mathtt{CF}^*_{\mathrm{TY}}$ represents a notion of *indirect* classification that is grounded on both raw data and theoretical knowledge. For example, if $\mathtt{testarossa} \sqsubseteq_{\mathrm{TY}} \mathtt{car}$ and $\mathtt{CF}^*_{\mathrm{TY}}(\mathtt{testarossa}, u, t)$ hold, then also $\mathtt{CF}^*_{\mathrm{TY}}(\mathtt{car}, u, t)$, but not $\mathtt{CF_{TY}}(\mathtt{car}, u, t)$, holds.

We write $\mathtt{CF_{TY}}(x, u)$ and $\mathtt{CF}^*_{\mathrm{TY}}(x, u)$ when the type $x$ applies to (the whole) process $u$.

$$\textbf{d9}\quad \mathtt{CF}^*_{\mathrm{TY}}(x, u, t) \triangleq \exists y(\mathtt{CF_{TY}}(y, u, t) \wedge y \sqsubseteq_{\mathrm{TY}} x)$$

$$\textbf{t1}\quad \mathtt{CF}^*_{\mathrm{TY}}(x, u, t) \wedge x \sqsubseteq_{\mathrm{TY}} y \rightarrow \mathtt{CF}^*_{\mathrm{TY}}(y, u, t)$$

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[13] This approach matches well with the idea in Guarino and Stufano Melone (2015) where designers, during the development of a new type, think in terms of prototypes.

[14] Decock and Douven (2011) introduce a fuzzy classification in conceptual spaces.

The notion of (extensional) *inclusion* between types defined in (d10) does not consider the background knowledge in the framework. Note that $x \sqsubseteq_{\mathrm{TY}} y \rightarrow x \subseteq^{\mathrm{d}}_{\mathrm{TY}} y$ does not hold because $x \sqsubseteq_{\mathrm{TY}} y$ could use the available background knowledge (see (d3) and (d4)). By substituting $\mathtt{CF}_{\mathrm{TY}}$ with $\mathtt{CF}^{*}_{\mathrm{TY}}$ as in (d11), (t2), but not the vice versa, can be proved. Furthermore, different types may have the same extensions, that is, neither $x \subseteq^{\mathrm{d}}_{\mathrm{TY}} y \wedge y \subseteq^{\mathrm{d}}_{\mathrm{TY}} x$ nor $x \subseteq_{\mathrm{TY}} y \wedge y \subseteq_{\mathrm{TY}} x$ implies $x = y$. Empty-types, i.e., types that classify no object, are $\subseteq^{\mathrm{d}}_{\mathrm{TY}}$- and $\subseteq_{\mathrm{TY}}$-included in, but not subsumed by, all types. These remarks clarify the intensional nature of $\sqsubseteq_{\mathrm{TY}}$.

$$\mathbf{d}10 \quad x \subseteq^{\mathrm{d}}_{\mathrm{TY}} y \triangleq \mathtt{TY}(x) \wedge \mathtt{TY}(y) \wedge \forall ut(\mathtt{CF}_{\mathrm{TY}}(x,u,t) \rightarrow \mathtt{CF}_{\mathrm{TY}}(y,u,t))$$

$$\mathbf{d11} \quad x \subseteq_{\mathrm{TY}} y \triangleq \mathtt{TY}(x) \wedge \mathtt{TY}(y) \wedge \forall ut(\mathtt{CF}^{*}_{\mathrm{TY}}(x,u,t) \rightarrow \mathtt{CF}^{*}_{\mathrm{TY}}(y,u,t))$$

$$\mathbf{t}2 \quad x \sqsubseteq_{\mathrm{TY}} y \rightarrow x \subseteq_{\mathrm{TY}} y$$

Finally, *empirical classification* explicitly refers to the observational process collecting the information about the object under analysis: $\mathtt{eCF}(x,u,p)$ stands for "according to the observational process $p$, the object $u$ is classified under the quality $x$". As a simplification hypothesis, observational processes are assumed to be instantaneous, i.e., $\mathtt{eCF}$ is more informative than $\mathtt{CF}$ (a13).

$$\mathbf{a}13 \quad \mathtt{eCF}(x,u,p) \rightarrow \mathtt{CF}(x,u,\mathbf{end}(p))$$

The heterogeneous observational procedures admissible to test given (kinds of) qualities or the devices and procedures to be used in specific situations are usually part of the background knowledge of the designers (they may be independent of the artefact type under design) and can be regulated by axioms on $\mathtt{eCF}$.[15]

## 3 The Designing Process

According to Dym and Little (2005), designing concerns "the systematic, intelligent generation and evaluation of specifications for artefacts whose form and function achieve stated objectives and satisfy specified constraints." Designing activities aim to develop physical *specifications* (aka *layouts*) to match given *requirements*. A specification (as output of designing) depends on the requirement (as input of designing) that it is supposed to implement.

Requirements are (clusters of) properties that according to clients, makers or designers would be satisfied by the designed items. In the philosophical literature, Kroes (2012) and Houkes and Meijers (2006) insist on *functional* requirements, i.e., constraints on the physical capacities of products.[16] As Vaesen (2011) points out, however, this view excessively emphasises the role of functionalities. Safety, durability, recycling, marketing, and manufacturing are only few examples of requirements commonly considered. In our approach, for the sake of generality, requirements may involve the entire spectrum of qualities. Specifications are (clusters of) *physical*

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[15] Recall that neither empirical nor direct classification under a quality guarantees the object to (ontologically) *instantiate* such quality; measurement only *supports* this instantiation.

[16] Gärdenfors (2000) proposes to analyze functional properties in terms of *affordances*.

qualities that designers believe to be sufficient for the designed artefact to match pre-collected requirements. As in Thomasson (2007), the features that characterise an artefact type are *stipulatively* determined by designers (makers) possibly by relying on their background knowledge.

We represent both requirements and specifications by types. The difference resides $(i)$ in the role requirements and specifications play in the designing process (in particular, specifications depend on requirements); and $(ii)$ in the fact that specifications concern only physical qualities like shape, color, material, dimensions, structure, etc. (*how objects are*), while requirements usually consider also physical capacities (*what objects can do*). We partially capture $(i)$ by introducing the primitive relation $\mathtt{DSGN}(s, r)$ standing for "the type $s$ (the specification) has been designed to match the type $r$ (the requirement)" or "the specification $s$ is the output of a designing activity with input $r$". Regarding $(ii)$, we need to identify the qualities that can be used to characterise specifications. The exact list of these qualities (hereby called *layout* qualities) depends on the type of objects under design, on manufacturing constraints, etc. Here we just introduce the primitive $\mathtt{LQT}(x)$, such that $\mathtt{LQT}(x) \rightarrow \mathtt{QT}(x)$, standing for "$x$ is a *layout* quality".[17] The quality domains are uniform, i.e., they cannot contain both layout and non-layout qualities (a14). Axiom (a15) constrains the first argument of DSGN (the specification) to be a type characterised only by layout qualities.

**a**14 $\bigwedge_{i=1}^{\eta}(\neg\exists xy(\mathrm{D}_i(x) \wedge \mathrm{D}_i(y) \wedge \mathtt{LQT}(x) \wedge \neg\mathtt{LQT}(y)))$

**a**15 $\mathtt{DSGN}(s, r) \rightarrow \mathtt{TY}(s) \wedge \mathtt{TY}(r) \wedge \forall xa(\mathtt{CH}(s, x, a) \rightarrow \mathtt{LQT}(x))$

Some comments are due. First, DSGN considers neither the underlying designing process, nor the involved agents (designers, clients, etc.). The framework can be extended to cover these aspects.

The relation between requirements and specifications is not one-to-one, since the same requirement can be implemented by different specifications, and the same specification can implement different requirements.

However, specifications must be *coherent* with requirements, i.e., designers do not embrace any specification that, according to the background knowledge in the framework, contradicts requirements (see Kroes (2006) for more details). By (a16), if a requirement is globally characterised by a quality that implies (via correlation or subsumption) a layout quality, the latter is implied by a quality characterising the specification. One may modulate (a16) by taking into account the salience of the quality $x$ with respect to the requirement $r$. For instance, layout qualities with salience lower than a give threshold could be ignored.

**a**16 $\mathtt{DSGN}(s, r) \wedge \mathtt{CH}(r, x, a) \wedge (\mathtt{CR}^*(x, y, r) \vee x \sqsubseteq y) \wedge \mathtt{LQT}(y) \rightarrow$
$\exists zb(\mathtt{CH}(s, z, b) \wedge (\mathtt{CR}^*(z, y, s) \vee z \sqsubseteq y))$

By (a17), if a specification is characterised by a quality $x$ that (in the scope of the specification) correlates to $y$ and the requirement is characterised by $z$ within the

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[17] The distinction between layout and non-layout qualities is similar to the one between *characteristics* and *properties* in Weber (2014).

same domain of $y$, then the requirement's quality $z$ subsumes $y$. Again low-relevant qualities of the requirement may be ignored.

**a**17 $$\mathtt{DSGN}(s,r) \wedge \mathtt{CH}(s,x,a) \wedge \mathtt{CR}^*(x,y,s) \wedge \mathtt{CH}(r,z,b) \wedge \bigvee_{i=1}^{\eta} (\mathtt{D}_i(y) \wedge \mathtt{D}_i(z)) \rightarrow y \sqsubseteq z$$

Third, a design can be considered as *successful* when the resulting specification matches the requirement, so that the objects directly classified under the specification $s$ are also directly classified under the requirement $r$, i.e., $s \subseteq^d_{\mathrm{TY}} r$ holds. However, this constraint is empirically testable only by *extensively* inspecting all the produced artefacts. A weaker notion of successfulness may be introduced by relying on intensional subsumption: $s \sqsubseteq_{\mathrm{TY}} r$ assures that all the qualities of $r$ have a more specific, in terms of correlation or subsumption, correspondent quality in $s$ (without excluding the possibility for $s$ to have additional qualities that are not relevant to $r$).[18] A design for which $s \sqsubseteq_{\mathrm{TY}} r$ holds is called *certified*, i.e., according to the background knowledge, *in principle* it works. Certification may be used to evaluate the design of artefacts that are not yet physically produced. Galle (1998, 2008) discusses the situation where "[an] architect may truthfully tell his client that 'the house' he is designing complies with the fire safety regulations, even though there is not yet any house at hand to comply with anything" (Galle 1998, p.66). Suppose that the architect proposes the specification $s$ and that $r'$ represents the fire safety contraints. If $s \sqsubseteq_{\mathrm{TY}} r'$ holds, the above compliance is guaranteed by the knowledge in the framework. However, certified designs could result wrong after checking the qualities of the produced artefacts because $x \sqsubseteq_{\mathrm{TY}} y$ does not imply $x \subseteq^{\mathrm{d}}_{TY} y$, i.e., $x \sqsubseteq_{\mathrm{TY}} y$ could be proven on the basis of incorrect correlations or subsumptions. On the other hand, uncertified designs are not necessarily wrong; simply, the (partial) knowledge available in the framework is not enough to support the design choices. For the safety regulations, one would need to build the house according to the specification and to empirically check the house for $r'$.

Fourth, in layout specifications, designers may use non-atomic qualities. These specifications are compatible with a whole spectrum of qualities, namely all the qualities subsumed by the ones in the specification. For instance, if `testarossa` is characterised by `red`, both magenta and scarlet are equally acceptable colors. Similarly, for qualities that correspond to intervals of linearly ordered domain, e.g., [`1505kg`, `1507kg`] that, assuming a $1kg$ resolution, subsumes `1505kg`, `1506kg`, and `1507kg`. Design *alternatives* and *underspecifications* can be represented in this way.[19]

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[18] Axioms (a16) and (a17) do not guarantee that the specification satisfies the requirement; the framework may lack correlations about what layout qualities are necessary to exhibit some properties in the requirement.

[19] As noted in Section 2.4, the notion of tolerance is more complex. For instance, while in [`1505kg`, `1507kg`] the qualities `1505kg`, `1506kg`, and `1507kg` are equally judged, `1505kg`±`1kg` expresses a preference for the quality `1505kg`.

In an engineering context, together with the layout, one also needs to design the *manufacturing plan* (the *make plan*), i.e., the way in which the objects with the required layout must be produced.[20]

The designing process may be articulated in (at least) two steps: the implementation of the requirement into a specific physical layout, and the implementation of the layout into a make plan.[21] `DSGN` represents the first step while for the second one we rely on $\texttt{MFCT}(m, s)$ standing for "the type of processes $m$ is the make plan that implements the physical specification $s$".

As in the case of `DSGN`, `MFCT` considers neither the development of the make plan nor the involved designers. Furthermore, the same specification can be implemented by different make plans and the same make plan can implement different specifications. By introducing correlations between object- and process-qualities, the coherence axioms (a16)-(a17) may be adapted to `MFCT` and a notion of successful manufacturing design may be introduced. We do not consider these correlations hereby, which are more complex than the ones holding between object qualities, since they concern knowledge about how qualities can be achieved by constraining production processes.

## 4 The Notion of Artefact Type

By exploiting the framework introduced in Section 2 extended with the `DSGN` and `MFCT` primitives discussed in Section 3, we now provide a formal analysis of selected notions of artefact type. Section 4.1 examines some options focused on physical properties, Section 4.2 considers intentional properties, whereas Section 4.3 discusses the role of historical properties. We assume that specifications, requirements, and make plans are characterised only in terms of *physical* qualities, i.e., intentional or historical qualities are not directly considered in the characterisation of these types (see Sections 4.2 and 4.3 for more details).

### 4.1 Physical Perspectives

As we saw in the previous section, the `DSGN` primitive allows to distinguish the input of the designing process – that usually refers to functional requirements – from its output – that usually specifies the physical layout chosen by designers to implement the requirements.

By relying on this separation, different notions of artefact type can be distinguished.

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[20] For a philosophical analysis of manufacturing plans see Houkes and Vermaas (2014).

[21] Garbacz (2013) considers additional steps that would constitute an interesting extension of our proposal.

A first option is to reduce artefact types to layout specifications as in (d12) or as in (d13) for certified designs (where $\mathrm{ATP}(x)$ stands for "$x$ is an (technical) artefact type").

$$\mathbf{d}12\quad \mathrm{ATP}(x) \triangleq \exists y(\mathrm{DSGN}(x,y))$$

$$\mathbf{d}13\quad \mathrm{ATP}(x) \triangleq \exists y(\mathrm{DSGN}(x,y) \wedge x \sqsubseteq_{\mathrm{TY}} y)$$

The choice of a specific classification relation among the ones introduced in Section 2.4 may impact the extension of the artefact type $x$ that is however intensionally characterised only in terms of the designed layout qualities.

A second option is to provide a fundamental role to the required capacities, see (d14). This option is supported by some cognitive studies (Mandler 2004; Nelson 1996) according to which the nature of artefacts is grounded on their capacities, therefore the physical layout is relevant in recognizing artefacts of a given type only when it is a reliable cue for the intended capacities.

$$\mathbf{d}14\quad \mathrm{ATP}(x) \triangleq \exists y(\mathrm{DSGN}(y,x))$$

A third option, supported by some cognitive studies especially about children (Bloom 1996), consists in assuming that both layouts and capacities contribute to the classification under artefact types.[22] According to (d15) an artefact type is the *composition* of the specification and the requirement: $\mathrm{CMP}(x,y,z)$ stands for "the type $x$ is a composition of types $y$ and $z$". Without aiming at providing a theory for combining or composing types,[23] (d16) captures a formal viewpoint on composition.[24] Since a type can be globally characterised by a unique quality in a given domain, when $y$ and $z$ are characterised in terms of qualities $p$ and $q$ within the same domain, (d16) selects $(i)$ the quality with the highest salience when $p = q$, or $(ii)$ the most $\sqsubseteq$-specific one.

$$\mathbf{d}15\quad \mathrm{ATP}(x) \triangleq \exists yz(\mathrm{DSGN}(y,z) \wedge \mathrm{CMP}(x,y,z))$$

$$\begin{aligned}\mathbf{d}16\quad & \mathrm{CMP}(x,y,z) \triangleq \\ & \forall qa(\mathrm{CH}(x,q,a) \leftrightarrow (\exists bc(\mathrm{CH}(y,q,b) \wedge \mathrm{CH}(z,q,c) \wedge a{=}\mathbf{max}(b,c)) \vee \\ & \qquad (\mathrm{CH}(y,q,a) \wedge \neg\exists pb(\mathrm{CH}(z,p,b) \wedge p \sqsubset q)) \vee \\ & \qquad (\mathrm{CH}(z,q,a) \wedge \neg\exists pb(\mathrm{CH}(y,p,b) \wedge p \sqsubset q))))\end{aligned}$$

Because the same specification can implement different requirements and the same requirement can be implemented by different specifications, according to (d12) and (d14), artefact types are not univocally determined by designs, and design successfulness does not improve the situation. Definition (d15) guarantees a stricter link

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[22] Section 4.2 will make explicit the difference with respect to the dual theory of artefacts (Kroes 2012).

[23] Gärdenfors (2000, ch.4) discusses alternative models for combining concepts. See also Hampton and Winter (2017) for a recent discussion on concepts composition.

[24] We did not introduce an explicit identity criterion for types, therefore the unicity of the compound cannot be guaranteed. In addition, (d16) makes sense only when coherence axioms hold.

between artefact types and designs, even though the same artefact type could still be connected to several designs. It easy to see that no systematic subsumption relations hold among the types defined via (d12), (d14), and (d15). Furthermore, as already said, the choice of the classification relation greatly impacts the *extensions* of the artefact types (see Section 2.4). In particular, salience-sensitive classifications allow to move away from a purely essentialist conception of types and, by modulating salience weights, to emphasise or diminish the role of some characterising qualities. For instance, designers could adopt (d15) together with (d8) and assign a salience lower than the threshold $\bar{a}$ to all the requirements. In this case (d14) and (d15) could define extensionally coincident but intensionally different artefact types. However, only in the first case the requirements remain irrelevant whatever classification relation is chosen, i.e., (d14) could be seen as a more explicit model of the intention of designers to ignore requirements in the classification process.

In the modeling options discussed in this section, intentionality appears only at the level of the designing process and its input/output types. Artefact types are the product of the intentions of designers but nothing guarantees that what is classified under the types is intentionally made. For example, according to the previous definitions, natural objects with certain physical characteristics could be considered as artefacts of a given type. Sections 4.2 and 4.3 explore the possibility to capture the intentional nature of artefacts also at the individual level.

### 4.2 Intentional Perspectives

As discussed in the Introduction, some philosophical theories attribute to technical artefacts both an intentional and a physical nature, e.g., Houkes and Meijers (2006), Kroes (2012), and Baker (1995). On the one hand, technical artefacts are physical objects; on the other hand, they are functional objects, i.e., they are intentionally designed and produced to exhibit specific capacities. Consider a desk with physical characteristics like shape, weight, dimension, etc. Physical laws allow to deduce all its physical capacities, e.g., to sit on, to lay down, and to support objects but not the fact that, for instance, only the last one was intended by the desk's designers.

In the field of knowledge representation, Borgo and Vieu (2009) extend this idea to artefacts that are created but not necessarily designed. For instance, a paperweight is created when an agent intentionally selects a physical object (or an amount of matter), e.g., a pebble, attributing to it certain capacities. Borgo and Vieu embrace a multiplicativist view according to which both the paperweight and the pebble exist, and the first is *constituted* by, but is different from, the latter. The capacities of the physical substratum are inherited by the artefact, but the latter has new *intentional* qualities, namely the *attributed capacities* that depend on the intentions of the creator at the time of the creation.[25] In this view the intentional dimension *defines* the nature of individual artefacts, i.e., it founds their identity.

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[25] According to Borgo and Vieu (2009), an artefact (as intentionally selected object) might lack some of the attributed capacities, e.g., it may malfunction. This would mean that the attributed capacities are not selected (by the creator) among the ones that the artefact's constituent exhibits.

Following these views, we can introduce intentional qualities into the domain of quantification to characterise artefact types. Note that Kroes does not explicitly commit to the existence of such qualities. A way to see them is to consider the work of Chisholm (1982) on *converse intentional properties*, i.e., properties that explain the copula *is* as *is meant-to-be*, e.g., *being meant to fly*, *being meant to cut*. For every physical quality $p$ one can assume the existence of a corresponding intentional quality $q$ that represents *being meant-to-be* $p$; formally, $q \mapsto_i p$. More precisely, physical (PQT) and intentional (IQT) qualities are disjoint and $\mapsto_i$ is a one-to-one relation between them, see (a18), (a19), and (a20).

$$\textbf{a}18 \quad q \mapsto_i p \rightarrow \mathrm{IQT}(q) \wedge \mathrm{PQT}(p)$$

$$\textbf{a}19 \quad \mathrm{PQT}(p) \rightarrow \exists! q(q \mapsto_i p)$$

$$\textbf{a}20 \quad \mathrm{IQT}(q) \rightarrow \exists! p(q \mapsto_i p)$$

Given a type $y$ characterised only in terms of physical qualities, its intentional counterpart $x$ is defined as in (d17). All the definitions of artefact types taken into account in Section 4.1 can be rewritten by considering the intentional counterparts of the involved (physical) types. In principle it is possible to adopt an intentional stance also towards the specification, not only towards the requirement.

$$\begin{aligned}\textbf{d}17 \quad \mathtt{iCNP}(x, y) \triangleq\ & \mathrm{TY}(x) \wedge \forall qa(\mathtt{CH}(x, q, a) \rightarrow \mathrm{IQT}(q)) \wedge \\ & \mathrm{TY}(y) \wedge \forall qa(\mathtt{CH}(y, q, a) \rightarrow \mathrm{PQT}(q)) \wedge \\ & \forall pa(\mathtt{CH}(y, p, a) \leftrightarrow \exists q(\mathtt{CH}(x, q, a) \wedge q \mapsto_i p))\end{aligned}$$

The dual theory of technical artefacts can be represented by modifying (d15) as in (d18) according to which an artefact type is the composition of the specification and the intentional counterpart of the requirement.

$$\textbf{d}18 \quad \mathrm{ATP}(x) \triangleq \exists yzu(\mathtt{DSGN}(y, z) \wedge \mathtt{iCNP}(u, z) \wedge \mathtt{CMP}(x, y, u))$$

This definition allows to rule out natural objects and to introduce a notion of *malfunctioning* that singles out some defective aspects of the design: an artefact can malfunction because, even though it matches with the specification and it is meant-to-have all the physical capacities in the requirement, it does not have some of these capacities, indeed from $q \mapsto_i p \wedge \mathtt{CF}(q, u, t)$ it does not follow $\mathtt{CF}(p, u, t)$.[26]

The introduction of intentional properties also raises some problems. First, their ontological nature is debatable. They are *relational* properties, i.e., intentional propositions hold because somebody (e.g., a designer) intends an individual to have certain qualities. Despite the debate (Franssen and Kroes 2014b), no consensus on relational properties exists.[27]

Second, Kroes (2006) and the ICE-function theory (Houkes and Vermaas 2010)[28] consider explanatory or justification connections between functional and physical

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[26] Salience-dependent classifications allow for an additional notion of malfunctioning. The lack of some (combinations of) qualities present in the specification, lack that is tolerated by graded classifications, could cause the object to clash with some requirements. In an engineering perspective, this scenario is realistic when the full check of the specification is time or resource consuming.

[27] Gärdenfors (2014) only briefly discusses relational concepts concerning roles in events.

[28] The ICE-function theory is also based on use-plans, which are not considered here.

qualities. For instance, an object *is meant to cut* by the designers because they believe, on the basis of their expertise, past experiences, know-how, etc., that the designed layout would guarantee the physical capacity to cut. The holding of $\mathtt{CF}(p, u, t)$ when $\textsc{iqt}(p)$ is analysed as: "the designers believe that if, at $t$, $u$ has the specified layout qualities it also has the physical qualitiy which is the counterpart of the intentional quality $p$". In our framework, by understanding correlations and subsumptions as explicit representations of shared beliefs of designers, we are back to certified designs and to the notion of artefact type in (d13). In this case, $(i)$ *direct* classification under intentional qualities is ruled out since the use of the background knowledge is usually necessary; and $(ii)$ the empirical grounding of the classification under intentional qualities is provided by the empirical grounding of the classification under the layout qualities. In the case of non-certified designs, i.e., when the layout choices of the designers are not supported by past experience or knowledge (explicitly encoded in the system), one needs to access the mental states of designers, e.g., by means of psychological technics like questionnaires or the analysis of their behaviours. Reference to experts' mental attitudes is however problematic from a psychiatric and medical perspective (Levine and Fink 2006). It is also out of the scope of compliance (quality control) tests which are commonly performed in engineering contexts by physically measuring products (during and after the manufacturing process), rather than by checking them against intentional properties, see Groover (2007, ch.40) and Romero Subirón et al. (2018). In this case the empirical grounding of the (direct) classification under intentional qualities becomes problematic.

### 4.3 Manufacturing Perspectives

In the approaches analysed so far, make plans do not play any role for the definition of artefact types. To take them into account, an option is to restrict (d12) as in (d19), i.e., artefact types are layout specifications designed with certain requirements and for which a make plan exists. Similar restrictions can be done for (d14) and (d15). Even though (d19) considers the existential dependence on make plans, artefact types are still characterised only in terms of specifications and/or requirements, therefore the make plan impacts neither their intensional characterisation nor their extension.

$$\mathbf{d}19 \quad \textsc{atp}(x) \triangleq \exists yz(\mathtt{DSGN}(x, y) \wedge \mathtt{MFCT}(z, x))$$

Trivially, the qualities characterising a make plan can not be attributed to artefacts, their role is to constrain the *way* in which artefacts are produced, i.e., to specify the human or machine activities to be executed to obtain artefacts of certain types.

Following what done in the Section 4.2, one may introduce *historical* properties, namely, properties that objects have in virtue of some (causal) relationships with past processes. More specifically, we focus on properties explaining the copula *is* as *is produced by a process that bears certain characteristics*. Similarly to the case in the previous section, this move requires that for every quality $p$ of *processes* there exists a corresponding *historical* quality $q$ of *objects* representing *being produced by a p-process*; formally, $q \mapsto_h p$. By mimicking (a19) and (a20) for process ($\textsc{prqt}$) and historical ($\textsc{hqt}$) qualities, the *historical counterpart* of a make plan can be introduced as in (d20). One can consider this historical dimension in all the options discussed above. For instance, (d21) refines (d12) by characterising an artefact type in terms of both the layout qualities in the specification and the historical counterparts of the qualities in the make plan. In this way, the instances of the type must have the specified layout and must be produced by a process that complies with the make plan. This view is very close to the one of Houkes and Vermaas (2014), while Kassel (2010) and Kitamura and Mizoguchi (2010) consider the satisfaction of the requirements rather than the specification. This alternative can be easily represented by substituting $\texttt{CMP}(x, u, v)$ with $\texttt{CMP}(x, y, v)$ in (d21).

**d20** $\texttt{hCNP}(x, y) \triangleq \text{TY}(x) \wedge \forall qa(\texttt{CH}(x, q, a) \rightarrow \text{HQT}(q)) \wedge$
$\text{TY}(y) \wedge \forall qa(\texttt{CH}(y, q, a) \rightarrow \text{PRQT}(q)) \wedge$
$\forall pa(\texttt{CH}(y, p, a) \leftrightarrow \exists q(\texttt{CH}(x, q, a) \wedge q \mapsto_h p))$

**d21** $\text{ATP}(x) \triangleq \exists yzuv(\texttt{DSGN}(u, y) \wedge \texttt{MFCT}(z, u) \wedge \texttt{hCNP}(v, z) \wedge \texttt{CMP}(x, u, v))$

Similarly to the case of intentional qualities discussed in Section 4.2, the approaches discussed throughout this section address neither the ontological status of historical qualities nor their empirical grounding. Franssen and Kroes (2014b) embrace an even stronger perspective where artefacts are produced by processes which not only satisfy the make plan but are also *intended* by the designers to *realise the requirements*. Similarly, Thomasson (2007) assumes that artefacts are the products of human activities which are meant to realize some physical features. Adopting these views, one could, first, attribute intentional properties to processes, e.g., processes are meant to produce artefacts with given characteristics and, second, transfer such properties at the historical level via (d20). The drawback of this approach is the commitment to both intentional and historical properties.

These considerations call for a theory of technical artefacts that is able to take into account the intentional and historical dimensions of artefact types while avoiding ontological difficulties and being grounded on empirical engineering practices.

## 5 An Empirical Perspective

To avoid the issues concerning the relational and private nature of intentional or historical qualities, we explore in this section some options to capture the dual nature of artefacts by empirically grounding the classification under a type and therefore by committing only to physical qualities. To avoid committing to historical or intentional qualities, we differentiate between multiple 'modalities' to characterise artefact types. More precisely, we extend our framework by $(i)$ distinguishing three characterisation relations, i.e., a *physical* one ($\texttt{pCH}$), a *manufacturing* one ($\texttt{mCH}$), and an *intentional* one ($\texttt{iCH}$), and $(ii)$ by associating peculiar classification mechanisms to them.

For example, consider (d22) which states that the artefact type $x$ is physically characterised in terms of the specification $s$, it is manufacturing characterised in terms of the make plan $m$, and it is intentionally characterised in terms of the requirement $r$ (other options can be considered).[29]

$$\textbf{d22}\quad \mathtt{ATP}(x) \triangleq \exists srm(\mathtt{DSGN}(s,r) \land \mathtt{MFCT}(m,s) \land \forall qa(\mathtt{pCH}(x,q,a) \leftrightarrow \mathtt{CH}(s,q,a)) \land \forall qa(\mathtt{mCH}(x,q,a) \leftrightarrow \mathtt{CH}(m,q,a)) \land \forall qa(\mathtt{iCH}(x,q,a) \leftrightarrow \mathtt{CH}(r,q,a)))$$

According to (d22), the type $x$ is not a composition of physical, historical, and/or intentional qualities as in (d18) or (d21); it involves only physical qualities that intensionally characterise the type according to the different perspectives embraced by designers towards these qualities. Intuitively, pCH collects the physical qualities that characterise the layout of the artefact; mCH collects the physical qualities of the production process of the artefact, i.e., it characterises the way in which the artefact is produced; iCH collects the physical qualities that the artefact has been designed to exhibit. Accordingly, it is the intensional characterisation that explicitly takes into account designers' perspectives on the artefact type. In this view, artefact types are clearly separated from natural ones for which the manufacturing and intentional dimensions are not relevant. Also, it becomes fundamental to understand which empirically effective classification or testing procedures can be associated to the characterisation modalities in order to match their intuitive interpretation. For the pCH-qualities one can rely on the classification relations introduced in Section 2.4 grounded in standardised measurement procedures (or, in a cognitive perspective, in categorisation mechanisms); e.g., one can assume (f2) where $\mathtt{CF}_{\mathtt{ATP}}$ represents the new classification under a type. Manufacturing and intentional modalities require instead more complex mechanisms.

$$\textbf{f2}\quad \mathtt{CF}_{\mathtt{ATP}}(x,u,t) \rightarrow \mathtt{ATP}(x) \land \forall qa(\mathtt{pCH}(x,q,a) \rightarrow \mathtt{CF}(q,u,t))$$

Concerning the manufacturing dimension, one can check whether the artefact has been *produced* – in the sense of the relation PROD introduced in Section 2.3 – by a process which is classified – according to the standard classification relation for processes introduced in Section 2.4 – under all the physical qualities mCH-characterising the type, see (f3).

$$\textbf{f3}\quad \mathtt{CF}_{\mathtt{ATP}}(x,u,t) \rightarrow \mathtt{ATP}(x) \land \mathtt{PRE}(u,t) \land \exists p(\mathtt{PROD}(p,u) \land \forall qa(\mathtt{mCH}(x,q,a) \rightarrow \mathtt{CF}(q,p)))$$

The *empirical grounding* of the intentional dimension is more critical. Note that a position for which artefacts must have all the physical qualities (capacities) they have been designed for, e.g., as in (d13) or in (d15), would be empirically grounded but it would reduce artefacts to purely physical entities. In (d15) the distinction between

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[29] As said, designers may also assume that requirements are not all equally important, hence, they may distinguish soft requirements from hard ones (salience weights are useful for this purpose) tolerating discrepancies between the specifications and the requirements.

`pCH` and `iCH` becomes irrelevant at the classification level while (d13) maintains the difference but `iCH`-characterising qualities do not need to be empirically checked; one just relies on inference procedures starting from the `pCH`-qualities and the background knowledge in the system. Malfunctioning makes sense only in (d13) – but it would imply a ‘wrong’ background knowledge – and in both cases it is still possible for an artefact to be classified under different types; for instance, when its layout qualities physically imply a set of capacities containing the capacities considered in different requirements. This means that intensionally distinct types could *extensionally* coincide. The distinction between `pCH`- and `iCH`-qualities based on *when* they hold does not help to exit this physical view. For instance, (f4) assumes that `iCH`-qualities hold only at the end of the production process, i.e., when the artefact comes into existence. Still, a given artefact (at the beginning of its life) may have qualities satisfying several intentional characterisations even when its layout qualities and production is restricted. Interestingly, in this case one can provide a ‘dynamic’ interpretation of malfunctioning: when the artefact is produced, it exhibits all the qualities it has been designed for, but it can lose some of them during its life. This highlights the importance of the persistence conditions for artefacts (see Section 5.1 for a preliminary discussion on this topic, which is often ignored by artefacts theories).

$$\textbf{f4}\quad \mathtt{CF}_{\mathrm{ATP}}(x,u,t) \rightarrow \mathtt{ATP}(x) \wedge \mathtt{PRE}(u,t) \wedge \\ \forall qa(\mathtt{iCH}(x,q,a) \rightarrow \mathtt{CF}(q,u,\mathbf{beg}(u)))$$

To empirically ground the dual nature of artefacts, we propose to *procedurally embody* the intentional dimension of artefacts by explicitly including the empirical checks of the `iCH`-qualities into the make plan.[30] This view avoids intentional qualities but different `iCH`-dimensions would result in different make plans and, by assuming (f3), in different historical dependencies on manufacturing processes that include different *empirical checks*.[31] Differently from what stated at the end of Section 3, the make plan becomes dependent not only on the specification but also on the requirement as, e.g., in the case of (d22).

Our new relation of classification under a type $\mathtt{CF}_{\mathrm{ATP}}$ can be defined as in (d23).[32] In addition to require the satisfaction of all the `pCH`-characterising qualities, (d23) assumes that the manufacturing process is composed by (‘+’ represents the mereological sum, i.e., $p + c$ indicates the process that is completely constituted by the sub-processes $p$ and $c$) $(i)$ a ‘true’ production process $p$ causing the existence of the physical object $u$ followed by $(ii)$ a checking process $c$ composed by the testing of all

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[30] Houkes and Vermaas (2014) have a similar position towards the specification, i.e., they assume that the checks of the qualities in the specification are part of the manufacturing process. In this case, one could think that the designers intend the specification more than the requirement. See below for more details on this point.

[31] By understanding these checks as the physical embodiments of the goals of the production process, it is possible to establish a link with the previously discussed approaches in Houkes and Vermaas (2014), Kassel (2010), and Kitamura and Mizoguchi (2010).

[32] This relation can be modified following what done in Section 2.4 to take into account the salience of qualities. In this case the manufacturing process could lack some low-salient (tests of) qualities.

the $\mathtt{iCH}$-characterising qualities on $u$. According to (d22), the product $u$ *existentially* depends on the 'true' production process $p$ only, however to be classified under the type $x$ all the planned checks must be performed. Before $c$ is completed, $u$ exists but it cannot be classified under the type, i.e., there is a delay between the birth of $u$ and its classification under $x$. The introduction of the checks for the $\mathtt{iCH}$-qualities in the make plan (together with (d22)) can be seen as a step towards the idea of Franssen and Kroes (2014b), and Thomasson (2007) discussed at the end of Section 4.3 where artefacts are intentionally produced to realise the physical features corresponding to the requirements.

$$\textbf{d23}\quad \mathtt{CF}_{\mathtt{ATP}}(x,u,t) \triangleq \mathtt{ATP}(x) \wedge \forall qa(\mathtt{pCH}(x,q,a) \rightarrow \mathtt{CF}(q,u,t)) \wedge \\ \exists pc(\mathtt{PROD}(p,u) \wedge \mathbf{end}(p) = \mathbf{beg}(c) \wedge \mathbf{end}(c) \preceq t \wedge \\ \forall qa(\mathtt{mCH}(x,q,a) \rightarrow \mathtt{CF}(q,p+c)) \wedge \\ \forall qa(\mathtt{iCH}(x,q,a) \rightarrow \exists e(\mathtt{PART}(e,c) \wedge \mathtt{eCF}(q,u,e))))$$

In this view artefacts types are sort of *roles* (see Masolo et al. 2004), i.e., it is not essential for $u$ to be classified under the type. But one could also assume a different perspective where artefacts existentially depend on the whole manufacturing process (including the checking phases). According to (d24), the output of the 'true' production sub-process $p$ is an (intermediate) object $v$ different from $u$. In general, $u$ and $v$ are physically indistinguishable (assuming the checks do not have any physical impact) but they have different historical properties: $u$ is historically existentially dependent on $p+c$, i.e., the checking process $c$ is essential for $u$, while $v$ only on $p$.[33]

$$\textbf{d24}\quad \mathtt{CF}_{\mathtt{ATP}}(x,u,t) \triangleq \mathtt{ATP}(x) \wedge \forall qa(\mathtt{pCH}(x,q,a) \rightarrow \mathtt{CF}(q,u,t)) \wedge \\ \exists pcv(\mathtt{PROD}(p+c,u) \wedge \mathtt{PROD}(p,v) \wedge \mathbf{end}(p) = \mathbf{beg}(c) \wedge \\ \forall qa(\mathtt{mCH}(x,q,a) \rightarrow \mathtt{CF}(q,p+c)) \wedge \\ \forall qa(\mathtt{iCH}(x,q,a) \rightarrow \exists e(\mathtt{PART}(e,c) \wedge \mathtt{eCF}(q,v,e))))$$

Some remarks are due. First, a more satisfying way to represent the dependence of the make plan on the requirements would be to directly characterise its structure by including the checks.

Unfortunately, the representation of structural and part-of relations within the framework of conceptual spaces is problematic and is a matter of research (Fiorini Rama and Abel 2013, 2014).

Second, as in the case of (f4), malfunctioning has a dynamic connotation, i.e., according to (d23) and (d24) only the $\mathtt{pCH}$-characterising qualities are essential (modulo salience) for the artefact that could lose some of the $\mathtt{iCH}$-qualities that it has at the end of the production process (ideally assuming that all the checks are done in parallel and instantaneously). Furthermore, (d23) and (d24) avoid byproducts like scrap metal, sawdust, etc., to be classified under the artefact type because these

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[33] Note that (d24) does not constrain the persistence of $v$ and $u$. After the end of the checking phase, one could assume that $v$ goes out of existence or that both $u$ and $v$ persist by being physically coincident (but historically different).

objects do not pass the tests. `PROD` could also be strengthen by adding a selection mechanism, i.e., by assuming that the make plan specifies which production output must be considered for the checks.

Third, (d23) and (d24) can be seen as attempts to analyse the historical and intentional dimensions of artefacts in terms of the physical qualities of other entities related to the artefact in a given way. In this scenario, the classification under an artefact type is affected not only by the salience of the qualities that characterise the type but also by the *role* of these qualities in the designing process. Thus the use of the available (meta-)information concerning the way in which artefact types have been designed (represented in our framework by the characterisation modalities) allows to enrich Gärdenfors' theory of concepts.[34] Even though this approach applies only to designed types – natural types or general concepts are not covered and often lack an intentional dimension – it suggests a strategy to take into account complex categorisation processes grounded also in *relational*, not only in *intrinsic*, properties of objects.

Fourth, as said, the proposed approach is usable only when the designing process takes place. Note however that the assumed notion of design is relatively broad. For instance, consider the theory of Borgo and Vieu (2009) where artefacts may be created without being designed (and creation may consist just in the subjective attribution of intentional qualities to a pre-existent and non-artefactual object). By embracing (d23) or (d24), this purely selective process can be approximated by a $p$ process that includes only the selection (without modifying the physical object). However, the make plan contemplates also the checks of the requirements and our classification relations require these checks to be successful. To be classified under the type, the object needs to have the required capacities at least at the end of the whole manufacturing $p + c$ process. This goes against Borgo and Vieu (2009), because it prevents the possibility to have artefacts that malfunction from the beginning. Indeed, in our approach the selection process does not reduce to a purely mental activity with no physical manifestation, it is motivated by some intended qualities that however are physically tested before the classification.

## 5.1 Persistence of Artefacts Through Time

As we have previously seen, salience-sensitive classifications allow to avoid a strict essentialist stance, therefore artefacts or production processes could lack some of the qualities taken into account in the intensional characterisation of types (possibly, the qualities they lack can be different at different times). It is however worth stressing that the intensional characterisation of a type is static, it cannot change through time (the `CH` primitive is not temporally indexed). For instance, according to (d22)+(d24) (but similar arguments apply to (d22)+(d23)) the artefact must maintain its layout

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[34] This information is explicitly encoded using standardised languages in the documentation that supports the designing process and has a high degree of sharability, i.e., the choices of designers are not private as intentional qualities are, they are publicly available.

qualities while the manufacturing and the intentional dimensions do not impact its persistence, they reduce to a historical existential dependence on a manufacturing process of a given type that must include the check of the requirements at stake. Accordingly, the qualities that must hold at every time in which the artefact is classified under a type (modulo salience) and which could be relevant, e.g., to guarantee the artefact's warranty, are decoupled from the qualities that must hold when the artefact is produced and which are relevant, e.g., for (at least) quality controls.

Without the aim of an exhaustive analysis, we consider below some alternative options showing the complexity of persistence and identity criteria for artefacts even in the restricted contexts of engineering design and manufacturing. For instance, (d22)+(d25) requires artefacts to hold both the `pCH`- and the `iCH`-qualities. Differently, according to (d22)+(d26) layout qualities are just checked during the manufacturing process[35] while the artefact must hold the qualities it has been designed for.

**d25** $\mathtt{CF}_{\mathtt{ATP}}(x,u,t) \triangleq \mathtt{ATP}(x) \wedge \forall qa(\mathtt{pCH}(x,q,a) \rightarrow \mathtt{CF}(q,u,t)) \wedge$
$\forall qa(\mathtt{iCH}(x,q,a) \rightarrow \mathtt{CF}(q,u,t)) \wedge$
$\exists pcv(\mathtt{PROD}(p+c,u) \wedge \mathtt{PROD}(p,v) \wedge \mathbf{end}(p) = \mathbf{beg}(c) \wedge$
$\forall qa(\mathtt{mCH}(x,q,a) \rightarrow \mathtt{CF}(q,p+c)) \wedge$
$\forall qa(\mathtt{iCH}(x,q,a) \rightarrow \exists e(\mathtt{PART}(e,c) \wedge \mathtt{eCF}(q,v,e))))$

**d26** $\mathtt{CF}_{\mathtt{ATP}}(x,u,t) \triangleq \mathtt{ATP}(x) \wedge \forall qa(\mathtt{iCH}(x,q,a) \rightarrow \mathtt{CF}(q,u,t)) \wedge$
$\exists pcv(\mathtt{PROD}(p+c,u) \wedge \mathtt{PROD}(p,v) \wedge \mathbf{end}(p) = \mathbf{beg}(c) \wedge$
$\forall qa(\mathtt{mCH}(x,q,a) \rightarrow \mathtt{CF}(q,p+c)) \wedge$
$\forall qa(\mathtt{pCH}(x,q,a) \rightarrow \exists e(\mathtt{PART}(e,c) \wedge \mathtt{eCF}(q,v,e))))$

As already observed, (d24) allows for a 'dynamic' interpretation of malfunctioning while (d25) and (d26) assume the qualities in the requirements to be (modulo-salience) essential.

A more radical position should assume that both the intentional and the physical dimensions impact only the manufacturing process via the checks. According to (d27), the essential properties of artefacts that are produced in compliance with the make plan have only a historical nature. Note however that $\mathtt{PRE}(u,t)$ must hold, i.e., one relies on persistence conditions established for objects in general to track the artefact through time.

**d27** $\mathtt{CF}_{\mathtt{ATP}}(x,u,t) \triangleq \mathtt{ATP}(x) \wedge \mathtt{PRE}(u,t) \wedge$
$\exists pcv(\mathtt{PROD}(p+c,u) \wedge \mathtt{PROD}(p,v) \wedge \mathbf{end}(p) = \mathbf{beg}(c) \wedge$
$\forall qa(\mathtt{mCH}(x,q,a) \rightarrow \mathtt{CF}(q,p+c)) \wedge$
$\forall qa(\mathtt{pCH}(x,q,a) \rightarrow \exists e(\mathtt{PART}(e,c) \wedge \mathtt{eCF}(q,v,e))) \wedge$
$\forall qa(\mathtt{iCH}(x,q,a) \rightarrow \exists e(\mathtt{PART}(e,c) \wedge \mathtt{eCF}(q,v,e))))$

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[35] According to Houkes and Vermaas (2014), the layout qualities must be satisfied only at the end of the production process, but the artefacts may loose some physical qualities while keeping their identity.

These examples can be also seen as a first step towards the explicit representation of possible *principles of activity* for designed artefacts, i.e., law-like rules that establish when and how artefacts of a given type start to exist, exist, and cease to exist (see Carrara and Vermaas (2009) and Vaccari (2013) for more details on the role of principles of activity for characterising artefacts and functionalities). The introduction of different characterisation modalities are hereby exploited to define different views where principles of activity are characterised by taking into account physical, functional, and manufacturing qualities. It is important to note that, differently from what stated in Carrara and Vermaas (2009), such mixed characterisations are not just conjunctions of functional qualities with other artefacts' features; instead, they have a complex logical form – as made precise in (d22) together with (d23)-(d27) – reflecting the peculiar roles that these qualities have in determining how and when artefacts start to exist and persist through time.

## 6 Conclusions

We presented across the paper a formal framework by which a selected set of theories of technical artefacts has been represented and compared. The purpose is to provide a homogeneous way to express multiple viewpoints to better understand their similarities and differences in a formal setting. Similar works have been already proposed in the literature (Garbacz 2013). The novelty of our study relies on at least two orthogonal dimensions.

First, the framework builds on cognitive science studies about the categorisation of objects under concepts. This move allows to disentangle the multi-dimensional and intensional nature of artefact types from the way in which their extension is determined. This latter aspect is particularly relevant from an engineering perspective, where different compliance tests may be considered for the same (or similar) designed type(s), and where individual artefacts do not commonly exist at the design time. A cognitive perspective on artefact types proved also useful to manage compliance tests in presence of partial information about products and to model engineering common requirements such as the representation of design alternatives or underspecifications and the difference between soft and hard requirements.

Second, by identifying the pros and cons of each artefact theory, we proposed to conceptualize technical artefacts on the basis of engineering modeling principles escaping the common criticisms that artefact theories have to face. In particular, we saw that intentional theories avoid problems which physical theories suffer from. They introduce however the challenges of characterising the ontological nature of intentional properties and empirically testing such qualities at the level of individual artefacts.

These issues motivated the empirical approach proposed in Section 5 where intentional and historical qualities are avoided by introducing

different characterisation modalities to which specific empirical procedures for compliance tests are associated. The classification of artefacts under types can be thus inter-subjectively assessed via checking procedures by means of standardised techniques and measurement devices. In this way artefacts bear the qualities that have been explicitly specified at the design level and the possession of these qualities is verified following engineering modeling practices.

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