JOURNAL OF ENGINEERING DESIGN
2018, VOL. 29, NO. 10, 596–615
https://doi.org/10.1080/09544828.2018.1520204

Design for invention: a framework for identifying emerging design–prior art conflict

Pingfei Jiang [a,b], Mark Atherton[a,b], Salvatore Sorce[a,b], David Harrison[a,b] and Alessio Malizia[c,d]

[a]Institute of Materials and Manufacturing, Brunel University London, Uxbridge, UK; [b]College of Engineering, Design and Physical Sciences, Brunel University London, Uxbridge, UK; [c]School of Creative Arts, University of Hertfordshire, Hatfield, UK; [d]Faculty of Logistics, Molde University College, Molde, Norway

ABSTRACT
The increasing complexity of patented mechanical designs means that their novelty and inventive steps increasingly rely on interacting geometric features and how they contribute to device functions. These features and interactions are normally incorporated in patents through clear patent claims. However, patents can be difficult to interpret and understand for designers due to their legal terminologies. This suggests there is a need for greater awareness of relevant prior art amongst designers in terms of avoiding potential conflict. This paper presents a framework that helps designers obtain insight on relevant prior art and enables emerging design–prior art comparison. The framework mainly contains development of a patent graphical functional representation, a domain-specific ontology and a semantic database. The graphical representation presenting the functional reasoning of patents in terms of interacting geometric features. A domain-specific ontology enables knowledge sharing and conceptualisation, providing a standardised vocabulary for describing patented designs. By formulating patent data into a semantic database, commonality of working principles between an emerging design and prior art can be identified. This enables early identification of potential conflict and thereby could help designers steer their emerging designs away from protected solutions. A computer tool being developed based on this approach is also described.

ARTICLE HISTORY
Received 4 November 2016
Accepted 3 September 2018

KEYWORDS
Functional representation; ontologies; functional analysis diagram; functional geometry interaction; design for invention

1. Introduction

Mechanical designs are carried out to achieve desired outputs with known inputs. This specifies the overall function of a mechanical device being designed. Otto and Wood (2001) defined function as 'statement of a clear, reproducible relationship between the available input and the desired output of a product, independent of any particular form.' Various sub-functions, herein referred to as functions, can then be specified that contribute to the overall function. In mechanical engineering, functions are mainly realised by combinations of interrelationships between physical effects, geometric and material characteristics,

CONTACT Pingfei Jiang pingfei.jiang@brunel.ac.uk

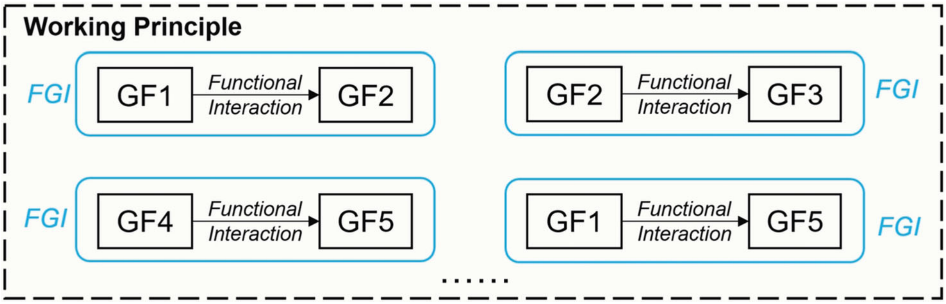

Figure 1. Functional Geometry Interaction (FGI).

known as the *working principles* (Pahl and Beitz 2006). In some mechanical designs geometric details play an important role in achieving device working principles, for example, corkscrews and beverage cans rely heavily on key geometric details for their intended function (Atherton et al. 2017). In this case, physical effects and material characteristics described can be considered as attributes of geometric features decided by the designer.

The geometric feature has been defined in the international standard for geometrical product specification (ISO 5459:2011 2011) in which it refers to lines, points or surfaces. More recently, geometric features are defined as entities that satisfy certain requirements (Sanfilippo and Borgo 2016). However, describing geometric features in terms of points and surfaces are not sufficient for understanding working principles. In this paper, the term is used in its broadest sense to describe higher level product elements that carry functional significance intended by the designer. It can be used for a product component part when appropriate, such as plates, rivets and their detail geometry such as holes, shoulders and surfaces.

Therefore, we can say that working principles of a mechanical design are achieved through functional interrelationships, or interactions, between geometric features that embody physical effects and material characteristics. Combinations of working principles contribute to the fulfilment of device functions. In this paper, we use the term *Functional Geometry Interaction* (FGI) to represent interacting geometric features (embodying physical effects and material characteristics) that carry a functional significance in a working principle. For example, in Figure 1 Geometric feature 1 (GF1) interacting with Geometric feature 2 (GF2) with a functional purpose and several FGI combined to produce device working principles.

Sometimes novel solutions to mechanical design problems carried out by designers are documented and protected by filing patents. 'Novelty' and 'Inventive step' are two essential criteria for a patent to be granted. Novelty can be understood as whether the design is new to a field of application. The inventive step can be seen as whether the design has an adequate distance from the current known state of the technology. Novelty and Inventive step are subjective legal judgements which are best made by professionals.

The primary aim of the paper is to demonstrate a framework incorporating patent graphical functional representations and a domain-specific ontology, which enables designers to identify emerging design–prior art conflict during their design process rather than afterwards. It is NOT intended to describe a legal method but rather a design approach to assist designers to understand prior art and compare it with their emerging design. They will then be able to, tacitly, avoid potential conflict and promote innovation. The framework fits into a greater research context in which it will be further developed into a computer assistant tool. Section 2 provides the research background explaining why patent infringement is a legal definition and how it is addressed in this paper. Functional modelling and ontology engineering background are also introduced in this section. Section 3 provides an overview of the framework followed by its development in detail. Applications of the framework to emerging design–prior art comparison are shown in Section 4. Research outcomes and the computer assistant tool being developed are discussed in Section 5 and the paper is concluded in Section 6.

2. Background

In order to survive in today's competitive environment companies strive to develop novel and innovative products which bring better performance and user experience. These inventions need to be protected and filing patents also contribute to a company's intangible assets. Furthermore, companies secure patents as a strategy to maintain their competiveness and future development (Soo et al. 2006). A granted patent prevents others from using the invention without the holder's permission.

> Patent applications have increased by 9% worldwide year-on-year for the past two years – according to the UK Intellectual Property Office – therefore increasing the likelihood that designers will unwittingly infringe on existing patents, also known as patented prior art. (McLaughlin 2017)

In order to prevent unnecessary avoidable litigation and ensure successful launch of a product, designers need to be assured that their new design is original and inventive whilst it is still developing or emerging through the design process. This emerging design must not infringe any prior art, which indicates a great need for designers to understand relevant patents, especially in their domain of expertise. However, patent documents are unique, technical and legal at the same time (Chen 2009). They are difficult and time-consuming for non-specialists to analyse due to their enormous and rich technical and legal terminology (Kim, Suh, and Park 2008). The most important and challenging part of a patent document for designers is its claims, which define what the invention is, plus the scope of protection and boundaries of the invention (Koster 2015). Patent claims can be classified into independent claims and dependent claims. Independent claims are self-contained, describing the invention in its broadest scope. Dependent claims refer to further detail of features described in the independent or dependent claims they are referring to. A patent claim section always starts with a main independent claim and may be followed by multiple dependent claims. Patent claims can be infringed in two ways: literal infringement and under 'doctrine of equivalents'. EPO (2016) defines literal infringement as infringing any one of the patent claims, which can be understood as elements of a single claim matching with elements of the accused design. Infringement under 'doctrine of equivalents' is determined when a product has insubstantial difference with the prior art and performs substantially in the same way. In other words, the product and prior art have similar working principles. Sometimes the claims do not necessarily mean exactly what they say (Brown & Michaels 2015), therefore interpretation of a patent is not an easy task even for experienced professionals who are normally patent attorneys. Apparently, patent infringement is a legal judgement that should be determined by the courts of law not the designers. Therefore in this study, we envisage that patent infringement can be tactically avoided by helping designers to understand prior art and identify common working principles between their emerging design and prior art. This might encourage them to create novel working principles that fundamentally differ from patented inventions. Ulrich and Eppinger (2016) have already suggested benefits of studying prior art: The designer can learn whether an invention infringes existing unexpired patents. The designer can also obtain insight on the similarity between their invention and prior art hence gain a sense of the likelihood of the invention patentability.

The patent analysis provides an effective way to study and understand prior art. Valuable information such as business trends, technological details and market opportunities, can be obtained by analysing patent documents (Chen 2009; Li et al. 2012). Research conducted by Cascini and Zini (2008) used function trees to represent components of an invention in order to measure patent similarities. Other examples include research conducted by Abbas, Zhang, and Khan (2014) on reviewing contemporary patent analysis techniques, Chen (2009) and Kim, Suh, and Park (2008) on investigating patent analysis visualisation, Li, Atherton, and Harrison (2014) on patent claim mapping in identifying patent claim conflicts. The majority of research on patents serves professionals who work closely with patents such as patent analysts, Research and Development specialists, suggesting that research in assisting designers to understand patents and identify emerging design–prior art conflict has been overlooked.

Designers are able to determine specific Research and Development directions by conducting a functional analysis of patents in the technical field of concern (Kang et al. 2015). Comparison of working principles between an emerging design and prior art can also be achieved through in-depth functional analysis (Jiang et al. 2017). Functional analysis and modelling is an engineering design tool to provide a systematic approach to technical problem solving (Pahl and Beitz 2006). It enables designers to study and develop products through analysing functional relationships between components, and also decompose, describe and relate functions a system is to perform in order to achieve end product success (Morris and Breidenthal 2011). Functional analysis and modelling exists in various formats and one way of classifying them is into form-independent and form-dependent models (Aurisicchio, Bracewell, and Armstrong 2013). Product Architecture Design Methodology (Stone, Wood, and Crawford 2000) is a typical form-independent model that starts with a black box defining the system overall function and input/output flows of energy, material and signal. An example of form-dependent functional models is the Functional Analysis Diagram (FAD) (Aurisicchio, Bracewell, and Armstrong 2012), which uses blocks to represent artefacts and coloured labelled arrows to represent useful and harmful functional interactions respectively.

Form-independent functional modelling methods, that typically represent designs in an abstract form connected by chains of functions and flows, pose challenges to designers in terms of their natural way of working. Whereas form-dependent methods, capable of representing precise and complete functional interrelationships between physical components, superimpose function structure onto physical structure, more naturally reflect the designers' rationale (Aurisicchio, Bracewell, and Armstrong 2012, 2013). For mechanical designs with interacting geometric features that are essential to device working principles, FAD appears to be appropriate for study due to its emphasis on functional interactions and the intuitive understanding enabled by graphical representation. However, the capability of FAD for representing detailed geometric features is unclear. Examples found in the literature (Aurisicchio, Bracewell, and Armstrong 2012; Lee et al. 2013; Michalakoudis et al. 2014) are limited to the component level where in this current study novel working principles are likely to be hidden in detailed geometric features. The FAD was first intended to be applied in process system design to capture functional relationships between subsystems, which explains why detail geometric features are overlooked. Therefore we have developed a FAD to enhance its capability in patent functional reasoning as described in Section 3.4.

As patents use ambiguous legal terms, converting them into standardised languages may help designers understand them more easily. Similarly, designs carried out by different people and organisations tend to use company or personal terms they feel comfortable with. However, there are circumstances where different terms are in fact referring to a similar design. For example, 'aperture' and 'hole' can describe the same type of opening that behaves identically and this could result in conflict of Intellectual Property (IP) regardless of the different names used. Similarly, 'separate' and 'disjoin' in different designs can, in principle, mean the same. Lechevalier, Gerbaud, and Bigeon (1998) also highlighted the difficulty of defining functions within a complex system, which often contains aspects of knowledge from diverse disciplines. Therefore, there is a need for a common standardised vocabulary for describing patents and designs in order to perform effective analysis and comparison. Ontology is broadly applied in developing the semantic web which can be seen as a web of data for people to create vocabularies and data sharing (W3C 2015). It is a fundamental conceptualisation of domains describing both abstract and concrete meanings (Kotis and Vouros 2006), and can also be seen as a repository of interlinked concepts from specific domains (Nicola and Missikoff 2016). In engineering, design ontology can be employed to enable knowledge sharing and development of standard design language (Ahmed, Kim, and Wallace 2007). As a shared knowledge base, ontologies can be developed around a specific application or product, normally called domain-specific ontology. In this paper, a domain-specific ontology is developed and employed into the framework to enable data conceptualisation and sharing.

In the next section, a new framework is presented that aims to help designers increase their IP awareness and identify emerging design–prior art conflict. Examples adopted in this study have been focused on beverage can patents because in such designs detailed geometric features are essential in accomplishing working principles and therefore we consider this as a suitable field for developing the framework. With a slight modification of patent data extraction and ontology methodology, the framework is expected to be applicable to a broad range of mechanical designs.

3. Framework for identifying emerging design–prior art conflict

3.1. Overview

An overview of the framework is presented in Figure 2. Patent independent claims will be the main source of knowledge extraction. Patent working principles extracted combined with the domain-specific ontology form a semantic database. The database enables designers to send queries containing emerging design novel working principles using FGI. Patents and common working principles identified can assist designers to develop

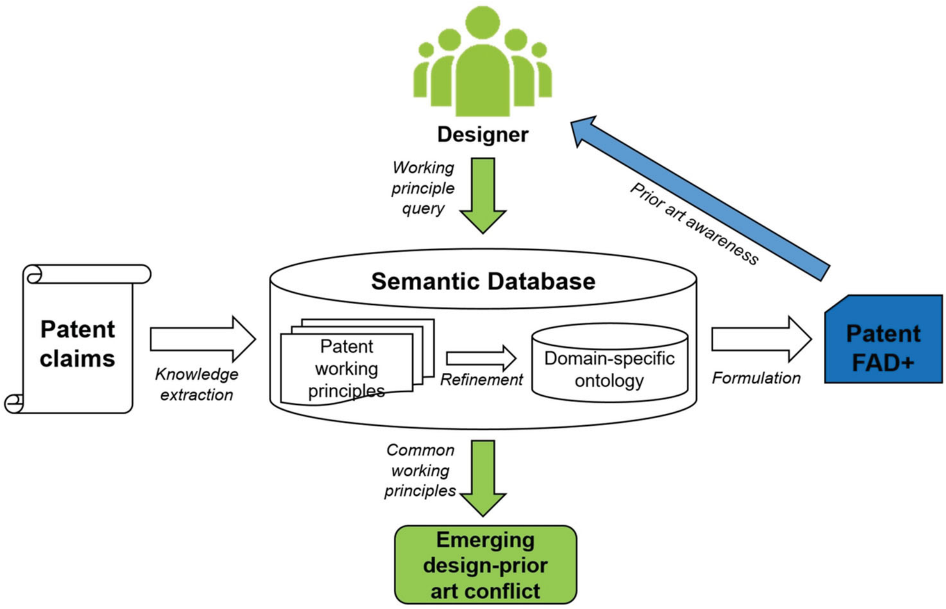

Figure 2. Framework for identifying emerging design–prior art conflict.

different solutions and ultimately develop innovative working principles in their emerging design.

Patent working principles represented by FGI can also be formulated and represented using graphical means, which is termed Functional Analysis Diagram Plus, or FAD+. It incorporates functional interactions represented by standardised ontological terms to provide common understanding. A patent FAD+ aims to provide intuitive understanding of an invention and hence increase the designer's qualitative prior art awareness.

Steps of the framework proposed can be summarised as follows:

(1) A patent is selected from the domain of interest by conventional search.
(2) Patent working principles in the form of feature relations and FGI are determined from the patent independent claims.
(3) A domain-specific ontology is developed from the initial patents processed in steps 1 and 2.
(4) Patent working principles and the domain-specific ontology are saved to the semantic database of patents.
(5) FAD+ diagrams are created describing patent working principles.
(6) Emerging design–prior art conflict is assessed by querying the semantic database of patents.

This framework shows how patent knowledge extraction, domain-specific ontology development, FAD+ and the semantic database established are to be used in order to compare an emerging design with the prior art. These activities are explained in Section 3.2 to 3.5 by using an example patent.

3.2. Patent knowledge extraction

A resealable can end assembly patent EP 2219961 (Ramsey and Althopre 2013) is used to demonstrate the knowledge extraction method. A cross-sectional view of the invention is shown in Figure 3. Feature ownership and FGI information are gathered from the patent independent claim shown in Figure 4. Words and phrases that describe the design are categorised into feature ownership, geometric features and functional interactions. For example, nouns describing invention features are classified as geometric features and verbs describing relationships between invention features are classified as functional interactions. Geometric features identified in the independent claim are highlighted using an underline, **feature ownership** information is highlighted in bold and ***functional interactions*** are highlighted in bold italic. Outcome of the knowledge extraction is presented in Table 1 and Table 2. At this point in time, patent information is gathered and processed manually. We are aware of text-mining and Natural Language Processing (NLP) tools available which we envisage can boost information extraction and processing. However, in this paper we focus on exploring the value of insight delivered by graphical representation and emerging design–prior art conflict analysis to help designers understand mechanical inventions, therefore how the data was collected is not our primary focus here.

Patent working principles have now been extracted from the patent independent claim and represented in the form of invention breakdown (Table 1) and 14 FGI (Table 2). This knowledge is documented in a spreadsheet first for evaluation and formulation. In the next section, a domain-specific ontology used to standardise patent working principles is developed.

3.3. Domain-specific ontology development

Development of a domain-specific ontology can follow typical ontology engineering methodologies such as Human-centred ontology engineering proposed by Kotis and Vouros (2006), and Engineering design integrated taxonomy introduced by Ahmed, Kim, and Wallace (2007). However, they are domain expert-driven and time-consuming to

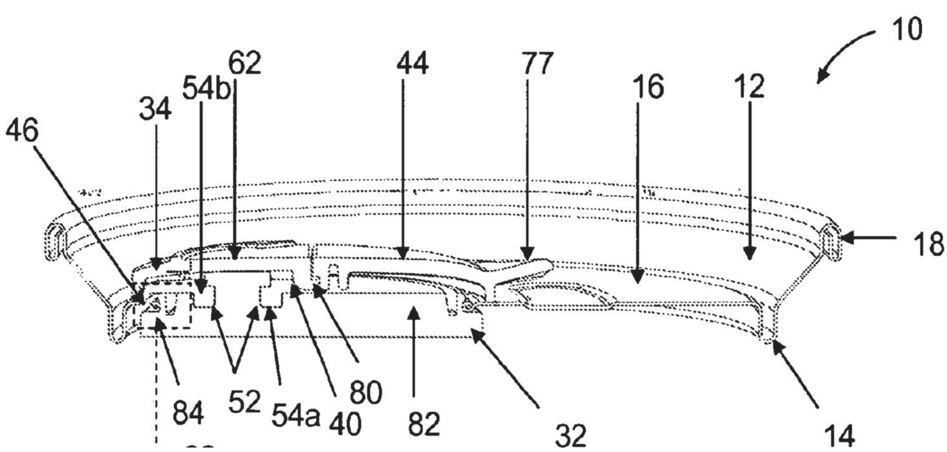

Figure 3. Cross-section view of can end patent EP 2219961.

A can end combination **comprising** a metal can end (10) and resealable closure (30) ***coupled to*** the can end, the can end (10) **comprising** a peripheral wall (12) and a center panel (16), the center panel (16) **including** an upper surface, an opposing lower surface, and an aperture (20) ***formed therethrough;*** the closure (30) **comprising** a base plate (32) and a top plate (34) ***coupled to*** the base plate at a first location, the closure (30) having (i) a sealed position in which at least one of the base plate (32) and top plate (34) ***contact*** the center panel (16) about the aperture (20) to ***form*** a seal, (ii) an intermediate position in which the closure (30) is ***proximate*** the aperture (20) but not sealed, and (iii) a fully open position in which the aperture (20) is ***exposed*** to enable pouring liquid through the aperture (20); the base plate (32) being ***downwardly moveable relative to*** the top plate (34) when moved from the sealed position to the intermediate position; the base plate (32) and top plate (34) being: (i) ***translatable together*** relative to the can end (10) from the intermediate position to the fully open position and (ii) ***translatable together*** relative to the can end (10) from the fully open position to the intermediate position; the base plate (32) being upwardly ***moveable*** into ***engagement with*** the center panel (16) from the intermediate position into a resealed position ***forming*** at least one of a bore seal and a flange seal.

Figure 4. Independent claim for patent EP 2219961 with **Feature ownership**, geometric feature and ***functional interaction*** information highlighted.

Table 1. Feature ownership knowledge in patent EP 2219961.

Geometric features	Feature Ownership indicator	Geometric features
Can end combination	comprising	Metal can end
Can end combination	comprising	Resealable closure
Metal can end	comprising	Peripheral wall
Metal can end	comprising	Center panel
Center panel	including	Upper surface
Center panel	including	Lower surface
Center panel	including	Aperture
Resealable closure	comprising	Base plate
Resealable closure	comprising	Top plate

develop making them too complex for the scope of this study. Therefore UPON Lite (De Nicola and Missikoff 2016), a rapid ontology engineering approach was adopted in the study. This approach provides six steps: *Lexicon*, *Glossary*, *Taxonomy*, *Predication*, *Parthood* and *Ontology*. The three steps (*Taxonomy*, *Predication*, and *Parthood*) can be performed in parallel and any two steps can be skipped depending on research interests. As a consequence, UPON Lite provides a rapid process for developing a domain-specific ontology, suitable for our application requiring a minimum of four of the above six possible steps. In this study, a common vocabulary is desired for systematically describing mechanical inventions hence *Taxonomy* is a suitable step. This is because in *Taxonomy*, ontology entities are hierarchically organised using isTypeOf relationships that provide references for linking a specific concept to a general one, such that semantic conceptualisation can be easily achieved. A major benefit of employing UPON Lite is that it enables real time and effective contribution from domain experts in developing the ontology and minimises the need for ontology engineers. This means that data documented in each step can be validated by

Table 2. Patent working principle represented by FGI in patent EP 2219961.

FGI	Geometric features	Functional interactions	Geometric features
FGI#1	Resealable closure	coupled to	Metal can end
FGI#2	Aperture	formed there-through	Center panel
FGI#3	Top plate	coupled to	Base plate
FGI#4	Base plate	contact	Center panel
FGI#5	Top plate	contact	Center panel
FGI#6	Resealable closure	proximate	Aperture
FGI#7	Resealable closure	expose	Aperture
FGI#8	Base plate	downwardly moveable relative to	Top plate
FGI#9	Base plate	translatable together	Top plate
FGI#10	Base plate	engage with	Center panel
FGI#11	Base plate	form	Flange seal
FGI#12	Center panel	form	Flange seal
FGI#13	Base plate	form	Bore seal
FGI#14	Center panel	form	Bore seal

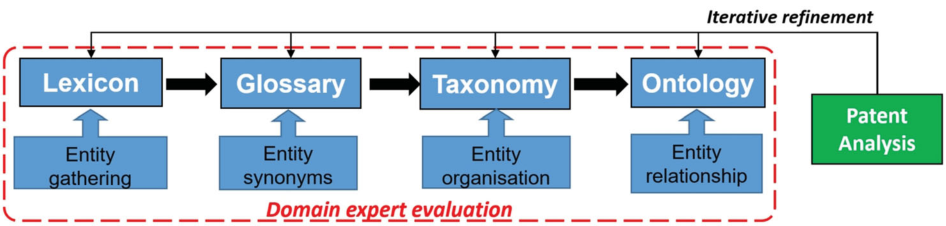

Figure 5. UPON Lite ontology engineering approach employed in this study.

Table 3. Part of beverage can design *Lexicon* sheet.

patent	FGI	function	product
action	object	assemble	shoulder
aperture	connect	finger	cover
transform	provide	expose	support
hinge	locate at	extend	align
cam surface	edge	score line	shaft

domain experts in parallel with completion of the next step. A configured domain-specific ontology can then be validated and improved through case studies. The UPON Lite-based ontology engineering approach employed in this study is outlined in Figure 5. Initially, data were structured in spreadsheets and shared with our industrial collaborator via a secure cloud service for the convenience of expert validation. Approved ontology data was then configured formularised into an ontology software for computerisation.

For this study, an ontology specific to beverage can designs was developed. Reconciled Functional Basis for design (RFB) (Hirtz et al. 2002) was employed as an information source and then developed to describe patent working principles. RFB is a common design language that aims to describe function in simple verb-object couplets. It has gone through rigorous validation that has contributed to its proven value in engineering design (Ahmed and Wallace 2003), and the ability to represent functions in specific domains. Geometric feature entities that relate to beverage can designs were collected mainly from patents provided by conventional keyword search and commonly seen 3D CAD modelling features. Part of *Lexicon*, *Glossary* and *Taxonomy* developed in this study are in shown in Tables 3–5.

Table 4. Part of beverage can design *Glossary* sheet.

Entity	Synonyms	Description
patent	prior art	Inventions that were filed and protected by a legal document
FGI	Functional Geometry Interaction	A pair of interacting geometric features
function	functional requirement	Device functions expressed in verb-object couplet
action	functional interaction	Developed from Function set of RFB, describing verb of device functions and functional interrelationships between geometric features
object		Developed from Flow set of RFB, describing the target objects of device functions
aperture	hole	Open space created, normally used for content dispensing or engaging another design feature
connect	link associate	Put two features together in a broad sense
assemble	join couple	Put two features together, normally by mechanical methods
cover	shield	Place a feature on top of another, normally function as a closure or protection
shaft	rod	A pole that can transmit mechanical energy or insert into other features
shoulder	skirt flange	Edges of features that extend outward that can engage other features

Table 5. Part of beverage can design *Taxonomy* sheet.

Top concept	1st level	2nd level
patent		
product		
function		
FGI		
geometric feature	component	rivet
		tab
		can end
		can body
	design feature	opening
		channel
		score line
		edge
		seam
		wall
		surface
action	branch	separate
		break
		eject
		dispense
		remove
		distribute
	channel	guide
		transport
object	material	liquid
		solid
	mechanical energy	speed
		acceleration
		force

The scope of initial data in Tables 3–5 was subsequently expanded to incorporate more expressions from patents that describe geometric features and functional interactions. A total number of 22 new entities gathered from 15 patents were added to the original ontology. In the *Ontology* stage, the relationships between entities established in previous stages

Table 6. Part of beverage can design *Ontology* sheet.

Entity	Relationship	Entity
patent	hasProduct	product
product	hasFunction	function
function	hasAction	action
function	hasObject	object
product	hasFGI	FGI
FGI	has1stFeature	geometric feature
FGI	has2ndFeature	geometric feature
FGI	hasFI	action

were defined, and recorded in spreadsheet format for expert validation. Part of the *Ontology* spreadsheet is shown in Table 6. Having established a domain-specific ontology above a standardised vocabulary for a patent FAD+ can then be developed.

3.4. Semantic database formation

A triple-store approach was used, which is a widely adopted purpose-built database for the storage and retrieval of triples through semantic queries (Rusher 2003). The basic form of a triple is Subject-Predicate-Object, which can be suitably used to describe GF1, FI and GF2 (see Figure 1) respectively. In the framework, one FGI (GF1-FI-GF2) corresponds to one triple. Resource Description Framework (RDF) was adopted to provide a standard model for data interchange. Patent working principles were encoded into RDF format, along with all the semantic relations defined in the domain-specific ontology.

In order to have the inventions and semantic data correctly encoded in the RDF format, we started from their spreadsheet representation. The static nature of such data structure was then suitably exploited to feed a specifically built application (app), developed in Visual Studio .NET and running on Windows OS (see Figure 6). This app scans spreadsheet sheets, rows and cells, and then composes the corresponding triples, according to the domain-specific ontology structure. Three types of output were generated from the app: Firstly, a JavaScript Object Notation (JSON) format of patent working principles, offering a human-readable representation of patent knowledge for easy evaluation. Secondly, an RDF format of patent working principles represented by sequences of triples. The RDF file was then used to populate an RDF database. Finally, a supplementary semantic RDF file derived from the domain-specific ontology to enable flexible queries. For example, the design is able to use synonyms to retrieve desired outputs. This was termed 'fuzziness' in our study.

The generated RDF files were then uploaded to an Eclipse RDF4J server (RDF4J n.d.). RDF4J is an open-source framework, formerly known as Sesame, for querying and analysing RDF data. In our case, we deployed it over an instance of an Apache-Tomcat web server. The RDF4J server can then be accessed both from a web interface (browser-based access) and from a URI (Uniform Resource Identifier – for programmatic access), both for querying and managing. The server accepts queries in different languages, and in our study SPARQL Protocol and RDF Query Language was used due to its broad application and popularity. SPARQL enables the designer to describe the working principles of an emerging design in the form of one or multiple queries such that possible matches from the database can be retrieved. For instance, in these queries the designer can specify emerging design geometric features, FGI or multiple FGI. By doing this the designer is able to obtain information of

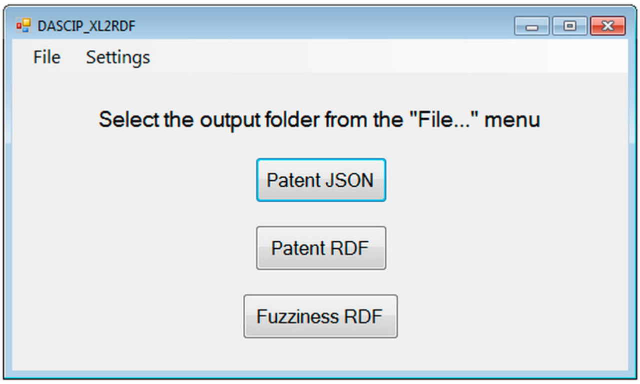

Figure 6. Windows app for XLSX to JSON + RDF translation.

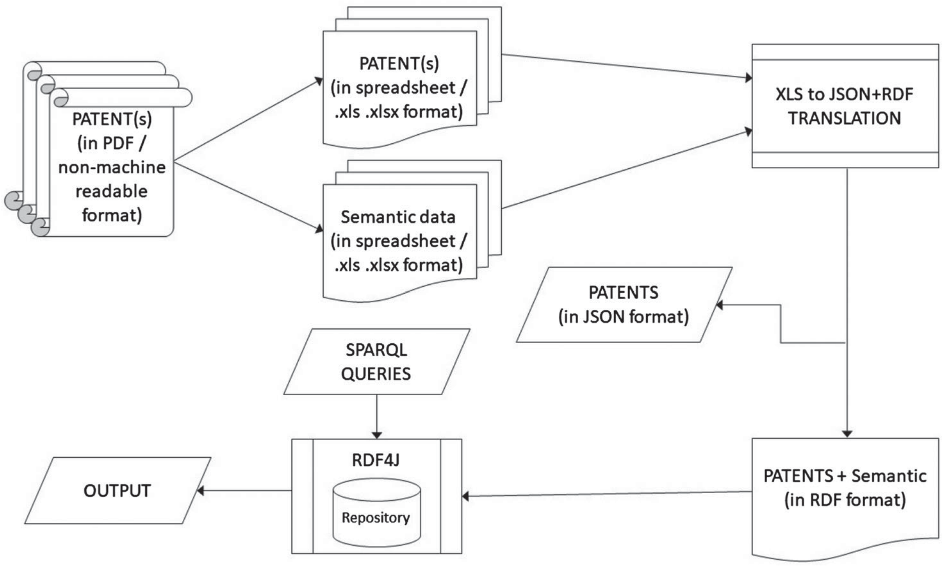

Figure 7. Patent data coding and semantic database establishment process.

any potential conflicted prior art. Figure 7 illustrates an overview of the patent data coding process, starting from the patents in their common form (e.g. PDF), to their representation in RDF along with supplementary semantic data, in order to allow SPARQL querying for potential conflicts. In the next section several example queries were conducted to demonstrate the emerging design–prior art comparison method.

3.5. *FAD+ represents working principle*

A FAD+ diagram of the example can end patent (EP 2219961), featuring invention breakdown and functional reasoning, is produced by referring to the patent working principles shown in Table 1 and Table 2, plus the domain-specifc ontology to standardise functional

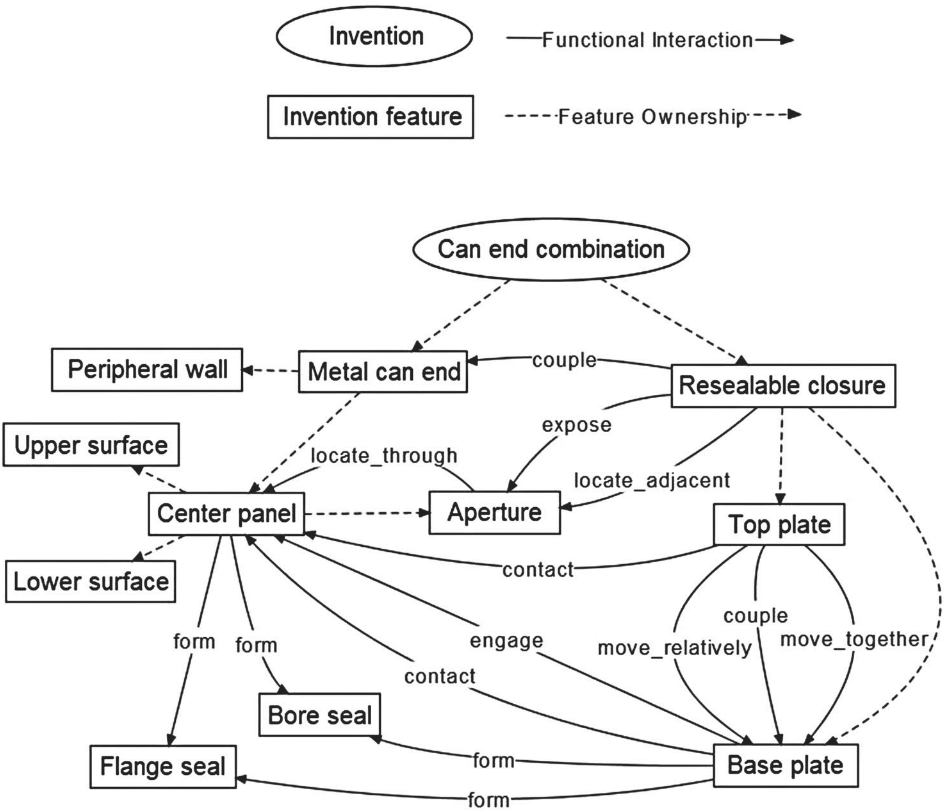

Figure 8. FAD+ for patent EP 2219961.

Table 7. Patent working principle represented by FGI with ontological expression of functional interactions.

FGI	Geometric features	Functional interactions	Ontological term	Geometric features
FGI#1	Resealable closure	coupled to	couple	Metal can end
FGI#2	Aperture	formed there-through	locate_through	Center panel
FGI#3	Top plate	coupled to	couple	Base plate
FGI#4	Base plate	contact	contact	Center panel
FGI#5	Top plate	contact	contact	Center panel
FGI#6	Resealable closure	proximate	locate_adjacent	Aperture
FGI#7	Resealable closure	expose	expose	Aperture
FGI#8	Base plate	downwardly moveable relative to	move_relatively	Top plate
FGI#9	Base plate	translatable together	move_together	Top plate
FGI#10	Base plate	engage with	engage	Center panel
FGI#11	Base plate	form	form	Flange seal
FGI#12	Center panel	form	form	Flange seal
FGI#13	Base plate	form	form	Bore seal
FGI#14	Center panel	form	form	Bore seal

interactions (see Table 7). Figure 8 illustrates FAD+ for patent EP 2219961. The software used in producing the FAD+ is designVUE, an open source mapping software developed by Imperial College London based on Tufts VUE (Imperial College London 2016).

The invention 'Can end combination' represented by the oval shape in Figure 8 refers to the device identified from the first sentence of the independent claim stated in Figure 4. The invention features represented by the rectangular shapes in Figure 4 correspond to geometric features identified from patent claims in Table 2. Feature ownership is represented by the dashed arrows and the functional interactions between geometric features are represented by the solid arrows. FAD+ aims to help designers to understand patent working principles that will not be as readily apparent from reading the patent document. The designer is able to recognise the invention structure by following the dashed arrows and explore the patent working principles by following the full arrows that map interacting geometric features. For example in Figure 8, Resealable closure *couple* to the Metal can end, and *expose* the Aperture. Top plate *couple* to the Base plate and is able to *move together* and *move relatively* to it.

4. Application of framework to emerging design–prior art comparison

In this study, 51 inventions protected by 25 beverage can patents were analysed and populated into an RDF4J database using the framework described in Section 3. The example patent EP 2219961 was used as an '*emerging design*' in the following case studies. When creating SPARQL queries ontological expression of working principles are required in order to perform a correct search.

4.1. *Geometric feature(s)*

Specifying geometric features of an emerging design indicates that the designer may want to know whether prior art has used similar geometric features. Examples of geometric features (see Table 7) selected from the '*emerging design*' are used in the queries with results retrieved presented in Figure 9 and Figure 10, showing the output of the database querying one geometric feature 'seal' and two geometric features 'plate & seal' respectively.

In Figure 9, patents containing ontological expression of the geometric feature 'seal' were presented. Further working principle information of those patents can also be retrieved. For example, patent expressions of 'seal' can be found in column *1stElementName*. This result can provide the designer with insight on how 'seal' contributes to patent working principles. Due to the employment of a domain-specific ontology, semantic relationships between features and functional interactions were considered and hence reflected on the results retrieved. For example, in Figure 10 patents containing geometric feature 'curl', 'bead' and 'handle' were also retrieved because of their semantic relationship in the ontology.

4.2. *FGI*

Specifying complete FGI in queries represents when the designer wants to check whether prior art contains similar novel working principles as their emerging design. Example FGI from Table 7 was used to conduct the search with results represented in Table 8.

Details of the matching FGI were not shown due to complexity and occupancy of space. Moreover, the most valuable information for the design is the patent number which the designer can then further investigate. The output of the last SPARQL query containing three

Patent	1stElementName	1stGF	FI	2ndGF
"US4951835"	"frangible seal"	REPO:seal	REPO:connect	REPO:surface
"US6998830"	"swinging seal"	REPO:seal	REPO:attach	REPO:lid
"US6998830"	"swinging seal"	REPO:seal	REPO:expose	REPO:opening
"US6998830"	"swinging seal"	REPO:seal	REPO:seal	REPO:opening
"US6998830"	"swinging seal"	REPO:seal	REPO:move	REPO:lid
"EP0513401 A1"	"compression seal means"	REPO:seal	REPO:locate	REPO:tab
"EP0513401 A1"	"compression seal means"	REPO:seal	REPO:locate	REPO:opening
"EP0513401 A1"	"compression seal means"	REPO:seal	REPO:cover	REPO:aperture
"US4951835"	"frangible seal"	REPO:seal	REPO:connect	REPO:tab
"US4951835"	"frangible seal"	REPO:seal	REPO:connect	REPO:can end
"US4170724"	"frangible seal"	REPO:seal	REPO:locate	REPO:component
"US4170724"	"frangible seal"	REPO:seal	REPO:locate	REPO:recess
"US4951835"	"frangible seal"	REPO:seal	REPO:connect	REPO:tab
"EP0513401 A1"	"compression seal means"	REPO:seal	REPO:seal	REPO:aperture
"US4681238"	"air-tight seal"	REPO:seal	REPO:locate	REPO:can body
"US4681238"	"air-tight seal"	REPO:seal	REPO:locate	REPO:opening

Figure 9. Output of RDF4J database by querying 'seal'.

FGI returned only one patent EP2263945. When this patent was investigated further it was found out that the '*emerging design*' (EP2219961) and EP2263945 are essentially describing the same design with very slight modification. Their patent images are shown in Figure 11.

The database outputs shown in these example queries provide an impression of the outcome of using the framework in emerging design–prior art conflict analysis. Outputs shown in Figure 9, Figure 10 and Table 8 are just preliminary results which will be further developed to provide better visualisation.

5. Discussion

The framework proposed in this paper offers a structural method to represent the working principles of mechanical inventions in graphical format and hence benefit designers' understanding. It also provides a means to help the designer to investigate commonality in working principles between their emerging design and prior art. As a result, the designer is able to increase their qualitative awareness of prior art and identify potential conflict during their design process rather than afterwards. The example of applying the framework in Section 4 demonstrates its potential to be further developed for use by designers. Some steps of the framework are currently being developed to be automated and more human-centred to reduce user effort. We believe that applying this developed framework will shorten the product development cycle and also prevent avoidable litigation. Our premise is that conflict of working principle in mechanical inventions can be identified through similarity of Functional Geometry Interaction (FGI) contained within both the emerging design and prior art. At the current stage of development, the patent data is gathered

Patent	1stElementName	1stGF	FI	2ndElementName
"US4681238"	"1obes"	REPO:plate	REPO:form	"original seal"
"EP2263945"	"base plate"	REPO:plate	REPO:form	"face seal"
"EP2263945"	"base plate"	REPO:plate	REPO:form	"bore seal"
"EP2263945"	"curl"	REPO:curl	REPO:form	"face seal"
"EP2263945"	"curl"	REPO:curl	REPO:form	"bead seal"
"EP2263945"	"curl"	REPO:curl	REPO:form	"bore seal"
"EP2263945"	"bead"	REPO:bead	REPO:form	"bead seal"
"US4951835"	"handle"	REPO:handle	REPO:break	"frangilbe seal"
"US8336726 B2"	"center panel"	REPO:plate	REPO:form	"flange seal"
"US8336726 B2"	"center panel"	REPO:plate	REPO:form	"bore seal"
"US8336726 B2"	"base plate"	REPO:plate	REPO:form	"bore seal"
"US8336726 B2"	"base plate"	REPO:plate	REPO:form	"flange seal"
"US4752016"	"circular member"	REPO:plate	REPO:form	"1iquid resistant seal"
"US4752016"	"top surface"	REPO:surface	REPO:form	"1iquid resistant seal"
"US4951835"	"handle"	REPO:handle	REPO:break	"frangilbe seal"
"US4951835"	"handle"	REPO:handle	REPO:form	"fluid tight seal"
"US4951835"	"handle"	REPO:handle	REPO:break	"frangilbe seal"
"US4951835"	"handle"	REPO:handle	REPO:break	"frangilbe seal"
"US4681238"	"lid opening"	REPO:opening	REPO:form	"air-tight seal"

Figure 10. Output of RDF4J database by querying 'plate' and 'seal'.

by manually extracting patent information through claims to ensure accurate knowledge input. Effectiveness of the framework is the priority rather than automation and quantity of data input.

Ontology as a shared knowledge base is able to provide a common vocabulary for mechanical patents. It also defines a semantic structure for describing patent working principles which was then employed to develop their RDF files. We have focused on beverage can designs and therefore relevant patents were used as initial data input for a domain-specific ontology development. The ontology data shown is limited to this particular domain for demonstration purposes. We envisage that different ontologies can be developed and employed into the framework for different applications.

A graphical approach to patent knowledge representation is not new to the field. However, as explained in Section 2, it appears that the majority of previous research was focused on measuring patent similarities for trend analysis and patent conflict. One of the main benefits of using FAD+ to represent patents is that it focuses on helping designers to understand patents more easily, i.e. it is meant to be read by designers. FAD literature pointed out that FAD requires better syntax in order to be reliable and consistent (Aurisicchio, Bracewell, and Armstrong 2013). The ontological expression is able to provide mutual understanding

Table 8. Output of RDF4J database for querying different FGI.

No. of FGI	Corresponding FGI in Table 7	FGI ontological expression	RDF4J Output
One	FGI#9	Plate *move_together* Plate	Patent "US8336726 B2" "US4951835" "US20140042164 A1" "WO9836987 A1" "WO9836987 A1" "US20060043092 A1" "WO9836987 A1" "WO200362084 A1"
Two	FGI#4 FGI#9	Plate *contact* Plate; Plate *form* Seal	Patent "US4681238" "EP2263945" "US8336726 B2" "US4752016" "US4951835"
Three	FGI#1 FGI#2 FGI#3	Component *couple* Can_end; Aperture *locate_through* Plate; Plate *couple* Plate	Patent "EP2263945"

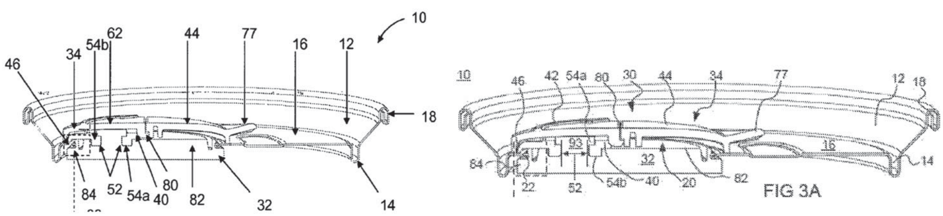

Figure 11. Images from the 'emerging design' (Left) and EP2263945 (Right).

of terms for describing functional relationships. And to the contrary, replacing patent feature expression may result in misinterpretation of patent working principles. For example, Top plate and Base plate in Figure 6 will both be 'Plate' in ontological expression, which may become challenging for the designer to distinguish the difference. More importantly, at the current stage of development FAD+ is used in combination with patent drawings such that the designer can easily recognise corresponding features from both. Therefore in FAD+ functional interactions are expressed using ontological terms while patent expressions of geometric features are kept original.

At this point, FAD+ was manually constructed using the knowledge extracted from patent claims. It is expected that the level of expertise required to produce a FAD+ is 2 to 5 years in order to ensure sensible knowledge extraction. The time taken to produce the FAD+ shown in Figure 6 was less than 10 minutes based on the knowledge extracted (Table 7). FAD+ can be automated by processing patent JSON files generated by the Windows application.

The ontology search method presented has a significant advantage in terms of ambiguity tolerance than conventional keyword search. The framework presented is not a legal method to investigate patent infringement but by helping to improve designers understand similar working principles in the prior art at relatively early stages of design it can help to tactically avoid potential infringement. After initial examination of the results, the designer can further investigate matching patents in order to obtain in-depth understanding of patent working principles and hence be able to improve their emerging design to avoid any future conflict. Employment of a semantic database and SPARQL query provides a tangible opportunity for comparison quantification. For instance, a similarity score can be calculated based on a scoring schema acting as a quick indicator of conflict.

In our research context, this framework contributes to a computer assistant tool, provisionally named Design Assistant for Semantic Comparison of Intellectual Property (DASCIP) being developed. DASCIP will be a standalone program capable of importing 3D CAD models, allowing designers to annotate their design with its working principles. Commonality among working principles and corresponding prior art can then be highlighted for designers to investigate further. Its user interface and knowledge extraction automation are currently being developed. We envisage that applying DASCIP in product development will help designers to increase their qualitative awareness of IP and identify potential infringement during the design process, and hence avoid risk of potential infringement and shorten product development cycle.

6. Conclusion

IP awareness is becoming significant and necessary among mechanical designers as a result of increasing complexity of mechanical devices and their novel working principles increasingly relying on detail design features such as geometric features and the way they interact. This encourages designers to engage with relevant patents, understand their working principles and potentially compare their emerging designs to those prior art. Commonality of working principles can help designers develop novel and possibly patentable designs. In this paper, a framework is proposed for analysing mechanical patents and the means to graphically represent patent knowledge. Case studies have demonstrated the method of conducting emerging design–prior art comparison by virtue of sending SPARQL queries to a semantic database. Different emerging design information can be specified in the queries such as geometric features and FGI. The ontological relationship between terms ensured that semantic similarity of working principle was taken into account when results were retrieved. This framework is developed to be an essential element of a computer assistant tool DASCIP being developed. It will be employed during a product design process rather than later. We envisage that DASCIP can shorten the overall product design process cycle by avoiding potential emerging design–prior art conflict and thereby avoid costly litigation.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

We are grateful to the Engineering and Physical Sciences Research Council for funding this research (Grant reference: EP/N010078/1).

ORCID

Pingfei Jiang http://orcid.org/0000-0001-6163-2632

References

Abbas, Assad, Limin Zhang, and Samee U. Khan. 2014. "A Literature Review on the State-of-the-Art in Patent Analysis." *World Patent Information* 37: 3–13. doi:10.1016/j.wpi.2013.12.006.

Ahmed, Saeema, Sanghee Kim, and Ken M. Wallace. 2007. "A Methodology for Creating Ontologies for Engineering Design." *Journal of Computing and Information Science in Engineering* 7 (2): 132. doi:10.1115/1.2720879.

Ahmed, S., and K. Wallace. 2003. "Evaluating a Functional Basis." Proceedings of the ASME Design Engineering Technical Conference, Vol. 3. 901–907, Chicago, September 2–6. http://www.scopus.com/inward/record.url?eid = 2-s2.0-1842787609%26partnerID = 40%26md5 = 2607ae43742340f5191a132cbb622752

Atherton, Mark, Pingfei Jiang, David Harrison, and Alessio Malizia. 2017. "Design for Invention: Annotation of Functional Geometry Interaction for Representing Novel Working Principles." *Research in Engineering Design*. doi:10.1007/s00163-017-0267-2.

Aurisicchio, Marco, Rob Bracewell, and Gareth Armstrong. 2012. "The Function Analysis Diagram." Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Chicago, August 12–15. doi:10.1115/DETC2012-70944

Aurisicchio, Marco, Rob Bracewell, and Gareth Armstrong. 2013. "The Function Analysis Diagram: Intended Benefits and Co-existence with Other Functional Models." *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 27 (3): 249–257. http://www.journals.cambridge.org/abstract_S0890060413000255%5Cnpapers3://publication/doi/10.1017/S0890060413000255.

Brown & Michaels. 2015. "How Do I Read a Patent? – the Claims."

Cascini, Gaetano, and Manuel Zini. 2008. "Measuring Patent Similarity by Comparing Inventions Functional Trees." *IFIP International Federation for Information Processing* 277: 31–42. doi:10.1007/978-0-387-09697-1_3.

Chen, Rain. 2009. "Design Patent Map Visualization Display." *Expert Systems with Applications* 36 (10): 12362–12374. doi:10.1016/j.eswa.2009.04.049.

EPO. 2016. "Intellectual Property Teaching Kit – IP Advacned Part I."

Hirtz, Julie, Robert B. Stone, Daniel A. McAdams, Simon Szykman, and Kristin L. Wood. 2002. "A Functional Basis for Engineering Deisgn: Reconciling and Evolving Previous Efforts." *Research in Engineering Design* 13: 65–82.doi:10.1007/s00163-001-0008-3.

Imperial College London. 2016. "DesignVUE." http://www.imperial.ac.uk/design-engineering/research/engineering-design/engineering-knowledge-and-data/designvue/.

Jiang, Pingfei, Mark Atherton, David Harrison, and Alessio Malizia. 2017. "Framework of Mechanical Design Knowledge Representations for Avoiding Patent Infringement." ICED 2017 Conference Proceedings, August 21–25, Vol. 6, 81–90.

Kang, Jiho, Jongchan Kim, Joonhyuck Lee, Sangsung Park, and Dongsik Jang. 2015. "A Methodology for Patent Function Analysis." Proceedings of International Conference on Economics and Business Management, 155–59, Phuket, July 29–30.

Kim, Young Gil, Jong Hwan Suh, and Sang Chan Park. 2008. "Visualization of Patent Analysis for Emerging Technology." *Expert Systems with Applications* 34 (3): 1804–1812. https://doi.org/10.1016/j.eswa.2007.01.033.

Koster, Bastiaan. 2015. *Topic 10: Introduction and Theory of the Patent Claim*. Harare: WIPO.

Kotis, K., and G. Vouros. 2006. "Human-Centered Ontology Engineering: The HCOME Methodology." *Knowledge and Information* 10 (1): 109–131. doi:10.1007/s10115-005-0227-4.

Lechevalier, C., L. Gerbaud, and J. Bigeon. 1998. “Functional Analysis for Static Converter Structure Design.” Proceedings of the 24th Annual Conference of the IEEE, August 31–September 4, 61–66.
Lee, Szu-hung, Pingfei Jiang, Peter Childs, and Keith Gilroy. 2013. “Functional Analysis Diagrams with the Representation of Movement Transitions.” Proceedings of the ASME 2013 International Mechanical Engineering Congress and Exposition, San Diego, November 15–21.
Li, Zheng, Mark Atherton, and David Harrison. 2014. “Identifying Patent Conflicts: TRIZ-led Patent Mapping.” *World Patent Information* 39: 11–23. doi:10.1016/j.wpi.2014.07.002.
Li, Zhen, Derrick Tate, Christopher Lane, and Christopher Adams. 2012. “A Framework for Automatic TRIZ Level of Invention Estimation of Patents Using Natural Language Processing, Knowledge-Transfer and Patent Citation Metrics.” *CAD Computer Aided Design* 44 (10): 987–1010. doi:10.1016/j.cad.2011.12.006.
McLaughlin, Aimee. 2017. “New Patent Software Aims to Encourage Designers to Be More Original.” *Design Week*. https://www.designweek.co.uk/issues/1-7-may-2017/new-patent-software-encourage-designers-creative-original/.
Michalakoudis, Ioannis, P. R. N Childs, Marco Aurisicchio, Nathan Pollpeter, and Neil Sambell. 2014. “Using Functional Analysis Diagrams as a Design Tool.” Proceedings of the ASME 2014 International Mechanical Engineering Congress and Exposition, Montreal, November 14–20.
Morris, A. T., and Julian C. Breidenthal. 2011. “The Necessity of Functional Analysis for Space Exploration Programs.” Proceedings of Digital Avionics Systems Conference, October 16–20.
Nicola, Antonio De, and Michele Missikoff. 2016. “Methodology for Rapid Ontology Engineering.” *Communications of the ACM* 59: 79–86.
Otto, Kevin, and Kristin L. Wood. 2001. *Product Design: Techniques in Reverse Engineering and New Product Development*. Upper Saddle River, NJ: Prentice Hall.
Pahl, G, and W Beitz. 2006. *Engineering Design: A Systematic Approach*. 3rd ed. London: Springer-Verlag. doi:10.1007/978-1-84628-319-2.
Ramsey, Christopher, and Christopher Althopre. 2013. “Resealable beverage can end and methods relating to same wiederverschliessbares.” EP2219961 B1.
RDF4J, Eclipse. n.d. “Eclipse RDF4J – a Java Framework for RDF.” Accessed October 24, 2017. http://rdf4j.org/.
Rusher, Jack. 2003. “TripleStore.” Semantic Web Advanced Development for Europe (SWAD-Europe), Workshop on Semantic Web Storage and Retrieval.
Sanfilippo, Emilio M., and Stefano Borgo. 2016. “What Are Features? An Ontology-Based Review of the Literature.” *Computer-Aided Design*. doi:10.1016/j.cad.2016.07.001.
Soo, Von W., Szu Y. Lin, Shih Y. Yang, Shih Neng Lin, and Shian Luen Cheng. 2006. “A Cooperative Multi-Agent Platform for Invention Based on Patent Document Analysis and Ontology.” *Expert Systems with Applications* 31 (4): 766–775. doi:10.1016/j.eswa.2006.01.014.
Stone, Robert B., Kristin L. Wood, and Richard H. Crawford. 2000. “A Heuristic Method for Identifying Modules for Product Architectures.” *Design Studies* 21: 5–31.
Ulrich, Karl T., and Steven D. Eppinger. 2016. *Product Design and Development*. 6th ed. New York, NY: McGraw-Hill Education.
W3C. 2015. “Semantic Web – W3C.” https://www.w3.org/standards/semanticweb/.