



Knowledge interoperability and re-use in Empathy Mapping: an ontological approach

Salvatore F. Pileggi ^{*,1}

School of Information, Systems and Modelling (ISM), University of Technology Sydney, Australia
 Centre on Persuasive Systems for Wise Adaptive Living (PERSWADE), University of Technology Sydney, Australia



ARTICLE INFO

Keywords:
 Ontology
 Data integration and re-use
 Semantic interoperability
 Semantic web
 Data engineering
 Knowledge engineering
 Design thinking
 Empathy mapping

ABSTRACT

Design Thinking is a human-centered approach extensively used across different domains that aims at problem solving, value creation for stakeholders and innovation by fostering creativity. The most characterising and critical step along the Design Thinking process is the empathy phase, in which stakeholder analysis is performed by looking at a given scenario from the perspective of different stakeholders. Such a methodology enables a systematic information gathering and organization that results in a deep understanding of actual problems, needs and expectations from the target stakeholders. The uniqueness of problems and the need for situation-specific data makes knowledge re-use not always practical, even within the most consolidated and experienced environments. In this paper we propose an ontological support to empathy mapping that aims to (i) establish an interoperable fine-grained data layer among the different data collected throughout the empathy mapping process, (ii) enable multi-scenario analysis underpinned by formal specifications and (iii) further empower the process through semantic enrichment and integration of insight from multiple sources and contexts. We believe this is the first step to design and properly integrate effective computational and AI-based functionalities along the creative design thinking process, as well as to enable in practice richer and more sophisticated approaches (e.g. through social networks).

1. Introduction

Design Thinking (Brown et al., 2008; Dorst, 2011) is a human-centered approach extensively used across different domains (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013) that aims at problem solving, value creation for stakeholders and innovation by fostering creativity (Kolko, 2018). Design thinking frameworks are currently applied in a number of disciplines other than the classical business context (Davis, 2010), such as, among others, social innovation (Brown & Wyatt, 2010), healthcare (Roberts, Fisher, Trowbridge, & Bent, 2016), software engineering (Ferreira, Conte, & Barbosa, 2015), pedagogy (Luka et al., 2014), policy-making (Mintrom & Luetjens, 2016), management (Liedtka & Ogilvie, 2011) and sustainability (Fischer, 2015). An additional mention is for educational context, where design thinking is extensively adopted with a wide extent (e.g. Oxman, 2004).

The most characterising and critical step along the Design Thinking process is the empathy phase (Köppen & Meinel, 2015), in which stakeholder analysis is performed by looking at a given scenario from

the perspective of different stakeholders. Such a methodology, that applies at an analysis level the well-known social concept of empathy (Stueber, 2013), aims to enable systematic information gathering and organization that results in a deep understanding of actual problems, needs and expectations from most relevant or target stakeholders.

In order to make such a process as effective as possible (Osterwalder & Pigneur, 2010), especially in a team-work and multi-disciplinary contexts (Seidel & Fixson, 2013), analysis based on empathy is normally supported by simple specific visual tools known as empathy maps (e.g. Bland, 2012).

Why interoperability and re-use in empathy mapping? Design Thinking results very effective in fact under the realistic assumption that each problem is somehow unique and, although certain principles and concepts may be generalised, situation-specific analysis and data are normally required. That is probably one of the main reasons, if not the main one, to apply empathy in order to better and deeper understand the various stakeholders in a given context. For instance, Personas at a different level of detail can be created by adopting empathy mapping

* Address: School of Information, Systems and Modelling (ISM), University of Technology Sydney, Australia.

E-mail address: salvatoreflavio.pileggi@uts.edu.au.

¹ ORCID ID: <https://orcid.org/0000-0001-9722-2205>

(Ferreira, Silva, Oliveira, & Conte, 2015).

However, the unique features that may characterise contexts and problems are still perfectly compliant with some kind of formalization in the context of a creative process for systems design. Indeed, existing tools for empathy mapping drive the knowledge building process by providing a more structured and consistent model of analysis. So, is the knowledge built as a result of an empathy mapping process re-usable? How? And in which extent? We believe that Design Thinking is evolving itself as a response to a continuously changing World (Bjögvinsson, Ehn, & Hillgren, 2012; Martin & Martin, 2009). As recent emerging concepts (e.g. computational design, in which the classical representation is replaced by simulation (Menges & Ahlquist, 2011), and data-driven design, based on the balance between analytical mastery and intuitive originality (Martin, 2010)) show, such an approach and the major technological trends around data and computation are progressively converging.

We believe that, in such a context, the formal structure of the knowledge, both with the capability to systematically re-use and enrich it through progressive integration and refining, may play a key role in the next evolution of Design Thinking, as well as in its application to cutting edge scenarios.

Ontology and Semantic Web. Addressing knowledge formalization, data integration and re-use in a context of interoperability, the concept of ontology (Guarino, 1995) becomes definitely central. Additionally, a semantically enriched data-driven environment in a context of interoperability to support and foster creativity and innovation naturally leads to the Semantic Web (Berners-Lee, Hendler, & Lassila, 2001) and the Linked Data (Bizer, Heath, & Berners-Lee, 2011) model. Intuitively, such a data infrastructure supports a relatively basic concept: everything can be potentially linked to everything across the Web under the assumption of semantic interoperability (Heiler, 1995).

In this paper we propose an ontological approach to empathy mapping implemented upon Semantic Web technologies (Cardoso, 2007).

Methodology and approach. Design Thinking tools underpin a common philosophy to problem solving but may differ very much from each other, as well as they may be customised and used in different ways depending on context, extent and intent. Therefore, a rigorous approach to knowledge management based on the formal analysis of existing tools might not be effective in this case and also it could not respond to practical needs. Taking advantage of the ontological approach and of the advanced features provided by the current semantic technology, we have proposed an open and extensible vocabulary that allows a non-prescriptive approach to data structures. Since we are not proposing new tools or techniques for Design Thinking, in our humble opinion, this approach can be considered to be reasonable and doesn't imply specific risks as the core vocabulary provided is expected to evolve and be extended as the function of users needs and requirements of the different target systems.

Research relevance. This research work aims to pragmatically enable the knowledge building process and the related data structures requested by the problem space analysis in Design Thinking within the Semantic Web. Such a key step potentially creates a novel environment and context for Design Thinking in which human creativity meets the most modern digital platforms as a response to a data-intensive society. It determines a number of direct and tangible implications as well as great potentialities in perspective. Indeed, from a practical point of view, the semantic approach provides the capability to progressively define and eventually describe the problem context by adopting a non-prescriptive approach supported by an extensible vocabulary which allows semantic linking at a global level. Additionally, according to a more holistic view, the ontology-based approach can be considered the ideal infrastructure to design and integrated AI-based features applying, among others, the most sophisticated techniques in terms of NLP (Otter, Medina, & Kalita, 2020) and Web data mining (Ristoski & Paulheim, 2016). We expect a further and more consistent integration of content from online social networks to become more and more relevant in the

next future (Pileggi, Fernandez-Llatas, & Traver, 2012) in the context of ideation processes. Last but not least, the pandemic we are currently living has pointed out and remarked the need to be flexible and adaptive in challenging conditions (Manzanedo & Manning, 2020). A cutting edge knowledge management could definitely facilitate a consistent development in such a direction.

Structure of the paper. This introductory part of the paper is completed by the following section that addresses related work. The core part of the paper (Section 3) provides an extensive explanation of the ontological approach to empathy mapping and of its implementation. An example of use of the ontology related to a simplified scenario is also proposed in the same section. Section 4 deals with some considerations on possible practical applications of the ontology, as well as results are discussed at a more holistic level in Section 5 looking at the next generation tools for Design Thinking. The paper ends with a conclusions section which also addresses possible future work.

2. Related work

As far as the author knows, there are not many existing works on the topic in literature. For instance, in (Ramaprasad & Syn, 2013), the authors adopt ontology to support the evaluation of the realised design against the idealised one.

More holistically, within the business context, the ontological approach is very common to support a proper organization, structure and management of knowledge (Fensel, 2002) (e.g. Jackson, 2004). However, the knowledge resulting from an empathy mapping process is very specific and it would be hard to be managed in fact in a wide context. Focusing explicitly on the design process, ontologies are relatively common assets, for instance in the context of user-centered design (Negru & Buraga, 2012), and can play a role to foster or improve certain aspect of collaboration (Lee & Jeong, 2012) and even creativity (Fulea & Brad, 2011).

In this paper we propose an ontological support to empathy mapping that aims to (i) establish an interoperable fine-grained data layer among the different data collected throughout the empathy mapping process, (ii) enable multi-scenario analysis underpinned by formal specifications and (iii) further empower the process through semantic enrichment and integration of insight from multiple sources and contexts.

Ontologies have been extensively adopted to address data interoperability in a wide range of application domains such as, among the very many, network management (Wong, Ray, Parameswaran, & Strassner, 2005), urban planning (Pileggi & Hunter, 2017), healthcare systems (Khan et al., 2014), product data management (Panetto, Dassisti, & Tursi, 2012) and biological and medical data (Schriml & Mitraka, 2015).

Data integration is a key step to value creation (Lee & Jung, 2019Zhang et al., 2020), especially in a Big Data context (Dong & Srivastava, 2013), and, more in general, creates the condition to extended analysis (e.g. Pai, Yang, & Chung, 2017) and knowledge building (Hmelo-Silver & Barrows, 2008). Finally, semantic enrichment and linking contribute to create customised environments (e.g. Belsky, Sacks, & Brilakis, 2016).

3. An ontology for empathy mapping

The ontological approach proposed in this paper is, at least in theory, agnostic with respect to the concrete empathy map model adopted, as well as with respect to the context in which such tools are used (e.g. classic design thinking or other processes/techniques). That is because of the ontology characteristics which allow semantic equivalences and, more in general, a valuable support in terms of interoperability, which is understood at a semantic level. If properly used, those mechanisms can assure an integrated use of knowledge gathered by adopting different approaches, methods and tools.

In order to provide a development as tangible as possible, we refer to a typical and very popular empathy map model (Bland, 2012). Such a

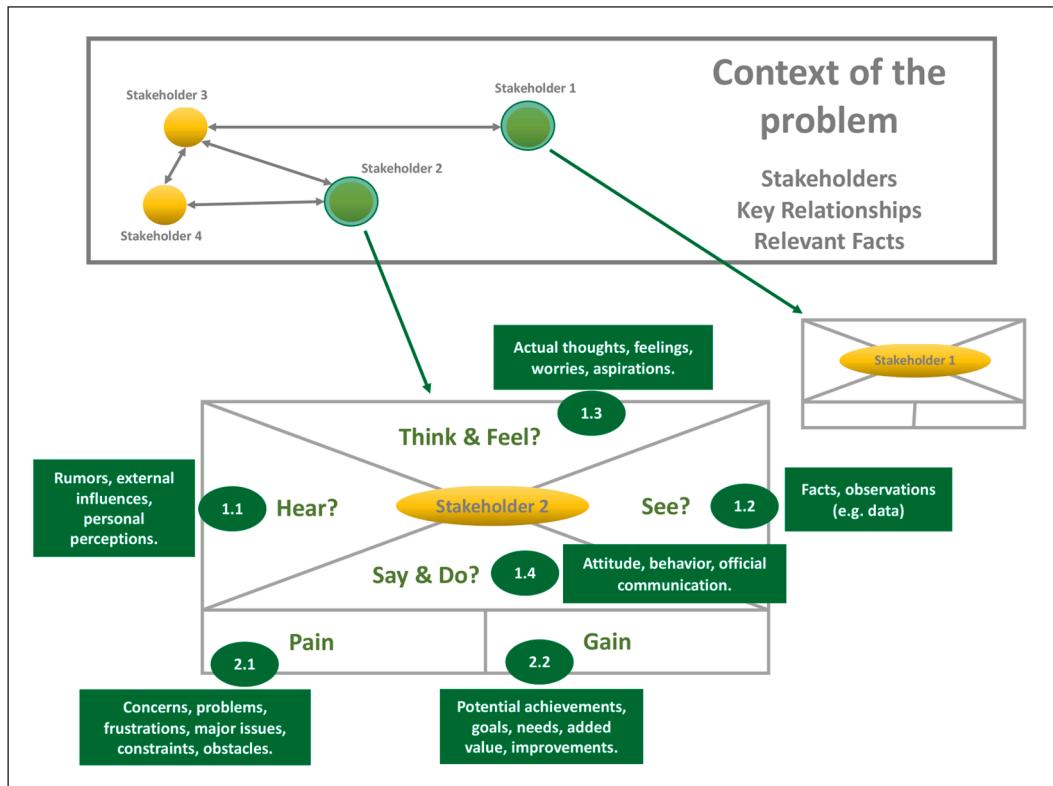


Fig. 1. Typical Empathy Map (Bland, 2012) in context.

model is briefly explained in the next subsection. Additionally, in order to make an ontology for empathy mapping effective in practice, also the context of the problem has to be properly modelled and formally specified. As explained in the next subsection, empathy mapping is an

attempt to analyse a given scenario from the perspective of single stakeholders. Therefore, the context of the problem is defined accordingly as a semantically enriched composition of interactions and facts involving target stakeholders.

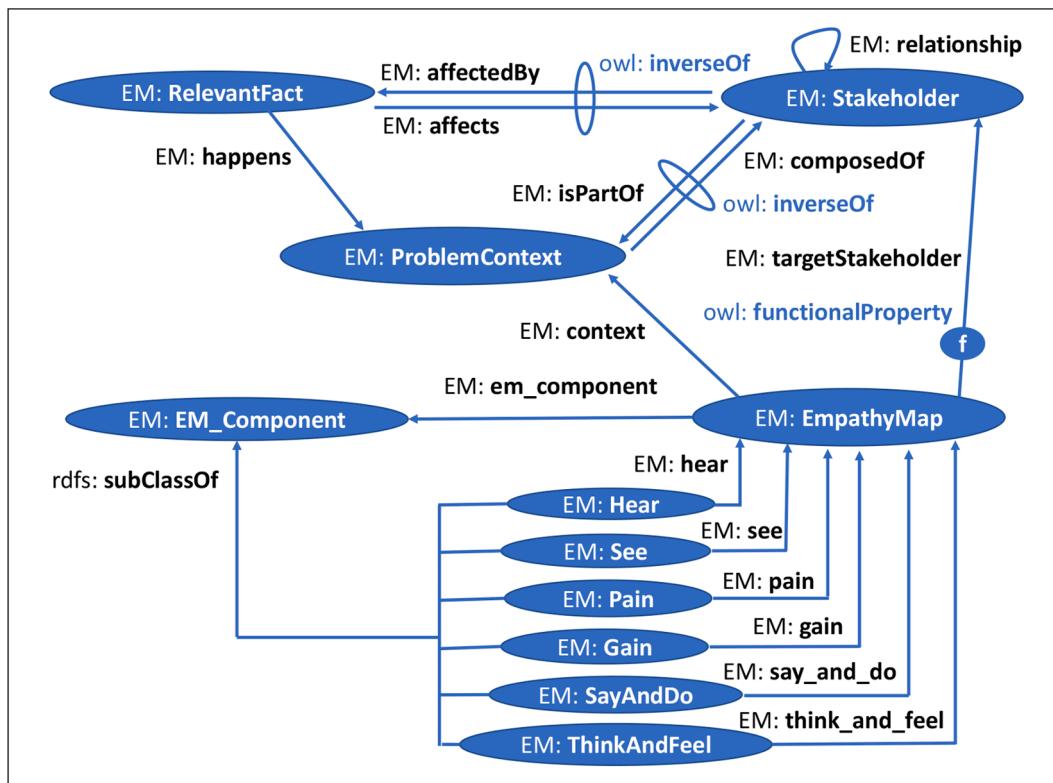


Fig. 2. Overview of EM Ontology.

Table 1
Main classes.

Class	Sub-class of	Description
<i>Problem_Context</i>	–	It identifies a given scenario, use case or target study case.
<i>Scenario</i>	–	Equivalent to <i>Problem_Context</i> .
<i>Stakeholder</i>	–	A stakeholder as in a common meaning.
<i>RelevantFact</i>	–	Fact, data or relevant information related to a context.
<i>EmpathyMap</i>	–	EM related associated with a given stakeholder.
<i>EM_Component</i>	–	Component of an EM as in its original structure (Fig. 1).
<i>Hear</i>	<i>EM_Component</i>	“Hear” component as in the EM’s original model.
<i>See</i>	<i>EM_Component</i>	“See” component as in the EM’s original model.
<i>Pain</i>	<i>EM_Component</i>	“Pain” component as in the EM’s original model.
<i>Gain</i>	<i>EM_Component</i>	“Gain” component as in the EM’s original model.
<i>SayAndDo</i>	<i>EM_Component</i>	“Say & Do” component as in the EM’s original model.
<i>ThinkAndFeel</i>	<i>EM_Component</i>	“Think & Feel” component as in the EM’s original model.

3.1. Understanding empathy mapping in context

The context of the problem aims to provide a description as formal as possible of the target scenario. In the context of the proposed framework, it is defined according to the model represented in Fig. 1, which includes three different key concepts as follows:

- **Stakeholder.** As in a common meaning, stakeholders are understood as the actors which have an interest or concern in a given context, which is object of attention or analysis.
- **Key Relationship.** It is some kind of relationship or interaction among stakeholders. The understanding and meaning may vary very much from case to case.
- **Relevant Fact.** It characterizes the scenario by providing situation-specific data and factual information. Such information normally aims to particularise a generic scenario involving stakeholder to reflect a more concrete and richer situation that include data and facts.

An empathy map (EM) is related to a single stakeholder. An exhaustive explanation of the methodology and related processes is out of the scope of this paper. However, a self-explanatory description is provided in Fig. 1 by adopting the reference model provided by Bland (2012).

3.2. Ontological representation

An overview of an ontology that materializes the model previously described is proposed in Fig. 2. Main classes and properties of the OWL (W3C, 0000) implementation are reported in Tables 1 and 2 respectively.

The class *Problem_Context* allows the unique identification of a given context characterised by a number of stakeholders and relevant facts that can be defined by adopting the respective classes (*Stakeholder* and *RelevantFact*). Stakeholders may be related to the context of the problem by adopting a pair of inverse object properties (*composedOf* and *isPartOf*), while a given fact is related by using the object property *happens*. Additionally, stakeholders and facts are associated with each other through a pair of inverse object properties *affectedBy* and *affects*.

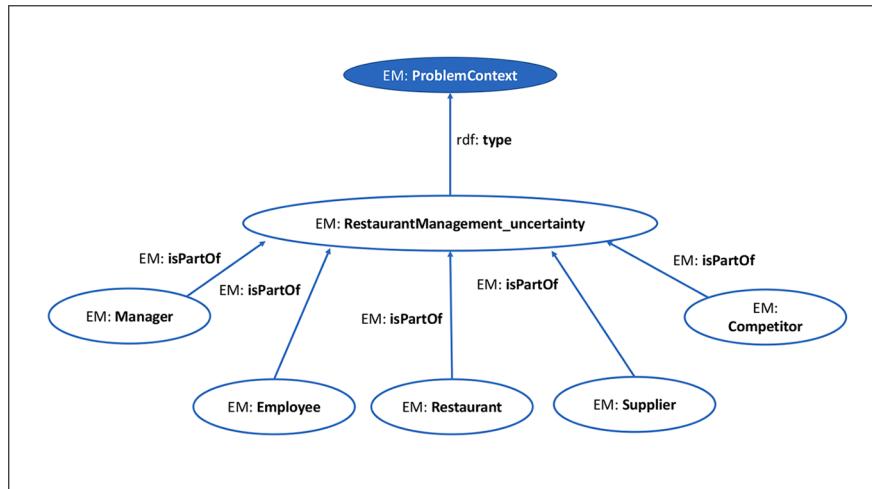
The different EMs are specified as members of the class *EmpathyMap*. Each map should be related to a given context through the object

Table 2
Main properties.

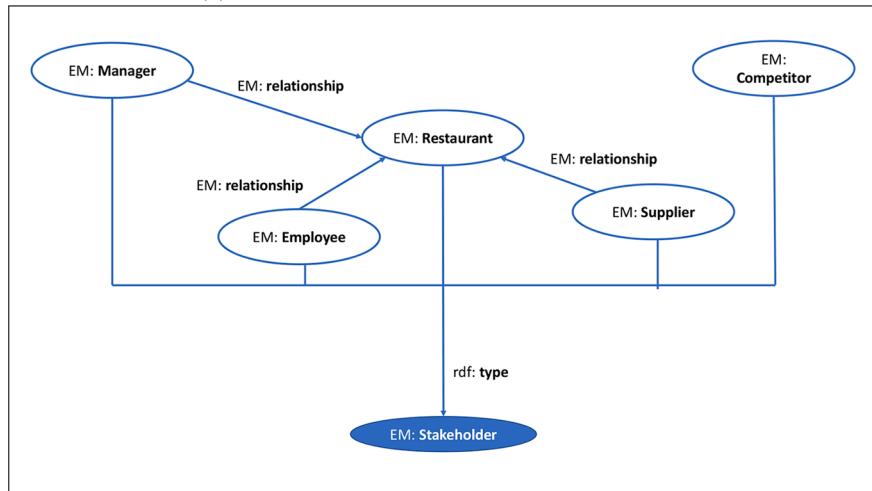
Property	Type	Domain	Range	Description
<i>composedOf</i>	Object	<i>ProblemContext</i>	<i>Stakeholder</i>	It relates stakeholders to the context.
<i>isPartOf</i>	Object	<i>Stakeholder</i>	<i>ProblemContext</i>	It relates stakeholders to the context.
<i>affectedBy</i>	Object	<i>Stakeholder</i>	<i>RelevantFact</i>	It associated stakeholders with relevant info.
<i>affects</i>	Object	<i>RelevantFact</i>	<i>Stakeholder</i>	It associated stakeholders with relevant info.
<i>happens</i>	Object	<i>RelevantFact</i>	<i>ProblemContext</i>	It relates relevant info to the context.
<i>context</i>	Object	<i>EmpathyMap</i>	<i>ProblemContext</i>	It links an EM to its context.
<i>targetStakeholder</i>	Object	<i>EmpathyMap</i>	<i>Stakeholder</i>	It associated the EM with a stakeholder.
<i>em_component</i>	Object	<i>EmpathyMap</i>	<i>EM_Component</i>	It relates a generic component to its EM.
<i>hear</i>	Object	<i>Hear</i>	<i>EmpathyMap</i>	It relates an “hear” component to its EM.
<i>see</i>	Object	<i>See</i>	<i>EmpathyMap</i>	It relates a “see” component to its EM.
<i>pain</i>	Object	<i>Pain</i>	<i>EmpathyMap</i>	It relates a “pain” component to its EM.
<i>gain</i>	Object	<i>Gain</i>	<i>EmpathyMap</i>	It relates a “gain” component to its EM.
<i>say_and_do</i>	Object	<i>SayAndDo</i>	<i>EmpathyMap</i>	It relates a “say & do” component to its EM.
<i>think_and_feel</i>	Object	<i>ThinkAndFeel</i>	<i>EmpathyMap</i>	It relates a “think & feel” component to its EM.
<i>description</i>	Data	–	–	Generic description for a concept.

property context and to a stakeholder through the property *targetStakeholder*. The structure of an EM is defined by specifying the components or sections. Such different elements are sub-concepts of the class *EM_Component* and may be related to a map by using the property *em_component*. In the reference case study considered in this paper, 6 different components have been specified as represented in Fig. 2. These components correspond to the sections of the original reference model (Bland, 2012).

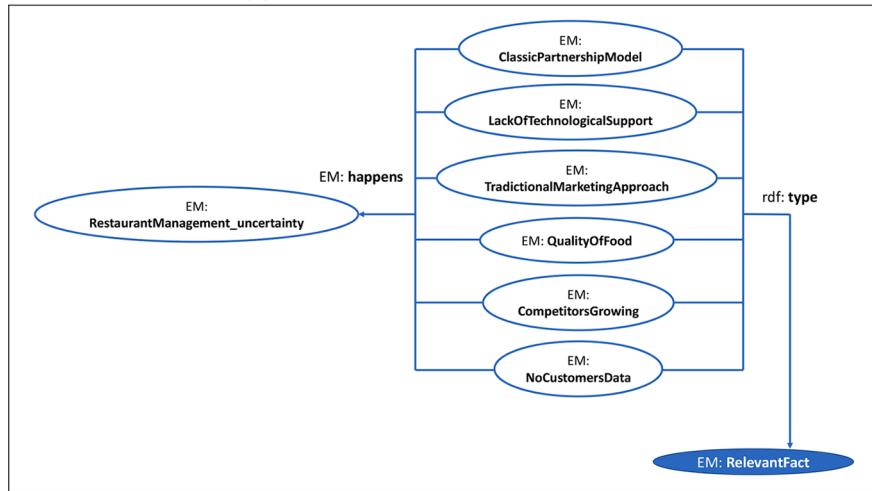
Semantic Enrichment and External Linking. Looking at applications in the different contexts and domains, in the most general terms, a significant enhancement identifiable a priori is the capability to semantically enrich (e.g. Abel, Gao, Houben, & Tao, 2011; Angeletou,



(a) Problem context and related stakeholders.



(b) Relationship among stakeholders.



(c) Characterization of the target scenario.

Fig. 3. Partial specification of a target scenario.

2008; Belsky et al., 2016) the original conceptual model, as well as to link external data, information and, eventually, knowledge. Indeed, if enabled in the Semantic Web, the proposed data infrastructure provides such a support by creating a descriptive environment in which annotations based on different vocabularies are integrated together. As any content in the Web is uniquely identifiable, the supporting ontology creates a unique point of convergence for the target knowledge system.

Cross-scenario analysis and knowledge re-use. At an application level, a semantically enriched and interoperable environment increases the capability in terms of both synthesis and analysis. Indeed, the overall knowledge building process becomes ontology-driven and results in enhanced features from a knowledge re-use and retrieval perspective. In the concrete case object of this study, cross-scenario analysis is fully supported.

3.3. An example of use

This section provides an example of use of ontology previously described to address a concrete synthetic business case. In order to keep the example as easy and understandable as possible, we propose a very simplified business case related to the management of a restaurant which is facing some challenge due to its very traditional approach to business and everyday operations. Additionally, we describe the main data infrastructure only with a focus on the most relevant aspects. Details (e.g. descriptors, labels and not primary relationships) are not reported.

More concretely, we first address the formal specification of the target scenario both with its characterization, then we describe examples of EMs and, finally, we deal with some relatively complex query examples.

3.3.1. Formal specification of the scenario

Fig. 3 proposes an example of formal specification of a target sce-

number of stakeholders (Manager, Employee, Restaurant, Supplier, Competitor) are associated with the target problem through the property `isPartOf`. Relationships existing among stakeholders are proposed in Fig. 3b and are established by using the property `relationship`. Finally, a number of characterizations (instances of the concept class `RelevantFact`) are related to the target scenario (through the property `happens`) to characterize it (Fig. 3c).

3.3.2. Formal specification of empathy maps

The diagram in Fig. 4 shows the formal definition of two EMs (`Manager_EM` and `Employee_EM`) associated through the property `targetStakeholder` with the manager and the employee respectively. The EMs are also related to the context scenario `RestaurantManagement_uncertainty` by adopting the property `context`.

An informal specification of synthetic EMs is proposed in Fig. 5, while their partial formalization by adopting the proposed ontology is represented in Fig. 6. As shown, the dynamic use of the vocabulary allows an easy definition for the key data infrastructure that, as previously discussed, can be characterised and semantically enriched depending on the application context.

3.3.3. Complex query

The preferred interaction mode with ontological structure is definitely based on the adoption of rich query languages (Kollia, Glimm, & Horrocks, 2011) (e.g. SPARQL W3C, xxxx). Complex query supports an high level of abstraction as queries may be designed just looking at the main ontological schema.

Basic examples of query to support single scenario as well as cross-scenario analysis are reported below. Q1 retrieves all characterizations of a given scenario; Q2 retrieves all EMs both with the characterizations associated; finally, Q3 returns the participation of a given stakeholder X in the different scenarios.

Q1: Retrieving all characterizations of a given scenario *S*.

```
SELECT *
WHERE {
  {S ?y ?x}
  UNION
  {?x ?y S}
}
```

nario. Such a definition, visually represented as a knowledge graph, focuses on key concepts and relationships and misses most details.

Q2: Retrieving all EMs and their characterizations.

```
SELECT *
WHERE ?x a EM:EmpathyMap.
      ?x ?y ?z
```

The problem context, `RestaurantManagement_uncertainty`, is defined as an instance of the class `ProblemContext`. As shown in Fig. 3a a

Q3: Retrieving the participation of a given stakeholder *X* in the different scenarios.

```
SELECT ?scenario
WHERE X EM:isPartOf ?scenario
```

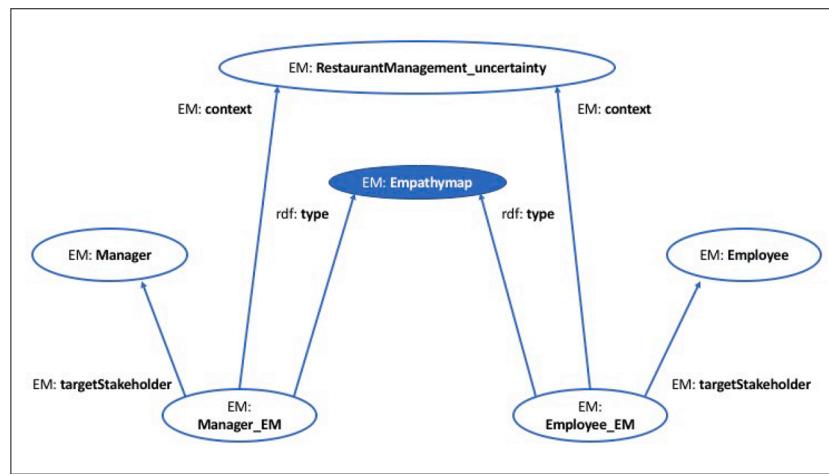


Fig. 4. Association of EMs with target stakeholders and scenario.

3.3.4. Visualizations

In terms of visualizations, ontological structures are (or may be) understood like Knowledge Graphs (Pujara, Miao, Getoor, & Cohen, 2013). The Knowledge Graph approach is very valuable as, if properly used, can combine multiple aspects from different disciplines, including data visualization (Friendly, 2008), data semantics (Madnick & Zhu, 2006) and complex network (Zhu, Corcoran, Shyy, Pileggi, & Hunter, 2018).

The visualization of the example proposed as a Knowledge Graph from our research prototype is proposed in Fig. 7a. It focuses on classes and individuals as per OWL specifications (W3C, 2000) but doesn't include attributes to keep the density of the graph relatively low. Our visualization approach adopts filled circles for classes and unfilled circles for individuals (instances). The number of instances belonging to each class is represented and the size of the corresponding representation is proportional to such a number. Additionally, the result of a given query can be visualised over the graph (Fig. 7b).

4. Applications

This paper focuses on the definition of a formal specification for EMs in context. Potential applications of such a data structure should mainly fall in the two following categories:

- **Expert systems/tools.** If Design Thinking methodologies need to be supported by computer-based tools, the proposed ontological approach can provide an effective, flexible and interoperable backbone to integrate and enable data, information and knowledge within the Semantic Web. Automatic reasoning, complex query, visualizations and ontology analysis (Guarino, 1995) may facilitate the development of advanced features (e.g. AI-powered).
- **Education.** Design Thinking is extensively adopted in education (Koh, Chai, Wong, & Hong, 2015). We believe that enabling knowledge re-usability and extended analysis capabilities may further foster creativity. Last but not least, the ontological approach could be functional to novel approach to learning (e.g. Pervasive learning Thomas, 2005).

- **Adaptive systems, disruption and non-deal conditions.** The complex and challenging situation we are living with the COVID-19 has quickly converted the adaptation to disruption and to non-ideal conditions a pressing need. At this stage, it is commonly assumed that a further digital support for consolidated methods, processes and practices is a smart move forward in terms of resilience and, definitely, a good direction looking at a sustainable future. Design Thinking is normally a team activity. Online platforms, among others, help teams to work remotely and, in this specific case, the ontological approach could be a determinant asset to an effective development upon sophisticated technology.

- **Multi, Inter, Trans-disciplinary environments; Knowledge sharing and Communication.** Additional challenges arise within environments which present multi, inter or trans-disciplinarity. Indeed, in such evolving domains problems are often approached from multiple perspectives that need to be properly integrated. It implies stronger requirements in terms of formal specification of concepts that also need to be related to already existing concepts from different disciplines. The communication of knowledge at the different levels may be critical, even within consolidated environments. Regardless of the intent and extent of the Design Thinking process, a significant heterogeneity is expected. The ontological approach proposed can facilitate the effective management and contribute to maximise value creation and knowledge sharing.

Approaching real-world scenarios From a technology perspective, the ontology proposed is developed in OWL and it is directly usable within any system that adopts semantic technology. While specification and query languages have been standardised by W3C,² the research community has provided a number of valuable assets that assume such standards, including reasoners (e.g. Pellet Sirin, Parsia, Grau, Kalyanpur, & Katz, 2007) and Hermit (Glimm, Horrocks, Motik, Stoilos, & Wang, 2014), editors (e.g. Protege Musen, 2015), ontology libraries (d'Aquin & Noy, 2012) and triple-store (Rohloff, Dean, Emmons, Ryder, & Sumner, 2007). The vocabulary provided assumes the 6 components model previously described. It can be extended or customised through ontological features (e.g. equivalent classes, properties, attributes or individuals as per OWL specifications) to work with other models that can eventually co-exist and work within a unique knowledge space. As an example, Fig. 8 shows in concept the semantic integration of different

² W3C – <https://www.w3.org>.

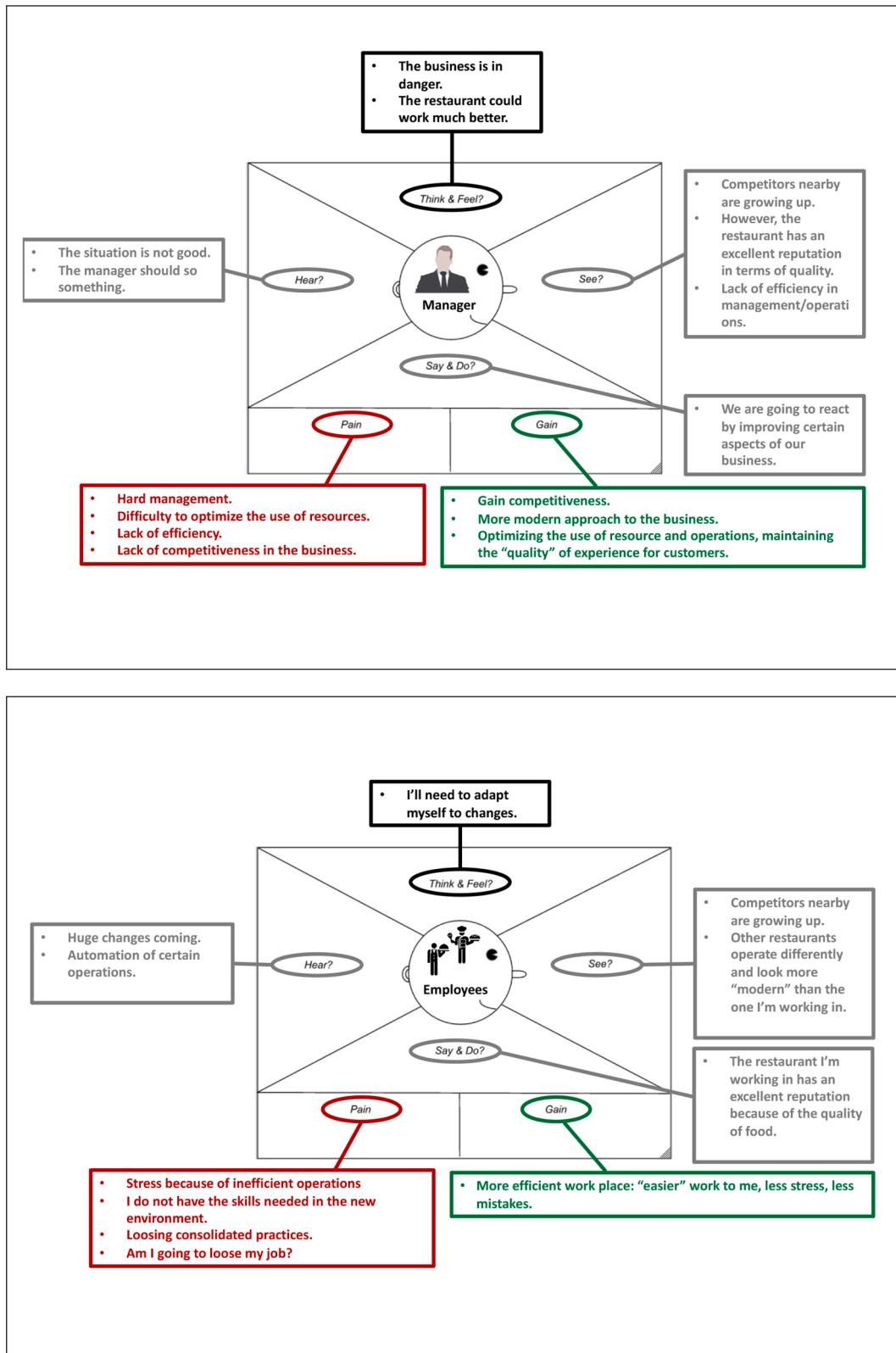


Fig. 5. Two EM examples.

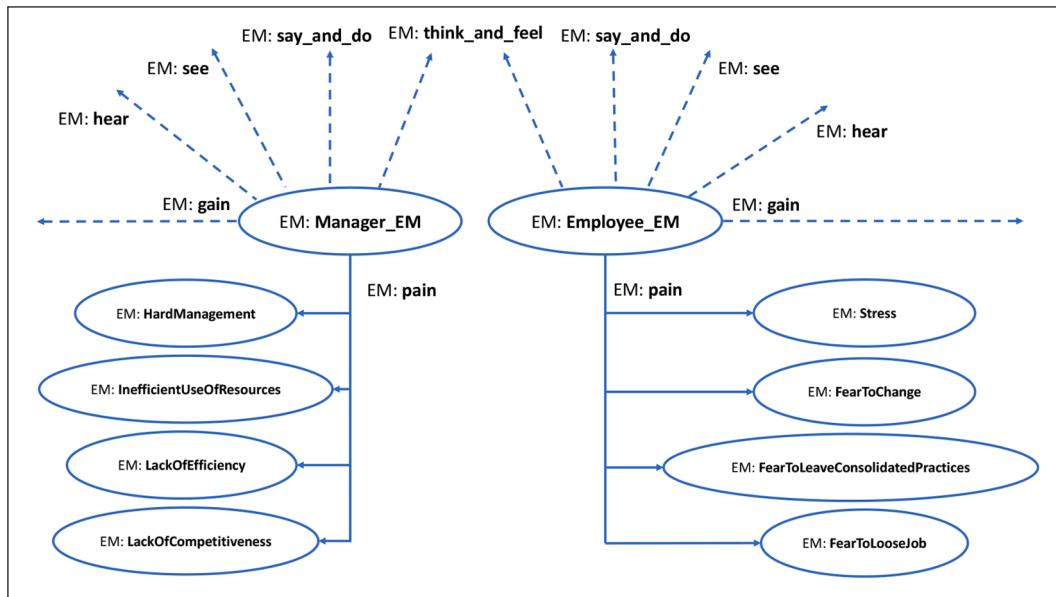


Fig. 6. Partial formal specification of EMs.

models characterized by 4 ([Gibbons, xxxx](#)), 5 ([Gibbons, xxxx](#)) and 6 components respectively. Intuitively, extensions and customised semantic relationships (equivalence in this specific example) may be defined by adopting OWL mechanisms. An exhaustive discussion of such mechanisms is out of the scope of this paper.

5. Towards AI-powered tools for design thinking

Artificial Intelligence (AI) applications are proliferating and the actual impact on our lives is topic of intense discussion ([Makridakis, 2017](#)) along a number of ethical concerns ([Russell, Hauert, Altman, & Veloso, 2015](#)). While the relationship between AI and creativity is definitely not a novelty ([Boden, 1998](#)), the last generation technology and its unstoppable evolution within a data-intensive society could radically change the current understanding of Design Thinking and, more in general, of system design.

The proposed ontological approach in a fully machine-processable context, which assumes interoperability at a Web – i.e. global – level, intrinsically enables the process within Knowledge-based Systems, which are constantly evolving themselves ([Zhang, Chen, Lu, & Zhang, 2017](#)). In general terms, a rich knowledge-base supported by smart interaction features defines a completely novel scenario in which creativity meets data-centric approaches at a high-level of abstraction.

The specific step addressed in the paper is related to stakeholder analysis by adopting empathy mapping. We believe that such a design step, characterised by a strictly analytical focus, can be especially benefited by the ontological approach which is likely to facilitate the combination of situation-specific and contextual information, as well as it could contribute to minimise biases and differentiate useful from misleading evidence. In other words, while the impact and effect in practice of AI on the whole Design Thinking process is largely to be assessed and can probably considered as application-specific, a restricted emphasis on the analysis step allows much more focused considerations which points towards a more evidence-based and data-driven resulting analysis. However, despite the optimistic interpretation, some risks are easily identifiable a priori as an analysis that relies

on a concrete knowledge base could further empower bias, eventually also from the organizational culture ([Elsbach & Stigliani, 2018](#)).

Overall, we do expect the ontological approach to make the knowledge resulting from the different sources (e.g. complex Business Analytics) actionable in practice and, in the limit of the possible, to be reusable in context.

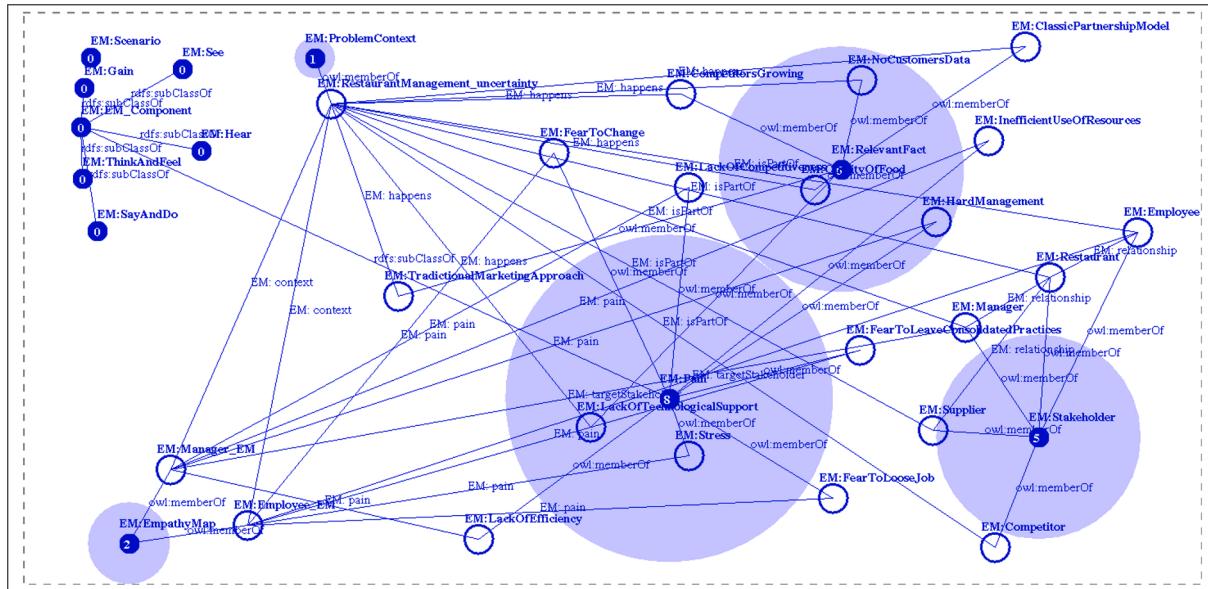
6. Conclusions and future work

Focusing on the empathy mapping phase, we have proposed an ontological approach to Design Thinking. As extensively discussed, it enables any system or tool adopting such a philosophy within the Semantic Web. The capabilities in terms of data integration and re-use via interoperability are automatically integrated with a number of advanced tools and techniques (automatic reasoning, complex query, visualization) to support the development of advanced feature within the different application domains.

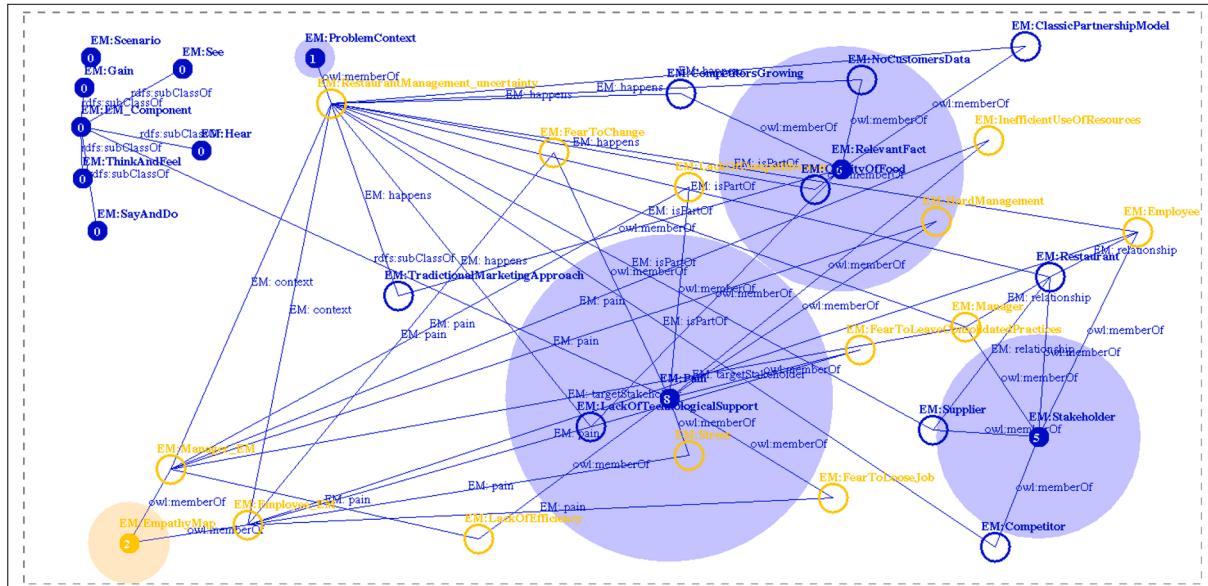
We believe that the ontological approach can drive and optimally support the application of Design Thinking in the context of the most relevant trends which currently assume or are based on large amount of heterogeneous data. We believe that, under the realistic assumption that any problem is somehow unique or presents anyway unique characteristics, increasing the capabilities in terms of analysis by properly supporting data-driven and evidence-based approaches can further empower the Design Thinking philosophy. The ability to systematically and automatically compare different scenarios or to perform cross-scenario analysis of a given stakeholder are clear examples of added value to system designers.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



(a) Visualization as a Knowledge Graph.



(b) Visualization of query result.

Fig. 7. Visualizations as a Knowledge Graph.

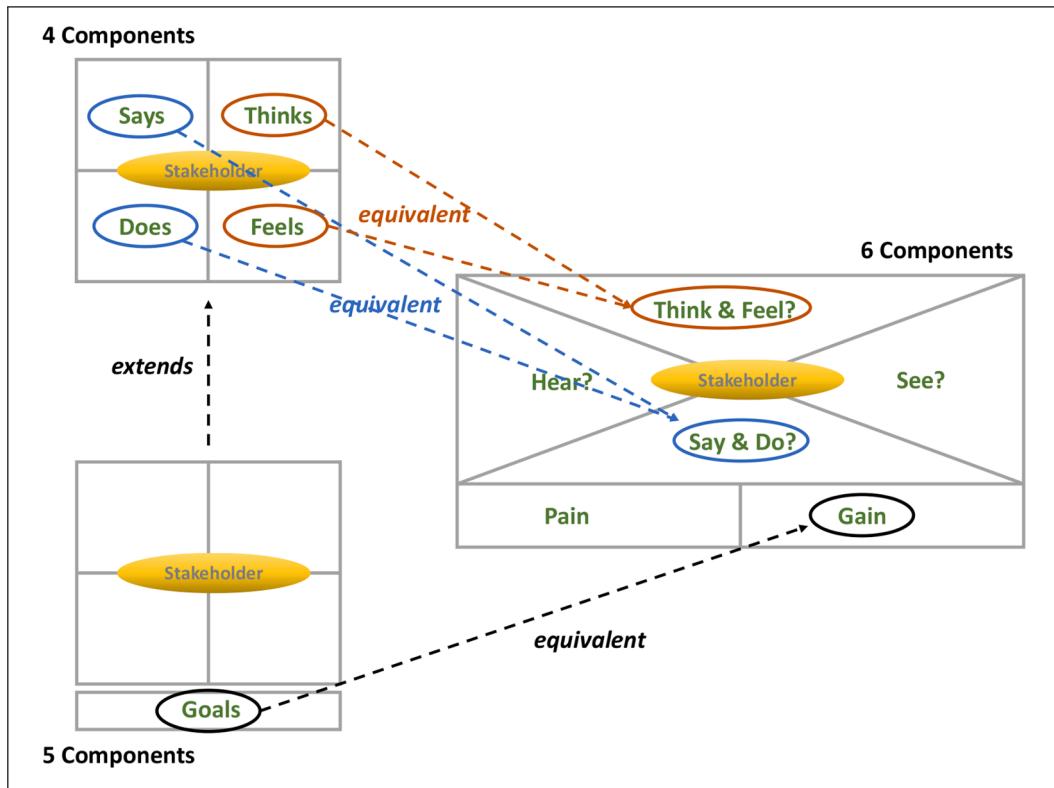


Fig. 8. Integration of models characterised by a different number of components.

Acknowledgements

I would like to thank the Editors and the anonymous Reviewers for providing a constructive, encouraging and addressable feedback that has contributed in a determinant way to improve this paper.

References

- Abel, F., Gao, Q., Houben, G.-J., & Tao, K. (2011). Semantic enrichment of twitter posts for user profile construction on the social web. In *Extended semantic web conference* (pp. 375–389). Springer.
- Angeletou, S. (2008). Semantic enrichment of folksonomy tagspaces. In *International semantic web conference* (pp. 889–894). Springer.
- Belsky, M., Sacks, R., & Brilakis, I. (2016). Semantic enrichment for building information modeling. *Computer-Aided Civil and Infrastructure Engineering*, 31(4), 261–274.
- Berners-Lee, T., Hendler, J., & Lassila, O. (2001). The semantic web. *Scientific American*, 284(5), 34–43.
- Bizer, C., Heath, T., & Berners-Lee, T. (2011). Linked data: The story so far. In *Semantic services, interoperability and web applications: emerging concepts* (pp. 205–227). IGI Global.
- Björgvinsson, E., Ehn, P., & Hillgren, P.-A. (2012). Design things and design thinking: Contemporary participatory design challenges. *Design Issues*, 28(3), 101–116.
- Bland, D. (2012). Agile coaching tip—what is an empathy map? Available in <http://www.bigvisible.com/2012/06/what-is-an-empathy-map>.
- Boden, M. A. (1998). Creativity and artificial intelligence. *Artificial Intelligence*, 103(1–2), 347–356.
- Brown, T., et al. (2008). Design thinking. *Harvard Business Review*, 86(6), 84.
- Brown, T., & Wyatt, J. (2010). Design thinking for social innovation. *Development Outreach*, 12(1), 29–43.
- Cardoso, J. (2007). The semantic web vision: Where are we? *IEEE Intelligent Systems*, 22 (5), 84–88.
- d'Aquin, M., & Noy, N. F. (2012). Where to publish and find ontologies? A survey of ontology libraries. *Journal of Web Semantics*, 11, 96–111.
- Davis, B. M. (2010). Creativity & innovation in business 2010 teaching the application of design thinking to business. *Procedia-Social and Behavioral Sciences*, 2(4), 6532–6538.
- Dong, X. L., & Srivastava, D. (2013). Big data integration. In *2013 IEEE 29th international conference on data engineering (ICDE)* (pp. 1245–1248). IEEE.
- Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies*, 32(6), 521–532.
- Elsbach, K. D., & Stiglani, I. (2018). Design thinking and organizational culture: A review and framework for future research. *Journal of Management*, 44(6), 2274–2306.
- Fensel, D. (2002). Ontology-based knowledge management. *Computer*, 35(11), 56–59.
- Ferreira, B., Conte, T., & Barbosa, S. D. J. (2015). Eliciting requirements using personas and empathy map to enhance the user experience. In *2015 29th Brazilian symposium on software engineering* (pp. 80–89). IEEE.
- Ferreira, B., Silva, W., Oliveira, E. A., Jr, & Conte, T. (2015). Designing personas with empathy map. In *SEKE* (Vol. 152).
- Fischer, M. (2015). Design it! solving sustainability problems by applying design thinking. *GAIA-Ecological Perspectives for Science and Society*, 24(3), 174–178.
- Friendly, M. (2008). A brief history of data visualization. In *Handbook of data visualization* (pp. 15–56). Springer.
- Fulea, M., & Brad, S. (2011). Ontology-based approach for supporting creativity in a pss design methodology. In *Functional thinking for value creation* (pp. 75–80). Springer.
- Gibbons, S. *Empathy mapping: The first step in design thinking*. URL: <https://www.ngngrp.com/articles/empathy-mapping/> (accessed: 8-02-21).
- Glimm, B., Horrocks, I., Motik, B., Stoilos, G., & Wang, Z. (2014). Hermit: an owl 2 reasoner. *Journal of Automated Reasoning*, 53(3), 245–269.
- Guarino, N. (1995). Formal ontology, conceptual analysis and knowledge representation. *International Journal of Human-computer Studies*, 43(5–6), 625–640.
- Heiler, S. (1995). Semantic interoperability. *ACM Computing Surveys (CSUR)*, 27(2), 271–273.
- Hamilo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction*, 26(1), 48–94.
- Jackson, P. (2004). *Ontology and business: Creating structure for storing and accessing organizational knowledge on intranets*.
- Johansson-Skoldberg, U., Woodilla, J., & Cetinkaya, M. (2013). Design thinking: past, present and possible futures. *Creativity and Innovation Management*, 22(2), 121–146.
- Khan, W. A., Khattak, A. M., Hussain, M., Amin, M. B., Afzal, M., Nugent, C., & Lee, S. (2014). An adaptive semantic based mediation system for data interoperability among health information systems. *Journal of Medical Systems*, 38(8), 1–18.
- Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H.-Y. (2015). *Design thinking for education: Conceptions and applications in teaching and learning*. Springer.
- Kolko, J. (2018). The divisiveness of design thinking. *Interactions*, 25(3), 28–34.
- Kollia, I., Glimm, B., & Horrocks, I. (2011). SPARQL query answering over OWL ontologies. In *Extended semantic web conference* (pp. 382–396). Springer.
- Koppen, E., & Meinel, C. (2015). Empathy via design thinking: creation of sense and knowledge. In *Design thinking research* (pp. 15–28). Springer.
- Lee, J., & Jeong, Y. (2012). User-centric knowledge representations based on ontology for aec design collaboration. *Computer-aided design*, 44(8), 735–748.
- Lee, O.-J., & Jung, J. J. (2019). Integrating character networks for extracting narratives from multimodal data. *Information Processing & Management*, 56(5), 1894–1923.
- Liedtka, J., & Ogilvie, T. (2011). *Designing for growth: A design thinking tool kit for managers*. Columbia University Press.
- Luka, I., et al. (2014). Design thinking in pedagogy. *The Journal of Education, Culture, and Society*, 2, 63–74.
- Madnick, S., & Zhu, H. (2006). Improving data quality through effective use of data semantics. *Data & Knowledge Engineering*, 59(2), 460–475.

- Makridakis, S. (2017). The forthcoming artificial intelligence (ai) revolution: Its impact on society and firms. *Futures*, 90, 46–60.
- Manzanedo, R. D., & Manning, P. (2020). Covid-19: Lessons for the climate change emergency. *Science of the Total Environment*, 742, Article 140563.
- Martin, R. (2010). Design thinking: Achieving insights via the “knowledge funnel”. *Strategy & Leadership*.
- Martin, R., & Martin, R. L. (2009). *The design of business: Why design thinking is the next competitive advantage*. Harvard Business Press.
- Menges, A., & Ahlquist, S. (2011). *Computational design thinking: Computation design thinking*. John Wiley & Sons.
- Mintrom, M., & Luetjens, J. (2016). Design thinking in policymaking processes: Opportunities and challenges. *Australian Journal of Public Administration*, 75(3), 391–402.
- Musen, M. A. (2015). The protégé project: A look back and a look forward. *AI Matters*, 1 (4), 4–12.
- Negru, S., & Buraga, S. (2012). A knowledge-based approach to the user-centered design process. In *International joint conference on knowledge discovery, knowledge engineering, and knowledge management* (pp. 165–178). Springer.
- Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers*. John Wiley & Sons.
- Otter, D. W., Medina, J. R., & Kalita, J. K. (2020). A survey of the usages of deep learning for natural language processing. In *IEEE Transactions on Neural Networks and Learning Systems*.
- Oxman, R. (2004). Think-maps: Teaching design thinking in design education. *Design Studies*, 25(1), 63–91.
- Pai, F.-P., Yang, L.-J., & Chung, Y.-C. (2017). Multi-layer ontology based information fusion for situation awareness. *Applied Intelligence*, 46(2), 285–307.
- Panetto, H., Dassisti, M., & Tursi, A. (2012). Onto-pdm Product-driven ontology for product data management interoperability within manufacturing process environment. *Advanced Engineering Informatics*, 26(2), 334–348.
- Pileggi, S. F., Fernandez-Llatas, C., & Traver, V. (2012). When the social meets the semantic: Social semantic web or web 2.5. *Future Internet*, 4(3), 852–864.
- Pileggi, S. F., & Hunter, J. (2017). An ontological approach to dynamic fine-grained urban indicators. *Procedia Computer Science*, 108, 2059–2068.
- Pujara, J., Miao, H., Getoor, L., & Cohen, W. (2013). Knowledge graph identification. In *International semantic web conference* (pp. 542–557). Springer.
- Ramaprasad, A., & Syn, T. (2013). Design thinking and evaluation using an ontology. In *European design science symposium* (pp. 63–74). Springer.
- Ristoski, P., & Paulheim, H. (2016). Semantic web in data mining and knowledge discovery: A comprehensive survey. *Journal of Web Semantics*, 36, 1–22.
- Roberts, J. P., Fisher, T. R., Trowbridge, M. J., & Bent, C. (2016). A design thinking framework for healthcare management and innovation. In *Healthcare* (Vol. 4, pp. 11–14). Elsevier.
- Rohloff, K., Dean, M., Emmons, I., Ryder, D., & Sumner, J. (2007). An evaluation of triple-store technologies for large data stores. In *OTM confederated international conferences on the move to meaningful internet systems* (pp. 1105–1114). Springer.
- Russell, S., Hauert, S., Altman, R., & Veloso, M. (2015). Ethics of artificial intelligence. *Nature*, 521(7553), 415–416.
- Schriml, L. M., & Mitraka, E. (2015). The disease ontology: fostering interoperability between biological and clinical human disease-related data. *Mammalian Genome*, 26 (9), 584–589.
- Seidel, V. P., & Fixson, S. K. (2013). Adopting design thinking in novice multidisciplinary teams: The application and limits of design methods and reflexive practices. *Journal of Product Innovation Management*, 30, 19–33.
- Sirin, E., Parsia, B., Grau, B. C., Kalyanpur, A., & Katz, Y. (2007). Pellet: A practical owl-dl reasoner. *Web Semantics: Science, Services and Agents on the World Wide Web*, 5(2), 51–53.
- Stueber, K. (2013). Empathy. *International Encyclopedia of Ethics*.
- Thomas, S. (2005). Pervasive, persuasive elearning: Modeling the pervasive learning space. In *Third IEEE international conference on pervasive computing and communications workshops* (pp. 332–336). IEEE.
- W3C - OWL 2 Web Ontology Language Document Overview (Second Edition). <https://www.w3.org/TR/owl2-overview/>. Accessed: 18-09-20.
- W3C - SPARQL 1.1 Overview. URL: <https://www.w3.org/TR/sparql11-overview/> (accessed: 18-09-20).
- Wong, A. K. Y., Ray, P., Parameswaran, N., & Strassner, J. (2005). Ontology mapping for the interoperability problem in network management. *IEEE Journal on Selected Areas in Communications*, 23(10), 2058–2068.
- Zhang, Y., Chen, H., Lu, J., & Zhang, G. (2017). Detecting and predicting the topic change of knowledge-based systems: A topic-based bibliometric analysis from 1991 to 2016. *Knowledge-Based Systems*, 133, 255–268.
- Zhang, Y., Sheng, M., Zhou, R., Wang, Y., Han, G., Zhang, H., Xing, C., & Dong, J. (2020). Hkgb: An inclusive, extensible, intelligent, semi-auto-constructed knowledge graph framework for healthcare with clinicians' expertise incorporated. *Information Processing & Management*, 57(6), Article 102324.
- Zhu, G., Corcoran, J., Shyy, P., Pileggi, S. F., & Hunter, J. (2018). Analysing journey-to-work data using complex networks. *Journal of Transport Geography*, 66, 65–79.