An Ontology-Based Well-Founded Proposal for Modeling Resources and Capabilities in ArchiMate

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Abstract— **The importance of capabilities and resources for portfolio management and business strategy has been recognized in the management literature and on a recent proposal to extend ArchiMate, which includes these concepts in order to improve ArchiMate's coverage of portfolio management. This paper presents an ontological analysis of the concepts introduced in that proposal, focusing in particular on the resource, capability and competence concepts. As a result, it proposes well-founded recommendations for improvements, enhancing its suitability and integration possibilities.**

Keywords: Capability, Resource, Enterprise Architecture Modelling, Ontology-based Semantics, ArchiMate

I. INTRODUCTION

Constant shifts in markets, competition, technology and regulation drive organizations to promote changes, and to continuously adapt and improve their organizational structures and business processes. Failing to address these shifts affects organizational performance negatively [1]. A fundamental question in the field of strategic management is how organizations gain and sustain competitive advantages [2]. Research has shown that the average period during which organizations are able to sustain their competitive advantage has decreased over time [3]. This suggests that organizations have to build successive temporary advantages [4]. In order to be able to accomplish this, an organization needs to employ its resources and capabilities in the most effective and efficient manner. This observation is not only valid at the level of one organization, but also within business networks, in which organizations establish partnerships with the goal of pooling their capabilities and resources and improving their own inter-enterprise relationships. A major concern on strategic management focuses on improving the usage of organizational capabilities and resources, in order to improve performance, quality and to reduce costs [5] [6]. The suggestion that organizational resources and capabilities are key success factors for competitive advantage have been proposed already in the 90's [7] and is still a predominant topic [8].

In the work presented in [9], many organizations have been analyzed in order to answer the question "to what extent do access and changes to resource bases influence the development of dynamic capabilities in new firms?". The work provides statistical evidence for the relationship between organizational resources and the subsequent capabilities of the organization. Different resources lead to different capabilities, and the changes of resources over time have a great impact on organizations' capabilities [9].

Resources-centric theories regard an organization as a bundle of resources [10]. They suggest that the resources' properties (e.g., rare, valuable, non-substitutable or inimitable) confer organizations competitive advantage [11]. However, these works also observe that resources by themselves are not useful unless they are correctly employed [10]. Furthermore, the way they are used defines the outcome: [12] stated that "exactly the same resources when used for different purposes or in different ways and in combination with different types or amounts of other resources provide a different service or set of services".

Given the importance of capabilities and resources for the enterprise, an approach to integrate capabilities and resources in the discipline of Enterprise Architecture (EA) has been proposed in [13]. This approach entails the extension of the ArchiMate enterprise architecture modeling language [14] with Business Strategy and Valuation Concepts (BSVC). The BSVC includes the definition of the concepts of capability, resource, competence and risk. Its aim is to improve ArchiMate's portfolio management capabilities and to align it with the disciplines of business strategy and portfolio management. The various concepts are related to each other and to the ArchiMate core, and it is demonstrated how they could be used in enterprise modeling.

Similarly to other earlier ArchiMate extension proposals (e.g., the motivation extension [15]), the initial development of the BSVC has been conducted without a rigorous definition of the semantics of the proposed modeling elements. The absence of such definitions could lead to several modeling and communication problems. For example, when various modelers share a model, this could lead to the False Agreement Problem [16], in which each modeler would come to a different interpretation of the same model and would not be aware of the conflict. This would result in enterprise architecture models that cannot serve their purpose

as tools for communication between stakeholders, and would decrease their value in the pursuit of informed decision-making.

In order to address this shortcoming, this paper discusses the semantics of the resource, capability and competence modeling elements, and proposes well-founded recommendations for improvements of the original proposal. We analyze and interpret the elements of the extension with respect to the Unified Foundational Ontology (UFO). The remainder of this paper is structured as follows. Section II describes the Business Strategy and Valuation Concepts extension briefly and introduces a running example. Section III introduces the ontological foundational concepts used in our analysis. Sections IV, V and VI provide interpretations for the concepts of capability, resource and competence, respectively. Each concept is interpreted according to the metamodel, the textual definitions, and the examples of usage provided proposed in [13], and in the related literature. Section VII summarizes our findings and postulates a number of improvement recommendations. Section VIII discuss related work. Finally, Section IX presents our conclusions and outlines future work.

II. THE BUSINESS STRATEGY AND VALUATION CONCEPTS EXTENSION

The BSVC extension is based on the analysis and review of relevant business strategy and portfolio management literature [13]. For this reason, many concepts present in other approaches, such as [17] and [18] have been incorporated in the BSVC.

Table 1 shows the definitions and concrete syntax for the modeling elements introduced by the extension. Note that in this section we have preserved the definitions that were provided originally in [13]. These will be object of analysis in Sections IV, V and VI.

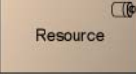Table 1. Original definitions and syntax of BSVC constructs

Modeling element	Definition	Concrete syntax
Resource	"an asset owned or controlled by an individual or organization"	Resource
Capability	"the ability (of a static structure element, e.g., actor, application component, etc.) to employ resources to achieve some goal"	Capability
Competence	"the definition of competence […] is almost identical with that of personnel-based resources".	Resource

Figure 1 shows the metamodel fragment, as proposed in [13], for the integration of the BSVC with the ArchiMate core metamodel and its extensions [14].

The *resource* concept is prominently present in most valuation techniques, in business modeling approaches, and in constraint optimization models in which they are mathematically defined and constrained. This confirms the importance given to the concept in the management literature [13]. A resource represents an asset owned or controlled by an individual or organization. Resources are related to the
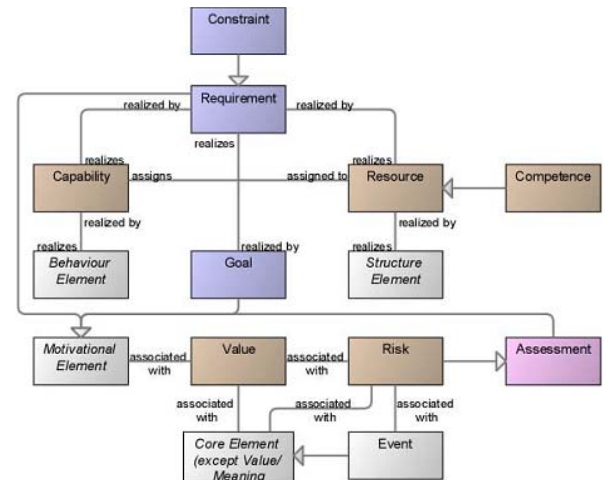

Figure 1- Proposal metamodel[13]

motivation extension, in particular to requirements and goals, through the realization relation. The argument for this relationship is the fact that goal achievement assumes availability and (constrained) consumption of certain resources. This view is based on the mathematical formulation of constrained optimization models, in which a goal function is minimized/maximized subject to a system of constraints (expressed as inequalities) imposed to the resources to be consumed for the achievement of the goal. Thus, a resource may realize a requirement, which in turn, may realize a goal. Furthermore, a resource is realized by structure elements, and is regarded in [13] as an abstraction of these elements.

Capability is defined as the ability (of a static structure element, e.g., actor, application component, etc.) to employ resources to achieve some goal. Similarly to resource, capability is regarded in [13] as an abstraction of some behavior. The assignment relationship between resource and capability expresses the ability to employ (i.e., configure, integrate, etc.) resources.

The *competence* concept is introduced in [13] as a specialization of resource based on definition of competence proposed by [19], which equates competence to personnel-based resources.

Figure 2 shows an ArchiMate model which we used as an example in this paper. The example focuses on the 'All Risks Insurance' product, and on the capabilities ('Claim Handling Capability', 'Insuring Capability', 'Selling Capability', etc.) associated with this product, The example also reviews the resources assigned to the capabilities ('Damage Assessment Resources', 'Money', 'Authorized Garage', etc.). As in any real business situation, in our example some restrictions may hold that constrain capabilities, and the usage of resources. We formulated them as requirements that must be satisfied: the Damage assessment team may not be larger than 20 full time employees, while the handling costs per claim should not be higher than 20 €. The example shows that capabilities may be decomposed into other capabilities, and may be realized by some behavior elements (as in the case of 'Insuring Capability' and 'Claim Handling Capability'). Similarly, resources can be decomposed and are realized by structure elements.
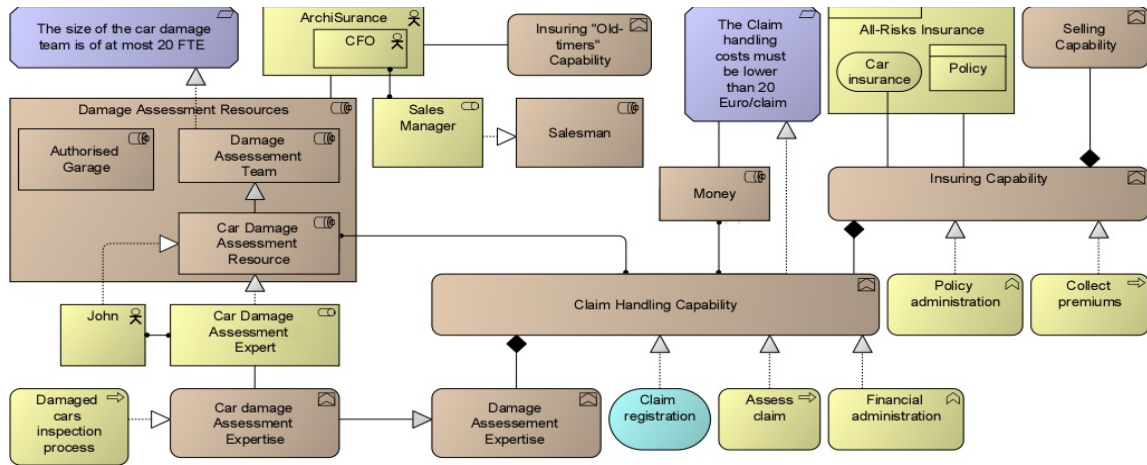
Figure 2- Running Example

III. ONTOLOGICAL FOUNDATIONS

In our ontological analysis we make use of the Unified Foundational Ontology (UFO) as semantic foundation. The UFO foundational ontology has been previously used to analyze and interpret the semantics of the ArchiMate motivation concepts, having led to recommendations of that proposal that have been incorporated in the latest ArchiMate specification [15]. Further, UFO has been also employed in other semantic analyses, such as that of ARIS EPCs [20], i*/TROPOS [21], goals and business processes models [22] and role-related concepts in EA [23]. For a full discussion regarding this ontological foundation we refer to [24], and [25]. This section is based on the UFO description in [15].

A fundamental distinction in this ontology is between the categories of individuals and universals. Universals are predicative terms that can be applied to a multitude of individuals, capturing their general aspects. Individuals are entities that exist in reality possessing a unique identity and that can instantiate one or more universals.

Further, UFO makes a distinction between the concepts of endurants and events. Endurants are individuals that persist in time while keeping their identity, in the sense that if we say that in circumstance *c1* an endurant *e* has a property *p1* and in circumstance *c2* a property *p2* (possibly incompatible with *p1*), e is the same endurant in each of these situations. Examples can include a particular person (say Peter) weighting 70kg in one circumstance and 78kg in a different circumstance, being the same individual (Peter) in all circumstances. Other examples include organizations (the University of Twente, the Federal University of Espírito Santo) and everyday objects (a ball, an apple, etc.). Events, in contrast, are individuals composed of temporal parts, they happen in time, in the sense that they extend in time and accumulate temporal parts. Examples include a particular execution of a business process, a meeting or a birthday party. Whenever an event occurs, it is not the case that all of its temporal parts necessarily occur. For instance, if we consider a business process "Buy a Product" at different time instants, at each time instant only some of its temporal parts are occurring.

A substantial is an endurant that does not depend existentially on any other individual, what is usually referred by the common sense term "object". In contrast with substantials, moments (also known as 'abstract particulars' and 'tropes' [26], [27]) are existentially dependent entities, i.e., for a moment x to exist, another individual must exist, named its bearer. Examples of moments include an apple's color, John and Mary's marriage, an electric charge on a conductor, etc. Moments include both qualities (e.g., color, weight, temperature) and dispositions (e.g., the fragility of a glass, the disposition of a magnet to attract metallic material). Dispositions are moments that are only manifested in particular situations, and that can also fail to be manifested. When manifested, they are manifested through the occurrence of events. Take for example the disposition of a magnet *m* to attract metallic material. The object *m* has this disposition even if it is never manifested, for example, because *m* was never close to any magnetic material. Nonetheless, *m* can certainly be said to possess that intrinsic property [27],[28].

Existential dependence can be used to differentiate intrinsic and relational moments. Intrinsic moments are dependent on a single individual, while relational moments (also called relators) depend on a plurality of individuals. Examples of the first include an apple's weight and color, while examples of the latter include John and Mary's marriage, John's enrollment at the University of Twente. A relator is the truth-maker of a material relation.

A universal is *rigid* if it necessarily applies to its instances, i.e., in every possible world (e.g., Apple, Person). A kind is the rigid substantial universal that supplies a principle of identity for substantial individuals that instantiate them. Every substantial individual must be an instance of exactly one kind. In contrast to rigid universals, a universal is *anti-rigid* if it does not apply necessarily to all its instances. Roles are anti-rigid and relationally-dependent universals (e.g., Student, Husband). This means that roles are played by a substantial whenever there is a relator connecting it to one or more other substantials or when it participates in an event playing what is called a processual role.

Whenever different kinds have similar properties they may be subsumed by substantial universals termed rigid mixins (e.g., Physical Object, Living Entity). Some mixins are

anti-rigid and represent abstractions of common properties of roles. These are termed role mixins. An example of role mixin is 'customer', which can be played by 'persons' and 'organizations'.

An agent is a specialization of substantial individual, representing entities capable of bearing intentional moments. These include mental states, such as individual beliefs, desires and intentions. Intentionality should not be understood as the notion of "intending something", but as the capacity to refer to possible situations of reality [29]. Every intentional moment has an associated proposition which is called the propositional content of the moment. In general, the propositional content of an intentional moment can be satisfied (in the logical sense) by situations in reality. Every intentional moment has a type (belief, desire or intention). The propositional content of a belief is what an agent holds as true. Examples include one's belief that the Eiffel Tower is in Paris and that the Earth orbits around the Sun. A desire expresses the will of an agent towards a possible situation (e.g., a desire that Brazil wins the Next World Cup), while an intention expresses desired states of affairs for which the agent commits to pursuing (internal commitment) (e.g., John's intention of going to Paris to see the Eiffel Tower).

Actions are intentional events, i.e., events with the specific purpose of satisfying (the propositional content of) some intention of an agent. The propositional content of an intention is termed a goal. Only agents are said to perform actions [22], as opposed to non-agentive objects that participate (non-intentionally) in events.

Agents can be further specialized into physical agents (e.g., a person) and social agents (e.g., an organization). Social agents are further specialized into institutional agents and collective social agents. Institutional agents are composed of a number of other agents, exemplifying what is termed a functional complex. "The parts of a functional complex have in common that they all possess a functional link with the complex. In other words, they all contribute to the functionality (or the behavior) of the complex" [24]. In addition to institutional agents, UFO also acknowledges the existence of collective social agents, which are distinguished from institutional agents in that all its members play the same role in the collective.

Similarly to agents, non-agentive objects can be specialized into physical objects and social objects. A category of social objects of particular interest to us is that of normative description. Normative descriptions are social objects that create social entities recognized in that context. Examples of normative descriptions include a company's regulations and public laws. Examples of social entities that can be defined by normative descriptions include social roles (e.g., president, manager, sales representative), social role mixins (whose instances are played by entities of different kinds, e.g., customer, which can be played by persons and organizations), social agent universals (e.g., that of political party, education institution), social agents (e.g., the Brazilian Labour Party, the University of Twente), social object universals (e.g., currency) and other social objects (e.g., the US dollar) or even other normative descriptions (e.g., a piece of legislation). Normative descriptions are recognized by at least one social agent. Figure 3 shows a fragment of the specializations of individuals in UFO.

IV. ONTOLOGICAL ANALYSIS OF RESOURCE

In this section we discuss the ontological analysis and interpretation of the *resource* modeling element introduced in [13]. We discuss possible interpretations in terms of UFO and consider the consequences of the various interpretations to the usage of the language. The problems revealed here are labeled and are object of recommendations in Section VII.

The Oxford Dictionary defines resource as "a stock or supply of money, materials, staff, and other assets that can be drawn on by a person or organization in order to function effectively". In [13], a similar intuition is put forward when motivating the *resource* element in the BSVC extension: "the achievement of a *goal* assumes the availability and (constrained) consumption of certain *resources*". Further, *resources* are also characterized as "assets owned or controlled by an organization".

Since "assets" are (valuable) things, in a first examination, this characterization seems to suggest that *resources* represent specific individuals, such as *business actors* (e.g., in case of staff as *resource*) or *business objects* (agentive
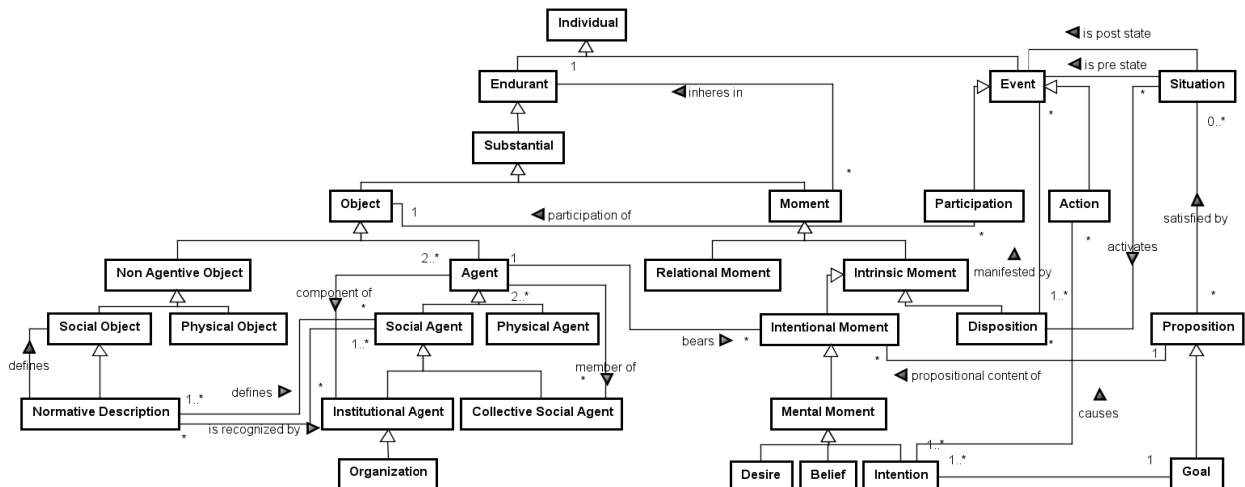

Figure 3 - Fragment of UFO depicting specializations of Individual

objects (agents) or non-agentive objects). Nevertheless, this interpretation would show a clear case of construct redundancy [24], as the additional *resource* modeling element would serve no purpose, being supplanted by the previously existing *structure elements* of the language (such as *business actor* and *business object*). We must conclude this is not the intention of the designers of the extension, which indicate further that a *resource* is "an abstraction of *structure elements*" and include a "realizes" relation that may be used to connect *structure elements* to the *resources* they "realize". This suggests that it is not the *specific structure* element that is represented using a *resource*, but some more abstract notion, which reveals the dependence on a *structure element* with certain characteristics without specifying the particular element involved. In other words, we understand that the *resource* element defines some type of *structure element* (a universal), and that the *structure element* that *realizes* the *resource* instantiates this type. An example of this would be a model that includes a *business actor* 'John' that *realizes* a *resource* called 'Car Damage Assessment Resource'.

If we further consider that *resources* are used in the scope of the efforts to achieve *goals*, we can understand that a *resource* refers to the role an object (agentive or non-agentive) plays when employed in the scope of these efforts. In the example above, 'John' functions as a 'Car Damage Assessment Resource' in some context of the organization (for example that of the process of assessing damages).

Further, in order to play a particular role, an object may be required to instantiate some particular type (what is called an "allowed type" in [30].) For example, any 'Car Damage Assessment Resource' may need to possess specific damage assessment skills, and thus instantiate some specific universal that is characterized by these skills.

Thus an intermediate conclusion is that *resource* represents an externally dependent universal (either a role or role mixin) that may be instantiated by objects of a particular allowed type. The fact that *resource* models both the role an object plays in a particular context of usage as well as its allowed type has some consequences to the terms used in the label of a resource. In some cases, such as 'Car Damage Assessment Resource', the context of usage is emphasized, focusing thus on the role or role mixin that is instantiated when the resource is used; in other cases, such as 'Money', the allowed type required for role playing is emphasized in the label.

An insight that comes out of this interpretation is that, as a role (mixin), a *resource* should have a context of usage, that in UFO is defined in the scope of a material relation (or in the scope of an event). This means some asset is a *resource* in a defined context, but not in others, e.g., the 'Car Damage Assessments Expert' is a *resource* in the 'Damaged cars inspection process' because of the 'Car Damage Assessment Expertise', but it should not be considered a *resource* for the 'Collect premiums' *process*. This is not directly expressible on the metamodel, because there is no notion of 'use' of *resources*. We label this as problem 'R1'.

The *resource* concept is also defined as "an asset owned or controlled by an individual or organization". Being "owned or controlled" is understood as being available for the organization, e.g. by an employment contract between employers and employees, or by having the right/ownership over a certain object. For the cases in which the *resource* is an agentive element (agent) we understand the 'controlling' in the context of the social relator that bounds the particular individual or organization with the first, e.g., the employment contract. *A* controls *B* means that there is (possibly a set of) meta-commitment of *B* towards *A*. In other words, *A* has meta-claims over *B* and, hence, the ability to delegate to *B* and, consequently to increase its social ability [31]. For the interpretations in which the *resource* is a non-agentive object, we understand "the control or owning of the asset" as the ability to have that element participate in an event of interest, in which the organization *A* has a certain right with respect to the object *O* (for example a right to use, to consume, to destroy, to sell, etc). The current metamodel does not allow the modeler to identify who controls the resource (aside from the use of the very general and abstract *associated with* relation, which has no specific semantics). This could be an issue when there are multiple business actors (different organizations, business departments) that could control this resource. We call the lack of expressiveness of control relations 'R2'.

Note further that the extension does not distinguish between resources potentially played by agents from those potentially played by non-agentive objects. We call this lack of expressiveness 'R3'.

Other examples of usage indicate that not only *business actors* and *objects* may realize a *resource,* but also that *business roles* may be said to *realize* a *resource*. In our example the 'Car Damage Assessment Expert' *business role realizes* the 'Car Damage Assessment Resource'. In this case, we should understand that whichever object instantiates the role represented by the *business role* may also instantiate the role (mixin) represented by the *resource*. Intuitively in the example, not only 'John' but also any other damage assessment expert is a 'Car Damage Assessment Resource'. For these cases, the language does not settle whether one or more individuals instantiating the role (mixin) represented by the *resource* are required, used or controlled in the particular context. In other words, it is not possible to express whether all the instances of that type are required, used or controlled, if just one instance of that type is required, used or controlled or if an arbitrary set of instances of that type are required, used or controlled. We label this as problem 'R4'.

Further, the current ArchiMate language does not address the cases in which the *resources* are objects of interest or raw materials (e.g., 'Money' in the running example or gold, diamond, gas, etc), i.e., passive non-agentive elements. We believe the language designers have tried to cover this stretching the *resource* element, and using it directly to represent such objects. However, these would be *resources* that do not have any *structure element* to *realize* them, since there are no *structure elements* that can represent these types of objects in ArchiMate (the passive structure of ArchiMate focuses primarily on information objects). Also, in these cases, the *resources* are role (mixins) and the language will not be able to express if the same instance is to be considered a *resource* in various contexts (e.g. usage of the same

amount of money in different contexts). Also, there is no possibility to express any property associated to the element itself (e.g., quantity of money, gold carats). We label this as problem 'R5'.

The *resource* concept is related to the motivation extension through the *realization* relation, in which a '*resource realizes a requirement'*. According to [15], a *requirement* corresponds to a normative description, which states that if a system (in a broad sense) is to exist, then it must satisfy a particular proposition. In this case, we understand that proposition refers to the object (or objects) playing the *resource* role. Any instance instantiating the role (mixin) represented by the *resource* must satisfy the *requirement's* proposition. To put it simply, a *requirement* adds characteristics to a *resource's* allowed type.

The proposal also states that "the achievement of a *goal* assumes the availability and (constrained) consumption of certain *resources*". However, *goals* are not associated directly to *resources* and the proposal is silent on the issue of resource consumption. *Resources* and *goals* are only indirectly related through the '*goal is realized by requirement'* and the '*requirement is realized by resource'* relations. At this point, no interpretation can be given to the textual definition and further investigation would be required on the *resources* availability and consumption topic.

Now we focus on the common ArchiMate relationships that apply to the *resource* concept (specialization and aggregation). We interpret the *specialization* relation between *resources* as subsumption between the roles or (role mixins) represented by the *resources*. The *aggregation* relation between *resources* suggests some sort of whole-part relationship (*aggregation* in ArchiMate may be represented by containment, see in Figure 2 the relation between 'Damage Assessment Resources' as a whole and 'Authorised Garage', 'Damage Assessment Team' and 'Car Damage Assessment Resource'). Since *resources* may represent both agentive and non-agentive objects, it would be possible to combine these with aggregation. We interpret this as a very general sort of whole-part relation known as mereological sum. We must note the fact that there is no distinction between AND or OR resource aggregations in ArchiMate. Thus, when *resources* are aggregated, it is unclear whether all the aggregated *resources* are required/used, or whether one or any arbitrary number of them is required. We label this 'R6'.

V. ONTOLOGICAL ANALYSIS OF CAPABILITY

In this section we discuss the ontological analysis and interpretation of the *capability* modeling element introduced in [13]. Problems found by the analysis are labeled and are object of recommendations in Section VII.

The proposal defined *capability* as "the ability (of a static structure element, e.g., actor, application component, etc.) to employ *resources* to achieve some *goal*. [...] Also *capability* assumes the ability to employ (i.e., configure, integrate, etc.) resources". The definition also states that "*capability* (similarly to *resource*) can be seen as an abstraction of some behavior of the static *structure element*".

We intuitively understand that a *capability* is attributed to some agent and gives that agent its power to bring about some behavior in order to achieve a desired outcome. From the excerpt "of a static structure element, e.g., actor, application component, etc.", the *capability* appears to belong to the specific individual that is to bring about the desired outcome. This would lead us to interpret that *capabilities* are dispositions in UFO. However, carefully examining the "abstraction of some behavior" fragment, and considering the same pattern that was employed by the language designers with respect to *resources* (as "abstractions of structural elements"), we understand that *capabilities* should be interpreted as types of dispositions (disposition universals in UFO).

Often a *capability* represents a general disposition type. For example, the 'car damage assessment expertise' *capability* is a general disposition type that is implicitly specialized into a more specific type (e.g. the capabilities to assess car damage produced by fire, to assess car damage caused by flood, to assess car damage after a crash).

This dispositional account is also applicable for cases in which the organization might hire a different company to perform processes realizing a capability and still state to have that *capability* (in this case because it has the disposition of delegating it [21], [31]). This is related to the idea of what an organization can "socially perform". If *A* has a meta-commitment from *B* to execute *S* then *A* (socially) can do *S*. An object can have dispositions which arise from its parts (or from the network of its delegation relations [31]).

Preferably, the language should allow us to infer which individuals bear the dispositions that are related to that *capability*. However, the original metamodel does not include relations between the *capabilities* and the *structure elements* that are said to have the *capabilities* (such as a *business actor* or *business role*). As a consequence, the language does not allow one to identify the individuals or types of individuals which bear dispositions of the type presented by the *capability* (aside from using the generic and semantically-neutral *association* of ArchiMate). In other words, it is not possible to express in the language which *structure element* has a *capability* (including the *capabilities* an organization has), unless it is *realized* by some *behavior element* (we label this as 'problem C1'). For the case of *resources*, these are assigned to a *capability* (in the sense that they are used in order to leverage *capabilities*), but *resources* themselves do not have *capabilities* in the original extension. This is exemplified in Figure 2, in which the organization has not assigned the 'selling capability' to any resource. Since the language cannot express which are the *capabilities* beared by the 'Salesman' *resource* and the 'Sales Manager' *structure element (business role)*, the organization is not able to know which *resource* or *structure element* has the required 'selling capability', to properly assign its performance.

The *capability* concept has three defined relationships according to the original metamodel. We now focus on "*capability* realizes *requirement*". Again, according to [15], a *requirement* corresponds to a normative description, which states that if a system (in a broad sense) is to exist, then it must satisfy a particular proposition. In this case, we understand that proposition refers to the dispositions that instantiate

the disposition universal represented by the *capability*. The dispositions must be in accordance to the *requirement*, in order to satisfy its proposition.

We now focus on the relationships '*capability realized by behavior element*' and '*resource assigned to capability*'. We understand that the first needs to be considered also with the participation of the *resource* (via the '*resource assigned to capability*' relationship). We understand that this pattern of relations can have two different interpretations (we label this as 'problem C2'). A first one is that the *resource* object has a disposition that instantiates the disposition universal represented by the *capability*, and that the participation of the *resource* manifesting its disposition is required in order to perform the *behavior element* (an event universal), e.g., the *capability* 'Car damage Assessment Expertise' on Figure 2 is to be manifested in the 'Damaged cars inspection process' *business process* in order for the organization to perform that process. The second possible interpretation is that the *capability* is acquired (by the *resource)* with the performance of the *behavior element* [28], i.e., the *resource* acquires a *capability* after the *process* is performed e.g. The 'Car damage Assessment Expertise' *capability* is acquired with the occurrence of the 'Damaged cars inspection process' *process*. In UFO, this can be interpreted as that, *s* is a situation in which the object has the disposition *d* and *e* is an event representing the *behavior element, e* is a pre-state of *s*. If no *resource* is represented, the object that is acquiring or manifesting the *capability* is unknown (we label this as 'problem C3'). In this case, one can argue that it is an organization's *capability*, but it is not possible to clearly define it without relating it to the object and the specification does not define this case. Even when related to the *resource* concept, since the *resource* that is acquiring the disposition represents a universal, a type element, the actual object that is acquiring the disposition is undetermined. The language is not expressive enough to state if one individual, all the individuals that instantiates the universal or an arbitrary combination of individuals instantiating the universal are acquiring the disposition. In both in interpretations it is not possible to know in advance if it is one individual, all the individuals that instantiates that universal or an arbitrary combination of them that are related to the disposition. In the first interpretation, is not possible to know how many objects are to manifest their dispositions in the event represented by the *behavior element*. In the later, it is not possible to know which object is to acquire the disposition. We label this as 'problem C4'.

Now we focus on the common ArchiMate relationships, that apply to the *capability* concept. The *specialization* relation between *capabilities* should mean that a disposition universal (type) subsumes other disposition universal and the *aggregation* relation between *capabilities* is interpreted as (complex) dispositions, that are dispositions based on other dispositions [28]. We must note the fact that there is no distinction between AND or OR *capability* aggregations in ArchiMate. The language lacks expressiveness to state optional *capabilities*. The language also lacks expressiveness to state if all the *capabilities* associated to a *behavior element* are acquired or manifested, if just one of them is acquired or

manifested or if an arbitrary number of them are acquired or manifested. We label this as 'problem C5'.

VI. Ontological Analysis of Competence

In this section we discuss the ontological analysis and interpretation of the *competence* modeling element introduced in [13]. Problems found by the analysis are labeled and are object of recommendations in Section VII.

The *competence* concept was introduced in [13] as a "specialization of *resource* (intangible or personnel-based)". The proposal states that "a core competence is a particular strength of an organization. Core competences are the collective learning in organizations, and involve how to coordinate diverse production skills and integrate multiple streams of technologies. Examples of core competences include technical/subject matter know-how, a reliable process and/or close relationships with customers and suppliers". This was "based on the fact that the definition of *competence* […] is almost identical with that of personnel-based resources". Personnel-based resources have been exemplified as "technical know-how, other knowledge assets including organizational culture, employee training, […]".

Based on the facts above, we understand that a *competence* is something that an element, when provoked, is able to do, or to perform. It addresses the element's capacity of performing an activity. At a first examination, this characterization seems to suggest that *competence* is to be applied to specific individuals, and that it would be the disposition that inheres in the individual. However, the original metamodel shows that *competence* is a *resource*, that is a universal. Based on the *resource* interpretation, as a universal, we conclude that the *competence* also represents a universal, which would be a disposition type, whose instances inhere in the objects that play the role represented by a *resource*.

Since a *competence* is a specialization of *resource*, it inherits the resource's relations. We now focus on the '*competence realizes requirement*'. According to *requirement* interpretation [15], we interpret this relation as: the disposition of the object satisfies the requirement's proposition. We understand that the *competence* is of the same disposition type as of the *capability* that is manifested (or acquired depending on the given interpretation) with the performance of the *behavior element* (event). The interpretation varies according to the interpretation given to the *capability* relationship (we label this as 'problem C2.1' since it is a consequence of C2). This can be interpreted as that: (i) by being able of executing a certain *behavior element* (an event universal), the *resource* object has a disposition *d* (of the *competence* defined type) that instantiates the type represented by the *capability* or; (ii) that *s* is a situation in which the object has the disposition *d* and *e* is an event representing the *behavior element, e* is a pre-state of *s*, in which the *d* is an instance of the *competence*. The relation '*competence* is *realized by structure element*' relates the dispositions to the elements that bears them. This is interpreted in UFO as that the object that represents the *structure element* bears a disposition of that disposition type. This is desirable, however, since it is not enforced by the language,

we label the lack of the knowledge on which object bears the disposition as 'problem C1.1' since it is associated to C1.

The interpretation of the *competence* concept points to the same ontological construct as the interpretation of the *capability* concept (we label this as 'problem C6'). The *competence* concept appears to have been introduced to fill the gap in the proposal that it is unknown which *capabilities* a *resource* (or *structure element*) has. This shows a case of construct redundancy in the language. According to [32], "construct redundancy occurs when more than one grammatical construct can be used to represent the same ontological construct". Our analysis confirms and explicates the informal suspicions raised in the original proposal text when it states that "depending on the (interpretation of the) definition of *competence*, one may argue that, for example it is more natural to introduce *competence* in the metamodel as a specialization of a *capability*" [13]. The original proposal also stated that "the semantic distance between *competence*, on one hand, and either *resource* or *capability*, on the other hand, is too small".

VII. ONTOLOGY-BASED RECOMMENDATIONS

In this section we propose improvements to the language according to the problems found during the ontological analysis.

A. Resource concept

Problem R1 – Since they represent roles (or role mixins) that objects may play, a *resource* should have a context. An element is a *resource* in a defined context, but it is not a *resource* in all situations. This is not enforced in the language, because there is no notion of 'use' of *resources*.

The relation between *resources* and *capabilities* should be enforced, to have the meaning of contextualizing the usage of the *resource* (e.g., 'Money' is allocated to 'Claim handling capability'). This solution should be in accordance with the solution to Problems C2 and C2.1.

Problem R2 – The current metamodel does not allow the modeler to identify who controls the resource. Representing who controls the resource would allow for a finer grained modeling of resource ownership, e.g., in the case when multiple organizations or business departments control different resources.

Problem R3 – The language does not distinguish *resources* that are realized by agents from those realized by non-agentive objects. This is a lack of expressiveness that could be addressed by specializing *resource*.

Problem R4 – For the cases in which a *resource* is realized by a business role (a universal), the language does not settle whether one or more individuals instantiating the role (mixin) represented by the *resource* are required in the context of usage. The addition of cardinality constraints in the language can solve this problem. In fact, the lack of such constraints has being experienced by industry and some ArchiMate tools already implement a *replication attribute* for similar purposes.

Problem R5 - The ArchiMate language does not address the cases in which *resources* are passive non-agentive elements (objects of interest or raw material, e.g., 'Money',

gold, diamond, gas, etc.) These *resources* do not have any *structure element* to *realize* them, since there are no *structure elements'* concepts that can represent these types of objects in ArchiMate. This implies that it is not possible to express if the same passive non-agentive object is to be considered a *resource* in various contexts. Also, there is no possibility to express any property associated to the object itself.

The ArchiMate language should add constructs to define passive non-agentive objects of interest, such as those mentioned above. This would expand the reach of the language's passive structure beyond information objects.

Problem R6 – There is no distinction between AND or OR *resource* aggregations in ArchiMate. The language lacks the expressivity to state optional *resources*. When the *resource* modeling element represents a pool of elements, the language does not define if all the *resources* on the pool are to be used, just one of them or any arbitrary number of them.

The ArchiMate language should (i) add distinctions between AND and OR aggregations; or (ii) add cardinality constraints in ArchiMate, in order to solve this problem.

These recommendations, if implemented, would improve the language and allow the specification of number of *resources* required to perform an activity, the specification of which *resources* are to perform *behavior elements* based on their intrinsic *capabilities*, the ability to model objects of interest and raw material as *resources* (passive non-agentive objects), to define which *resources* are required in a pool of *resources* and to distinguish between mandatory and optional *resources*.

B. Capability and Competence concepts

Problem C1 and C1.1 – The metamodel does not allow relations between the *capabilities* and the *structure elements* or the *resources* [individual or instances of the role (mixin)] that have those *capabilities*. Even for *resources*, the *resources* are assigned to manifest a *capability*, but *resources* have no *capabilities*. Consequently, it is not possible to express in the language which *structure element* bears dispositions of the type represented by a *capability* nor the *capabilities* the organization has, unless it is being *realized* by some *behavior element*.

A relationship should be added to the metamodel to express the *capabilities* of a *structure element*. The organization would then be able to select appropriately the *structure element* to be a *resource* in a *behavior element* based on its *capabilities*. The organization would also be able to know all the *capabilities* it can perform.

Problems C2 and C2.1 – The pattern of relationships on '*capability realized* by *behavior element*' and '*resource assigned to capability*' relations have two different ontological interpretations. As a consequence, the '*competence assigned to capability*' also has two different interpretations.

The proposal should clearly state the desired interpretation. If both interpretations are desirable, there should be two different relations to state them.

Problem C3 – If no *resource* is represented, the object manifesting or acquiring the *capability* is unknown at the '*capability realized* by *behavior element*' and '*resource assigned to capability*' relationships pattern.

The language should explicitly define the element manifesting or acquiring the *capability*. A solution would be to enforce a relation between the *capability* and the *resource* manifesting or acquiring it. It would also be possible to adopt a default referring to the organization being modeled, when no explicit relation is used.

Problem C4 – The language is not expressive to state the number/amount of *resources* that are related to the *capabilities*. For example, it is not possible to know how many instances of *resources* are to manifest their *capabilities* to perform a *behavior element*.

Similar to the solution to R4, a cardinality constraint addition in the language can solve this problem.

Problem C5 – There is no distinction between AND or OR *capability* aggregations in ArchiMate. The language lacks expressiveness to state optional *capabilities*. The language also lacks expressiveness to state if all the *capabilities* associated to a *behavior element* are manifested (or acquired), if just one of them is manifested (or acquired) it or if an arbitrary number of them are manifested (or acquired).

Similar to the solution to R6, the ArchiMate language should (i) add distinctions between AND and OR aggregations; or (ii) add cardinality constraints in ArchiMate.

Problem C6 – The interpretation of the *competence* concept points to the same ontological concept as the *capability* concept, which would be interpreted as construct redundancy. So, at first examination, the competence construct should be eliminated, and in any case, competence should no longer specialize resource. We nevertheless envision the possibility to specialize capabilities into those that can be related to agents (which could be *competences*) and those that can be related to non-agentive objects.

These recommendations, if implemented, would improve the language and make it able to express the *capabilities* a *structure element* has, allow the organization to assign *resources* to *behavior elements* when they have the required *capabilities*, express optional *capabilities*, eliminate the construct redundancy from the language leading to a more parsimonious language and clarifying the context of usage of resources, both for manifestation or acquisition of *capabilities* as to assignment of *resources* to *behavior elements*.

VIII. RELATED WORK

Some recent approaches have addressed the use of capabilities and resources on business strategy in EA. The Do-DAF framework [33] has a viewpoint for capabilities. It models capabilities in order to catalogue and combine them to support business activities and services. In [34], TOGAF has been extended to support the modeling of the capabilities a Business Component (BC) can perform. A BC is a business unit that encompasses a set of activities, supported by assets including people, processes and technology. The approach uses capabilities as "an idealized conceptual structure that describes what a BC can do to create value for customers".

In recent years, a number of enterprise modeling approaches have been subject to ontology-based analysis. In [35], the authors performed an ontological analysis to the Business Process Modeling Notation (BPMN). Nine ontological deficiencies related to modeling when using the BPMN

were found. In [20], the authors have defined the semantics of the ARIS framework concepts and relationships in terms of UFO. Problems regarding the ARIS Method were exposed and possible solutions to these problems were proposed. [15] performed an ontological analysis of the ArchiMate motivation extension proposal, unveiling problems and proposing improvement recommendations. To the best of our knowledge there are no comparable analyses addressing the modeling of capabilities and resources.

IX. CONCLUSIONS AND FUTURE WORK

In this paper, we have discussed an ontological analysis of the BSVC ArchiMate extension and the associated notions of *capability*, *resources* and *competences*. We have employed a comprehensive foundational ontology which incorporates concepts to deal with objects, relations, roles, events, dispositions, as well as social and intentional concepts. Our main aim has been to clarify the semantics of the proposed modeling constructs, which should contribute to the application of the language in practice as a communication tool for stakeholders involved in decision making.

We have been able to clarify that the *resource* element represents a type-level entity, capturing the role of a (agentive or non-agentive) object in a particular context of usage. Our well-founded recommendations should lead to a language that would allow improved *resource* planning (as it would allow the specification of the context of usage of *resources*, the specification of the number/amount of *resources* required to perform an activity, the distinction between mandatory and optional *resources*) and would cover a broader spectrum of *resources* (with the ability to model non-agentive objects of interest and raw material as *resources*).

By considering *capabilities* as a type of dispositions, we have been able to account for what it means for a *behavior element* to *realize* a *capability*. Our recommendations should lead to a language that would allow improved *resource* and *capability* oversight (as it would allow one to relate *capabilities* and *structure elements* that possess *capabilities*, as well as relate *resources* with *capabilities*).

By considering that *competences* also should be interpreted as representing types of *capabilities*, we have been able to diagnose a case of construct redundancy. We have traced the root of the problem to a lack of relations to express the *capabilities* of *resources*. Our recommendations seem to lead to a more regular and parsimonious solution for the expression of human *resources* and their *capabilities*, which was not fully addressed with the introduction of the *competence* construct.

Similarly to what was discussed in [15] concerning the analysis of the motivation extension to ArchiMate, we do not intend to suggest that the terminology used in this paper should replace the terminology currently used in ArchiMate, and we do not intend to imply that the UFO conceptualization should be exposed directly to users of the standard. The main role of the ontological analysis has been to provide us with a rigorous framework to analyze the BSVC proposal. In this sense, the ontological analysis can be seen as a tool for hypothesis formulation, and the recommendations that we

have identified here using ontological analysis should be considered as subject to further examination; for example, considering the pragmatic impact of amendments on the set of standards and its users. We have outlined the recommendations raised by the ontological analysis performed here and we believe that they can have direct application in the revision of the proposed metamodel before it reaches the standardization effort.

In our future efforts, we will investigate the relation between the *resource* element and the *value* element. The latter deserves careful attention from the perspective of semantic definition and ontological analysis, given its subjective nature and the flexibility in usage.

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