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Industry 4.0 Impact Propagation on Enterprise Architecture Models

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Abstract

Industry 4.0 (I4.0) brings a new revolution into the enterprises world, but this phenomenon is larger and covers organizations of different kinds: governmental, educational, cultural, healthcare, and other institutions. Enterprise Architecture (EA) provides a whole vision, using sets of models or blueprints, of an organization along with its information technologies, business processes and strategies. Many research and practical works are made to clarify the I4.0 impact on organizations or to guide EA practitioners through the transformation process that allows them to maintain the organizational alignment, performance, and competitiveness. However, in the reviewed literature we have not identified any conceptual work describing the I4.0 impact on enterprise architectures models. In this paper, we present an approach of propagation of I4.0 impacts through EA models. Our proposal includes an Industry 4.0 Impact Propagation Model and a process to apply it. In order to evaluate the completeness of the model and test the process, we applied it to one of the most known EA frameworks TOGAF (The Open Group Architecture Framework). We use the extended conceptual model of TOGAF version 9.2 to detail what would be the direct impact of an I4.0 transformation and how it can be propagated to identify all elements of EA models which should be adapted following the introduction of an I4.0 component into an organization. We discuss the results of this evaluation.

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1. Introduction

Nowadays, enterprises are immersed in a continuous evolution process because they have to cope with forced changes induced by the appearing of new challenges in their economic and competitive contexts. Most of these challenges are caused by the need of renovating current Information Technology (IT) and Information Systems (IS) architectures in order to support new organizational goals and strategies [1], [2], [3], [4]. For instance, the technical revolution named Industry 4.0 (I4.0), disrupts all enterprise functions related to product distribution, commercialization, and the way enterprise interacts with clients, suppliers, and competitors [5].

In order to face all these challenges, managers should know and control the current and potential capacities of the whole organization. Correspondingly, to assure changes implementation agility, managers need to have models of what are the current and potential IT platforms and business processes capacities, along with what is the degree of organizational flexibility to implement the required changes. In this context, Enterprise Architecture (EA) models are appreciated management and technical tools because they describe organizations from complementary viewpoints: Business, Information Systems (including software applications and data) and their Technology platform [6], [7]. These models represent the main enterprise elements from business goals and strategies to technical production platform passing through business and production processes, enterprise actors and their roles, information systems and their IT support platform [8], [9]; accordingly, when a demand for a business change arrives, managers may well calculate, based on the knowledge stocked in EA models, what are the possibilities of change and analyze them. Likewise, existing I4.0 models describe main industry elements, essentially, at operational and production levels [5], including product life cycle, without neglecting some elements involved in tactical decisions at managerial level [10]. For instance, the enterprise hierarchical levels axe allows industry managers and technicians to coordinate execution and monitor current performance in order to analyze and take decisions about the operational and production changes required by the industrial context; i.e. those coming from the connected world [11].

Our long-term goal is to specify how companies with established enterprise architectures should progress towards an EA state including components from Industry 4.0. In our previous work [12], we detected that the element called I4.0 component impacts almost all of the EA elements at all architecture perspectives. Considering that EA models are related to each other and they constitute the basis of EA approaches [13], [14], [15], [16], our intermediate research goal is to identify which elements of EA models are impacted by the introduction of an I4.0 component, and what is the severity of this impact. The analysis of the impact should take into account complex relationships between different EA models. Thus, in this paper, we study the impact from immediate interactions of I4.0 components with the corresponding EA elements to the indirect impact progressively identified through the connections between EA models and their elements. Our intention is to guide EA leaders through the progressive evolution of EA when integrating I4.0 components without substantial cost and time investment.

Our research goal in this paper is to identify which of the EA models and their elements should be adapted when introducing an I4.0 component into an existing EA. To deal with this problem we introduce a propagation approach in order to emphasize this piecemeal consideration of the I4.0 component impact. The propagation approach includes an I4.0 Impact propagation conceptual model and a process for helping its application.

To evaluate our proposal, we use a mixed approach: we establish a descriptive scenario to specify how and why we apply our proposal to an EA framework, more precisely to The Open Group Architecture Framework (TOGAF) 9.2 [16]. Within this scenario, we apply an analytical evaluation method by means of a static analysis to “examine structure of artifact for static quality” [17]. The main quality we want to check is the model completeness: whether the proposed propagation model includes all needed concepts to represent the Industry 4.0 impact propagation. In addition, we test our application process during this evaluation with regards to its feasibility and utility.

The rest of the paper is organized as follows. Section 2 presents an excerpt of works associated with our research. Section 3 describes the I4.0 impact propagation model and the associated process. In Section 4, we evaluate our proposal by its application to TOGAF 9.2 and we discuss the results. We conclude and outline our future work in Section 5.

2. Related Works

According to [18], the term digital transformation (DT) is referred as the process of transforming resources to digital. A DT process implies to convert main organizational resources from manual or physical to digital (virtual or abstract); consequently, it prompts enforced modifications on the organizational structure, business and production processes. This means that any change in the way of working, any inclusion of new objects and resources or the updates of them, any enhancement of the collaboration between machines (virtual or physical) and humans, modifying their roles and responsibilities, is a transformation that distresses the internal and external environment of the enterprise.

I4.0 initiative aims to transform the way industries and business organizations generate value, products and services by combining many new technologies, especially, artificial intelligent features. For instance, among the new combined and embedded technologies linked to I4.0 and this new way of creating business value, are: Internet of Things for interconnecting business objects with the standardization of digital tools, Cyber-Physical-Systems (CPS), cloud computing, the exploitation of organizational data for monitoring and increasing cooperative business functioning, called data analytics [19], [20], [21], and so on.

We present in this section an excerpt of main works concerning our topic. First, we mention the research and practical works related to the impact of digital transformation on the enterprise architecture approach as well as its future trends; then, we present the works associated with I4.0 model extensions to better fit the evolution of smart technologies.

The research work described in [22] investigates the evolution of EA considering new defined value-oriented mapping between digital strategies, digital business models and an improved digital enterprise architecture. The authors make a proposition for architecting digital services and products following, both, a value-oriented and a service perspective. The paper presented in [15] discusses the “Grand Challenges” of organizations in the future and exposes some theories and models for addressing them, especially, by enterprise architecture frameworks. The research presented in [23] explores the implications of digital transformation on EA; authors emphasize that enterprises increase their complexity by pertaining to digital ecosystems. They conclude that today’s digital environment demands enterprise adaptive capabilities in order to have an EA flexible et resilient. The work described in [24] present a set of concepts of digital transformation and EA; the work is based on selected publications taken from the literature for discussing the potential role of EA in supporting digital transformation and the existing gap in research on how to leverage EA for digital transformation. In the same way, the work in progress described in [25] aims to a specification of a conceptual architecture of smart systems for supporting the management of disruptions in the manufacturing domain. This approach is focused on software systems architecture based on a number of interrelated viewpoints according to the ISO 42010 standard. Finally, and almost in a technological direction, [26] presents a proposal to identify and analyze technical and technological gaps between existing and new emerging technologies for developing new reference models and architectures adjusted to next-generation enterprises. These works are specific to several architecture perspectives, thus, they do not consider EA models and perspectives within an integrated whole.

Subsequently, we reviewed more technical approaches that propose how to integrate new IT elements into EA models and, to solve explicit interoperability problems related to them. The research work described in [27] extends the EA data architecture with fine grained guidelines to include data analytic and other operational elements to capture, process and exploit the whole organizational and production data. A Service-Oriented Enterprise Architecture (SOEA) approach is proposed by [28] as a new holistic EA paradigm; it is based on a multi-layered and value-chained service-based scenario to cope with I4.0 technology revolution. [29] describes a proposal for adaptable EA, thus engineers can better cope with software and service-oriented applications development and maintenance. Later and, in order to make transparent the impact of business and IT changes over the enterprise architectural capabilities, same authors, introduce the Enterprise Services Architecture Reference Cube (ESARC) [30], which constitutes a meta-model to integrate architectural objects of Internet-of-Things into a holistic digital EA environment to leverage and extend previous EA efforts and, enable business value.

To complete the research works review, we revised I4.0 research works discussed in conferences, workshops and, on dedicated blogs and webpages. As mentioned, I4.0 proposes a reference architecture that arranges business functioning and new smart technology into the same structure. The architecture is represented by the model

RAMI4.0 proposed by the Standardization Council I4.0 (SCI4.0) and published by [14]. Many of research works are application scenarios of the framework [31], adaptations or extensions of RAMI4.0 in order to fit industrial particular requirements [32], the addition of security elements to the reference architecture [33] and, a standardization model for services [34]. There are other works that evaluate the RAMI4.0 architecture model in order to define its precision and fitness to assume enterprises digitalization needs, or to align it to an Intelligent Manufacturing Systems Architecture [15], [35], [36]. Same way, the work of [37] propose a simplification of the reference architecture in order to better apply I4.0 in enterprise situations. The work described in [38] considers the enterprise digital evolution through the integration between RAMI4.0 and the Industrial Internet Reference Architecture (IIRA). As the I4.0 component is the central element of the RAMI4.0 model, the works of [39] and [40] describe in detail, at technical level, how to implement and insert new I4.0 components into an IT infrastructure according to RAMI4.0. Finally, we refer to the work reported in [5] and suggesting to represent new business processes after the impact caused, by the I4.0 change, in the existing enterprise functioning model. This paper extends BPMN, a standard process modelling notation, to better represent the gap between current and future business process architecture states. The proposal excludes other management business features and their interactions; and, there is not a conceptual model that would allow a comparative analysis between the old and new business process models.

Summing up this section, we conclude that most of the revised works concern how enterprises and industries, immersed in a continuous changing context called digital transformation, apply either EA or I4.0 models. Some works recommend how to adapt I4.0 or EA models to context transformations, independently. Nevertheless, none of these works proposes an integrated approach about how to adapt EA models to I4.0. As digital transformation is driven by operational and technical initiatives that take advantage of a variety of intelligent and autonomous digital technologies, we consider that these technologies must be included as key elements into current enterprise and industry working models in order to better understand and face the disruption challenges.

Finally, we are aware that some of the works mentioned in this section, present their own conceptual models, most of them justified by practical needs and by the instantiation of business cases; but, the described models are still placed at a technical and operational enterprise production levels. As a result, they do not provide an explicitly conceptual or practical connection between the technical and operational levels on the one side and higher coordination, management and decisional levels one the other side. Therefore, we hold that there is a clear need for establishing what are the correspondences between concepts representing EA elements and those representing I4.0 components. These correspondences will make explicit the enterprise knowledge required, as EA models elements, for supporting leaders' and EA architects' project decisions as well as business managers' transformation decisions.

3. Industry 4.0 Impact Propagation Model and its Application Process

As mentioned before, the core of EA approaches is represented by conceptual models, reflecting enterprise elements at different levels: business processes, data, applications, and IT models. Conceptual links should be established in order to highlight possible relationships between an introduced I4.0 component and the corresponding elements of the EA models. By means of these established relationships, it will be feasible to identify all the impacted existing EA elements already included in EA models. As the impacted EA model elements are identified in a progressive manner following connections existing within the set of EA models, we call it a Propagation Model and we represent it using the UML class diagram depicted in Fig. 1. To respect the artifacts design principles [17] and to produce better guidelines while applying the propagation model, we add a description of its application process (Fig. 2).

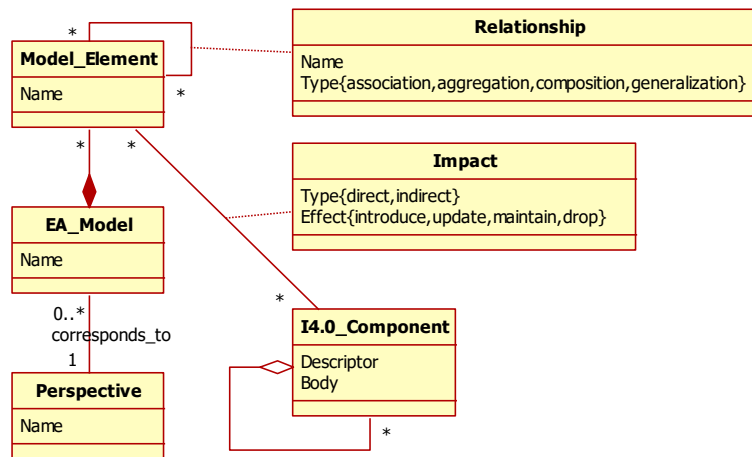


Fig. 1. Industry 4.0 Impact Propagation Model.

The propagation model is composed of the following elements:

Perspective. The EA models are grouped into perspectives described by their *names*. The perspectives list depends on the selected EA framework. For instance, the TOGAF EA framework [16] includes the Business, Information Systems (Application and Data), and Technology perspectives called Architectures. Each EA model belongs to a perspective (the *corresponds_to* association). However, in a concrete organization, a perspective could be not implemented.

EA Model. An EA model groups different model elements of the same type. EA models could be business process models, data models, applications models, technology models, and so on. An EA model (characterized by a *name*) is a composition of EA model elements (the composition link on the EA model class in the propagation model).

Model Element. A model element represents each single enterprise element included as part of any of EA models. It could represent a process, an object, an actor, a system or a technological enterprise component. Each model element has at least a *name*. Other characteristics depend on the model type.

Relationship. Model elements are related to each other. Possible relationship *types* are a simple association, an aggregation, a composition or a generalization. We use here the basic relationships type from UML [41], but this list is not exhaustive, it could be completed with others like sequence or exclusivity link. Each relationship has a *name* to characterize its nature.

I4.0 Component. I4.0 components correspond to various elements or components of digital technologies introduced into an organization. An I4.0 component could be an atomic or a composite one. To express the latest one, we use a recursive aggregation link on the I4.0 component. The I4.0 component has two main attributes: descriptor and body. A *descriptor* allows to identify the given component. For instance, in the RAMI4.0 framework, it corresponds to the Administration Shell [11]. The *body* is the core of the I4.0 component like in RAMI4.0 [11].

Impact. The impact represents an association class between a I4.0 component and an EA model element. Each I4.0 component can impact a number of EA model elements and each Model element can be impacted by several I4.0 components. For each, we can identify the *type* of impact: direct or indirect, and the *effect* of impact. With regard to the impact type, the direct impact is when the I4.0 component touches directly a model element. The indirect impact is deduced from the directly impact model element and from other model elements related to the directly impacted element by different relationships. Direct or indirect impacts may have different effects on model elements. Inspired from [42], the effect caused on model elements could be introduce new element, update element, maintain element, or drop element. *Introducing a new element* means that a new EA element should be added following the introduction of an I4.0 component. *Update element* implies that the corresponding EA element ought to be revised in order to extend or modify some of its attributes, functionalities and/or its interactions with other

elements. A *maintained EA element* remains the same (no impact). An *EA element can be dropped* if it is not required anymore after the introduction of the an I4.0 component.

In order to identify propagated impact through the whole set of the EA models within an organization, we suggest using the process presented in Fig. 2.

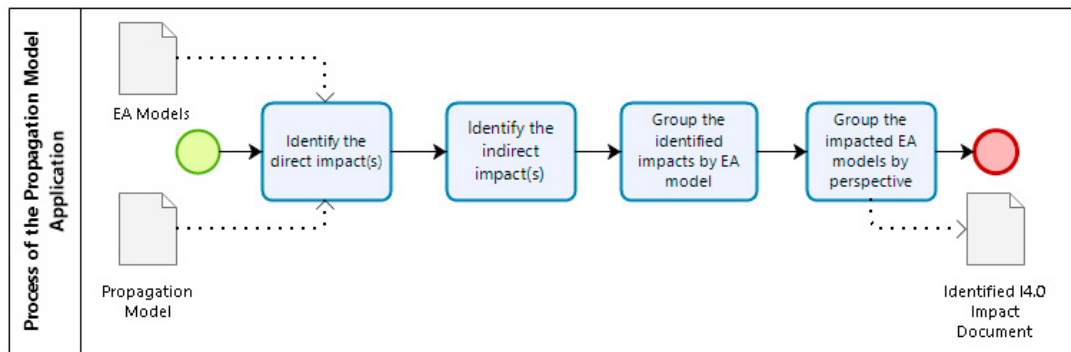


Fig. 2. Process of the Industry 4.0 Impact Propagation Model Application.

Identify the direct impact(s). Depending on the description of the I4.0 component, define the EA model element(s) which are directly touched and associate the corresponding impact effect. The EA Models and the proposed propagation model constitute the Inputs of this step.

Identify the indirect impact(s). Using the relationships between different model elements, deduce the related impacted elements and associate the corresponding impact effect.

Group the identified impacts by EA model. Put together the identified impact within the corresponding EA model and check consistency within each model (verify the presence of contradictory or double impacts within the same EA model and arbitrate).

Group the impacted EA models by perspective. Gather the impacted EA models within the corresponding EA perspective and check the consistency (verify the presence of contradictory or similar modifications within the same EA perspective and arbitrate). This step produces the final document containing the identified I4.0 impact.

4. Application to TOGAF 9.2

To validate the conception of the propagation model and to test the associated process, we have established the following scenario. Firstly, we selected The Open Group Architecture Framework (TOGAF) 9.2 [16] as one of the most known EA frameworks. TOGAF is an Open framework, thus it is accessed easily. Secondly, we reviewed its full content meta-model (cf. [16], p. 287) to check whether the EA model elements are clearly identified. The TOGAF 9.2 content meta-model “provides a definition of all the types of building blocks that may exist within an architecture, show how these building blocks can be described and related to one another” [16], thus it contains all EA entities (corresponding to model elements from the propagation model) and the relationships between them. Based on this, we confirmed our intention to use TOGAF 9.2 as EA framework for validation. Thirdly, we applied the propagation process step by step by carrying out a detailed analysis of all meta-model elements and their relationships (from both meta-model from p. 287 of TOGAF 9.2 and its detailed description given on pages 301-303 and 314-317 of TOGAF 9.2 [16]). Finally, we analyzed the obtained result to state about completeness of the proposal.

Identify direct impacts. We checked all TOGAF 9.2 meta-model entities (cf. Section 30.5 of TOGAF 9.2 [16], pages 301-303) to select the most complete list of entities which could be impacted directly by an I4.0 component

and qualify them as direct impacts. The inclusion criteria are (i) the TOGAF entity is an independent atomic component, (ii) it could be easily replaced by a new component of I4.0, (iii) it encapsulates a chunk of an application, data, or infrastructure. For instance, we have included the Physical Technology Component as it is “a specific technology infrastructure product or technology infrastructure product instance” [16] as a Commercial Off-The-Shelf (COTS) solution. We have excluded the Physical Data Component (“a boundary zone that encapsulates related data entities to form a physical location to be held” [16]) as it represents a sub-set of data entities, thus it does not correspond to an independent component easily replaceable. Another example of exclusion is the Logical Application Component which is “an encapsulation of application functionality that is independent of a particular implementation” [16]; as it is not implemented, it could not be replaced by an I4.0 component. The used strategy was to take each TOGAF entity and to check it with regards to the established criteria. The list of the identified direct impacts comprises seven (7) from 35 TOGAF 9.2 meta-model entities: Data Entity, Information System Service, Logical Technology Component, Physical Application Component, Physical Technology Component, Process, and Technology Service.

Identify indirect impacts. To identify indirect impacts, we used the TOGAF 9.2 meta-model relationships (cf. Section 30.7 of TOGAF 9.2 [16], pages 314-317). For each previously identified direct impact, we have repeated the following procedure: enumerate all other entities related by at least one relationship from the meta-model and its textual description (more complete than the graphical representation of the meta-model); if more than one relationship is present between two entities, enumerate all of them; qualify them as indirect impacts; for each indirect impact, select one or more possible impact effects; for impact, identify the corresponding EA model and EA perspective. For instance, Process is related to Control by “Is guided by” relationship. Due to the nature of this relationship, we deduce that the Control entity could only be updated further to the changes in a Process Entity. In TOGAF, the Control entity is a part of the Process Modelling Extension (EA model) within the Business Architecture perspective. Table 1 illustrates the first-level impact. The next levels are done in the same manner.

Group the identified impacts by EA model. Identified impacted TOGAF Entities were grouped into TOGAF Models (illustrated in Table 1). This step corresponds to the simple identification of the corresponding EA model from the TOGAF documentation. The consistency could be checked only in a case of a concrete project.

Group the impacted EA models by perspective. Identified impacted TOGAF Models were grouped into perspectives (shown in Table 1). This step includes the identification of EA perspectives from the TOGAF documentation. As for the previous step, the consistency could be checked in a given case.

Based on the application of the propagation approach to TOGAF 9.2, we have obtained the following evaluation results:

- The concepts of the propagation model (EA Element, I4.0 Component, Relationship classes, and Impact association class) are sufficient to represent links between an introduced I4.0 component and directly and indirectly impacted EA elements. This model proposes a quite simple but concise way to trace the I4.0 impact.
- In the whole, the initial propagation model was not sufficient as we did not include EA perspective as a class. Based on the first iteration of the application process, we noticed that it is important to have this additional aggregation level to check the global consistency at least for the EA frameworks containing this granularity level as TOGAF 9.2. But it could be optional, especially for small and medium organizations. As a result, the class EA perspective was added.
- With regards to the application process, we confirmed that it is useful to have main steps guiding in the propagation model application, In addition, we stated that first two steps could be applied on the EA framework; but, the third and fourth steps could be completely checked only in a given project of the I4.0 component introduction into EA models.
- Finally, we noticed as the major limitation of our proposal, that the feasibility of our approach depends on the solid knowledge about EA concepts and related technology, that EA leaders and practitioners ought to have in order to well apply it in real EA projects. Further, this background and expertise is essential to take advantage of the results attained after the application of the propagation model.

Overall, the evaluation of our proposal by applying it to TOGAF 9.2 allowed us to complete the model, to confirm its utility, and to identify its limitations. We aim to overcome these limitations as part of our future work.

Table 1. Industry 4.0 Impact Propagation Model Applied to TOGAF

Direct Impacts	Indirect Impacts	Possible Impact Effects	Corresponding EA Model	EA Perspective
Data Entity	Logical Data Component	Update	Data Modeling Extension	Data Architecture
	Business Service	Update	Core Model/ Behavior	Business Architecture
	Information System Service	Introduce, Update	Service Extension	IS Architecture
Information System Service	Data Entity	Introduce, Update, Maintain, or Drop*	Core Model/ Data Model	Data Architecture
	Data Entity	Introduce, Update, Maintain, or Drop*	Core Model/ Data Model	Data Architecture
	Business Service	Introduce, Update, Maintain, or Drop*	Core Model/ Behavior	Business Architecture
	Technology Service	Introduce, Update, Maintain, or Drop*	Core Model	Technology Architecture
Logical Technology Component	Logical Application Component	Introduce, Update, Maintain, or Drop*	Core Model	Application Architecture
	Logical Application Component	Update	Core Model	Application Architecture
	Logical Technology Component	Introduce, Update, Maintain, or Drop*	Infrastructure Consolidation Extension	Technology Architecture
	Physical Technology Component	Introduce, Update, Maintain, or Drop*	Core Model	Technology Architecture
Physical Application Component	Technology Service	Update	Core Model	Technology Architecture
	Business Service	Update	Core Model/ Behavior	Business Architecture
	Logical Application Component	Introduce, Update, Maintain, Drop*	Core Model	Application Architecture
	Physical Data Component	Introduce, Update, Maintain, Drop*	Data Modeling Extension	Data Architecture
Physical Technology Component	Physical Technology Component	Introduce, Update, Maintain, Drop*	Core Model	Technology Architecture
	Physical Application Component	Introduce, Update, Maintain, Drop*	Infrastructure Consolidation Extension	Application Architecture
	Physical Application Component	Update	Infrastructure Consolidation Extension	Application Architecture
	Logical Technology Component	Introduce, Update, Maintain, Drop*	Infrastructure Consolidation Extension	Technology Architecture
Process	Physical Technology Component	Introduce, Update, Maintain, Drop*	Core Model	Technology Architecture
	Control	Update	Process Modeling Extension	Business Architecture
	Event	Introduce, Update, Maintain, Drop*	Process Modeling Extension	Business Architecture
	Function	Introduce, Update, Maintain, Drop*	Core Model/ Behavior	Business Architecture
Technology Service	Organization Unit	Update	Core Model/ Organization	Business Architecture
	Product	Introduce, Update, Maintain, Drop*	Process Modeling Extension	Business Architecture
	Role	Introduce, Update, Maintain, Drop*	Core Model/ Organization	Business Architecture
	Business Service	Introduce, Update, Maintain, Drop*	Core Model/ Behavior	Business Architecture
Technology Service	Process	Introduce, Update, Maintain, Drop*	Core Model/ Behavior	Business Architecture
	Logical Technology Component	Introduce, Update, Maintain, Drop*	Infrastructure Consolidation Extension	Technology Architecture
	Information System Service	Update	Service Extension	IS Architecture

* The choice between these effects is made depending on the nature of the direct impact.

5. Conclusion and Future Works

In this paper, we propose an impact propagation model and the associated process to use when introducing an Industry 4.0 component into current EA models. The outcome of the proposal application is the identification of the set of EA models and their elements, that should be revised and adapted after the inclusion of new I4.0 components. In order to assure that the proposition is complete and viable, we examine it, as a general strategy, through the TOGAF 9.2 meta-model. This validation process was based on the detailed analysis of each of the meta-model concepts as well as of their relationships. Initially, we identified the direct impacts caused by I4.0 components over TOGAF meta-model entities; then, we determine those entities that may be impacted as a result of their relationships and dependencies, with those entities already identified as direct impacted entities. The obtained results will provide EA leaders and practitioners with practical guidelines and, EA researchers with a theoretical propagation model along with its associated application process. EA practitioners can use the proposal to optimize the existing EA models and, to make them up to date with regards to the digital evolution. From the theoretical point of view, the propagation model will serve as a building block for approaches of Enterprise Architecture 4.0 and their related conceptual models.

In our future research we envisage several directions: first, it is imperative to validate the propagation approach in a real EA project. Second, we envisage the possibility to provide a support tool to help practitioners to apply the propagation approach. Third, we will continue to prepare different building blocks to adapt EA frameworks to the I4.0 evolution. Finally, we intent to explore the flexibility of our approach to transcend from a single enterprise context to a business consortium like in a I4.0 business ecosystem.

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