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ICT in Business

A multi-criteria decision-making model for EA maturity models in the context of Industry 4.0

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MASTER'S THESIS

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“Let the future tell the truth, and evaluate each one according to his work and accomplishments. The present is theirs; the future, for which I have really worked, is mine”

Nikola Tesla

Abstract

Numerous maturity models exist and have been subject to criticism, from both an academic perspective and a practical perspective. They lack in (transparent) design, sound theoretical foundations and validations, and value to industry by providing specific guidance towards an increased maturity and resulting benefits. Additionally, maturity models do not incorporate the application domain of the organization (i.e. consumer of a maturity model).

To provide value for both academics and industry, a multi-criteria decision-making model is developed for comparing and selecting maturity models. A design-science research approach has been adopted for the design and evaluation of the model, and existing foundations were used for deriving the criteria.

Today we are allegedly experiencing the fourth industrial revolution (i.e. Industry 4.0). For this research Industry 4.0 has been explored and interpreted as the application domain. The elaboration on the concept Industry 4.0 was performed through literature review and expert interviews. Industry 4.0 is discussed in literature as a strategic initiative and as the ex-ante fourth industrial revolution. Analysis of the expert interviews on Industry 4.0 were more aligned with the vision of Schwab (2017). Industry 4.0 is driven by megatrends: physical, digital and biological. The biological trends were minimally acknowledged by the interviewed experts. The physical and digital trends are expected to impact the economy, business, government, education and research, national and global, but also the society and individual. Servitization, digitalization and automation of processes due to these trends requires a different ICT-landscape and new capabilities of people. Effective appliance of enterprise architecture can guide organization to realize the desired state. Therefore, the multi-criteria decision-making model is limited to the functional domain of enterprise architecture.

The design of the multi-criteria decision-making model is based on the Analytical Hierarchy Process and consists of nine weighted criteria. The criteria address the design, assessment and application domain of enterprise architecture maturity models. A practical tool has been developed in R which can be used for applying the model in practice. The resulting tool has been evaluated through the guidelines of Hevner et al. (2004) and is demonstrated on two existing enterprise architecture maturity models.

Key words: Enterprise architecture maturity models, Industry 4.0, fourth industrial revolution, multi-criteria decision-making model, Analytical Hierarchy Process (AHP)

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1 Introduction

Industrial revolution is an often-used phrase, and is often linked to the first industrial revolution that took place in 1780 in Great Britain and afterwards proceeded to the United States (Hoffmann, 1955).

There is still no commonly agreed upon understanding on what an industrial revolution comprises (Maynard, 2015). According to Deane (1979) an industrial revolution can be characterized by seven interrelated changes. If these changes are developed together to an sufficient degree, this would constitute an industrial revolution. Deane (1979) identified seven interrelated changes concerned with the process of production, economic changes, movement of population, type of production, change of production, capital resources, and new social and occupational classes.

Along with these seven changes, an industrial revolution has always been associated with a growing population and an increasing annual volume of goods and services produced (Dean, 1979). Lucas (2002) defines an industrial revolution as the onset of sustained income growth.

An industrial revolution has taken place two more times in the last 200 years (Drath & Horch, 2014). The first industrial revolution is known for the introduction of water and steam-powered mechanical production facilities; the second industrial revolution started in the 1870's and was centred around electrification and the division of labour; the third industrial revolution, also referred as the digital revolution, started in the 1970's and led to further automation of production processes with the incorporation of advanced electronics and information technology (Hermann, Pentek & Otto, 2016).

Today we are allegedly at the beginning of the fourth industrial revolution and we are looking ahead to the fifth industrial revolution (Peccoud, 2016). The figure below provides a timeline of the past, present and future industrial revolutions, and the key aspects of each revolution according to Peccoud.

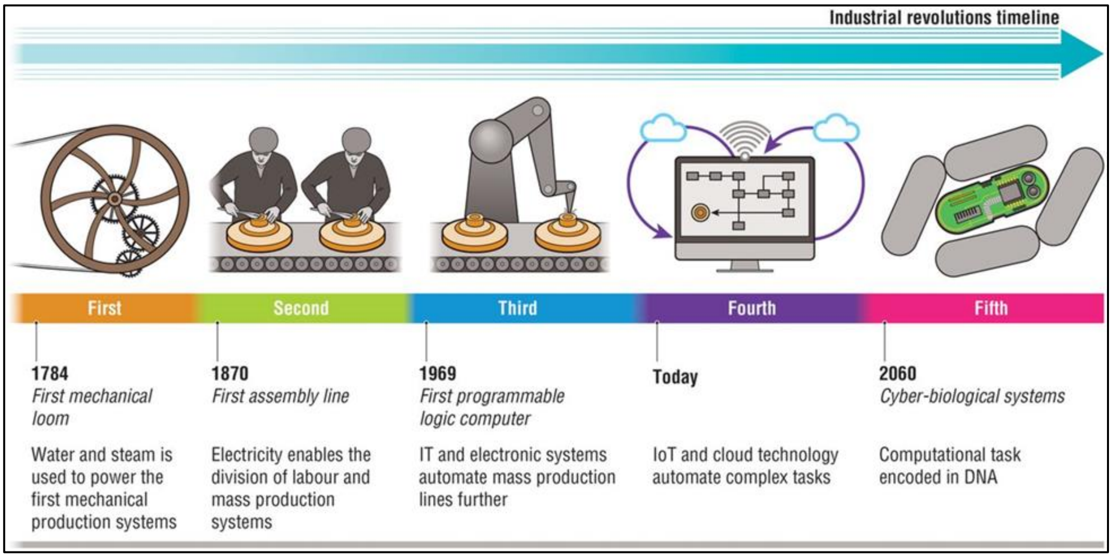


Figure 1. Industrial revolutions timeline (Peccoud, 2016, p. 4).

1.1 Context and research fields of the study

The overall context of the study is concerned with Industry 4.0. Within this context the field of enterprise architecture, and specifically enterprise architecture maturity, are researched.

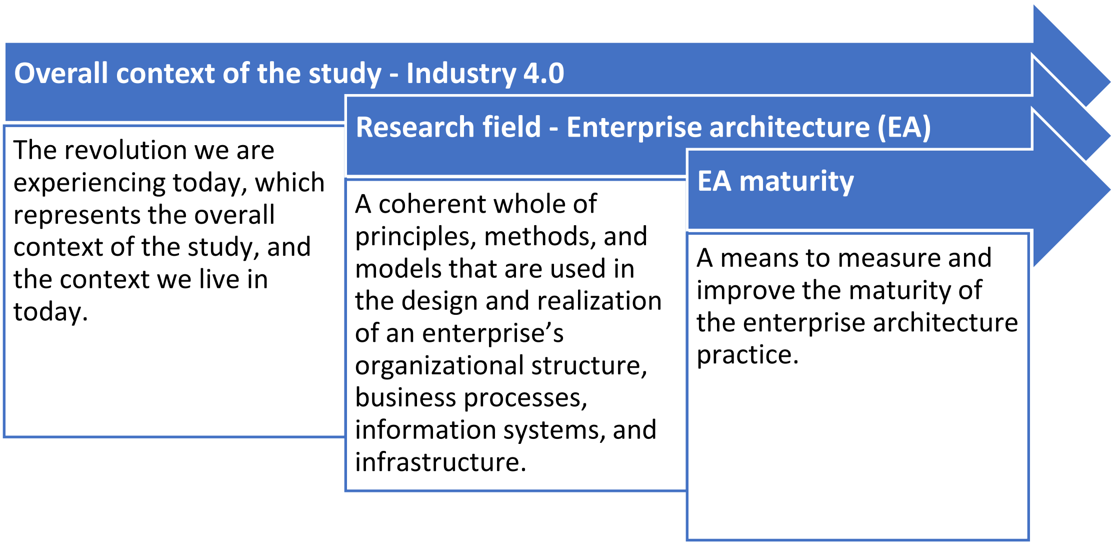


Figure 2. Context and research fields of the study

1.1.1 Industry 4.0

As stated by Lasi, Fettke, Feld and Hoffman (2014), "the term 'Industry 4.0' was established exante for a planned '4th industrial revolution', the term being a reminiscence of software versioning" (p. 239). For the context of this study, Industry 4.0 will be regarded as the possible fourth industrial revolution which we are experiencing today, and not as the German strategic initiative (i.e. Industrie 4.0) which was introduced by the German workgroup (Kagermann, Lukas & Wahlster, 2011).

They introduced it as a strategic initiative for Germany to create the desired competitive advantage in manufacturing by enabling the "smart factory". However, Kagermann, Helbig, Hellinger & Wahlster (2013) also refer to this strategic initiative, Industrie 4.0, as the fourth industrial revolution. Nonetheless, the fourth industrial revolution's scope encompasses more than just 'industrial' (Schwab & Davis, 2018). A more suitable framing of what industrial encompasses in this matter is the way Thomas Carlyle and John Stuart Mill referred to industry in the 19th century: all activities that flow from human effort (Schwab & Davis, 2018). Most of the strategic initiatives across the world refer to factories, manufacturing and production, when discussing Industry 4.0 or similar terms such as Smart Industry (Netherlands), Advanced Manufacturing (US), Made in China 2025. Unlike the concept of Industry 4.0, Japan introduced Society 5.0 which is not only restricted to the manufacturing sector, but its goal is to solve social problems through integration of physical and virtual spaces (Skobelev & Borovik, 2017). This is more aligned with the vision of Schwab & Davis (2018) on the fourth industrial revolution. For this research Industry 4.0 will be interpreted as the fourth industrial revolution which encompasses all sectors, not just manufacturing.

1.1.2 Enterprise architecture maturity

Enterprise architecture maturity belongs in the research field of enterprise architecture. Enterprise architecture is a relatively young research field as well, although not as young as Industry 4.0. Enterprise architecture has its origins in the field of information planning in the 80’s and has since evolved as the field we know today (Van Steenbergen, 2011). Multiple definitions of enterprise architecture have been developed and agreed upon. There is not one commonly agreed upon definition, but most of the definitions provide a similar understanding of enterprise architecture. The definitions of the two most referred by books on enterprise architecture are discussed in the following paragraphs.

Lankhorst (2009) defines enterprise architecture as “a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise’s organizational structure, business processes, information systems, and infrastructure” (p. 3).

According to Ross, Weill and Robertson (2006), “enterprise architecture is the organizing logic for business processes and IT infrastructure reflecting the integration and standardization requirements of the company’s operating model. The enterprise architecture provides long-term view of a company’s processes, systems, and technologies so that individual projects can build capabilities – not just fulfill immediate needs” (p. 9).

Both of these definitions contain similar elements: models, processes, systems and infrastructure. The definition of Lankhorst is adopted for this thesis. This definition is simple and complete, and does not require additional elaboration on other concepts such as the operating model of Ross.

Effective enterprise architecture practice can lead to several organizational benefits by improving in organizational alignment, information availability, resource complementarity, and resource portfolio optimisation (Tamm, Seddon, Shanks & Reynolds, 2011). These organizational benefits may include, but are not limited to:

- Increased responsiveness and guidance to change (Ross, Weill & Robertson, 2006);
- Improved decision-making (Bernard, 2012; Spewak & Hill, 1993, Johnson, Lagerström, Närman & Simonsson, 2007; Richardson, Jackson & Dickson (1990);
- Improved communication and collaboration (Bernard, 2012);
- Reduced costs (Bernard, 2012; Spewak & Hill, 1993; Ross & Westerman, 2004; Tamm, Seddon, Shanks & Reynolds, 2011);
- Business-IT alignment (Ross, Weill & Robertson, 2006);
- Strategic agility (Ross, Weill & Robertson, 2006; Tamm, Seddon, Shanks & Reynolds, 2011);
- More reliable operating platform (Ross, Weill & Robertson, 2006; Tamm, Seddon, Shanks & Reynolds, 2011).

Maturity models have been developed and applied to measure and improve the current situation of a selected domain (De Bruin, Freeze, Kaulkarni & Rosemann, 2005; Van Steenbergen, 2011). A lot of maturity models have been developed over the years for several functional domains, including enterprise architecture (De Bruin et al., 2005; Davenport, 2005; Mettler & Rohner 2009).

1.2 Research statement

The research initially started with a research proposal from Dr. Hans le Fever from the University of Leiden and Professor Dr. Stefan Pickl from the Bundeswehr University Munich regarding process modelling and optimization within Industry 5.0.

Industry 5.0 is a young research discipline, the first appearance of the term industry 5.0 was a few years ago (Saracco, 2014). Industry 5.0 is expected to be the next industrial revolution, but there is no common agreement or understanding of what industry 5.0 is and what it is not. Saracco (2014) argues that Industry 5.0 will be evolved around synthetic biology, and leads to smart materials which are programmed to eventually replicate and evolve on its own.

There are multiple views on the concept industry 5.0. However, academic literature on industry 5.0 is very limited. For instance, a search on ACM library and IEEE resulted in zero results on industry 5.0. Therefor other sources were consulted[1].

Most grey literature define industry 5.0 as a more closely collaboration between human and machine. They state it will create more work for humans, and increases their impact and influence on the process (Gotfredsen, 2016; InfinityQS Blog, 2017; Jarvis, 2016; Kospanos, 2017a; Kospanos, 2017b; Shea, 2016).

Saracco's view on industry 5.0 is in line with the limited academic literature found on Google Scholar. Sachsenmeier (2016) states the following: "While concepts such as smart cities and Industry 4.0 shine a spotlight on the process states enabled by digital/Web-based technologies, the changes brought about by synthetic biology are more fundamental and foreshadow a tectonic, disruptive, and even geostrategic shift: Industry 5.0 … Industry 5.0 discussions touch on the very essence of humanity's existence, physical integrity, and relationship with nature." Schütte (2017) also acknowledges the impact biologization will have on the fifth industrial revolution.

The limited amount of academic literature resulted in changing the research area to a closely related topic: Industry 4.0.

Industry 4.0 is a young research discipline as well. The term was introduced in 2011 by the German workgroup (Kagermann, Lukas & Wahlster, 2011). They introduced it as a strategic initiative for Germany to create the desired competitive advantage in manufacturing by enabling the "smart factory". However, Kagermann, Helbig, Hellinger & Wahlster (2013) also refer to this strategic initiative, Industry 4.0, as the fourth industrial revolution. Klaus Schwab (2017), the founder and executive chairman of the World Economic Forum (WEF), states that it goes beyond the smart connected machines and systems implied by the German workgroup.

The fourth industrial revolution (Industry 4.0) and the associated technologies and concepts are expected to have a big impact on all organisations, not just the big companies, but also the SME's (Leyh, Bley, Schäffer & Forstenhäusler (2016). The transformation organisations will have to go through will not only affect the technological aspects, but all aspects of an organisation. These aspects can be framed within the layers of enterprise architecture: business architecture (processes and actors), application architecture (information systems), data architecture and the technology architecture (infrastructure). In addition to providing overview and insight into coherence of these aspects, effective appliance of enterprise architecture contributes to the design and realization of new Industry 4.0 technologies and concepts. This research will explore the effects of assessing enterprise architecture maturity in the context of Industry 4.0.

1.3 Problem statement

Hevner, March, Park and Ram (2004) recognize a lag between academic research and its adoption in industry. This is also the case for maturity models. Maturity

[1] https://scholar.google.com/ & www.google.com/

models have been subject to criticism, both from an academic perspective and from an industry perspective.

From an academic perspective maturity models have been criticized for: (1) the lack of a formal theoretical foundation (Biberoglu & Haddad, 2002), (2) being oversimplified and lacking empirical foundation (Benbasat, Dexter, Drury & Goldstein, 1984; De Bruin, Freeze, Kaulkarni & Rosemann, 2005; King & Kraemer, 1984; McCormack et al., 2009), (3) the lack of testing in terms of validity, reliability and generalizability (De Bruin & Rosemann, 2005), (4) the lack of documentation on the design process, and a non-reflective adoption of the Capability Maturity Model (Becker, Knackstedt & Poeppelbuss, 2009; Becker, Niehaves, Poeppelbuss & Simons, 2010; Iversen, Nielsen & Norbjerg , 2010), (5) the lack of a methodology to design theoretically sound and widely accepted maturity models (Mettler, 2009).

From a practical perspective maturity models have been criticized for: (6) overemphasising on processes and disregarding people's capabilities (Bach, 1994), (7) not configurable in order to deal with organization's external and internal characteristics, such as the technologies and customer base of organizations (Mettler & Rohner, 2009), (8) the outcome which neglects multiple equal advantageous paths organizations can go through for improving their maturity (Teo & King, 1997), (9) the focus on predefined end-states instead of factors which drive evolution and change (King & Kraemer, 1984), (10) the lack of a description on how to perform the necessary improvement actions (Mettler, 2009), (11) a too strong focus on formalizing these improvement actions, accompanied by extensive bureaucracy, can have a negative effect on innovativeness of people (Herbsleb & Goldenson, 1996), (12) being subject to bias because data for the assessment is being obtained by asking people (Mettler, 2009).

Hevner, March, Park and Ram (2004) developed a conceptual framework and guidelines for understanding, executing, and evaluating the design-science research in Information Systems. Applying this framework and the accompanied guidelines attributes to research relevance by addressing business needs and research rigor by appropriately applying existing foundations and methodologies. The stated criticism on maturity can be mapped on the Information Systems Research Framework from Hevner et al. (2004) as shown in figure 1. This demonstrates the lack of relevance and rigor of maturity models.

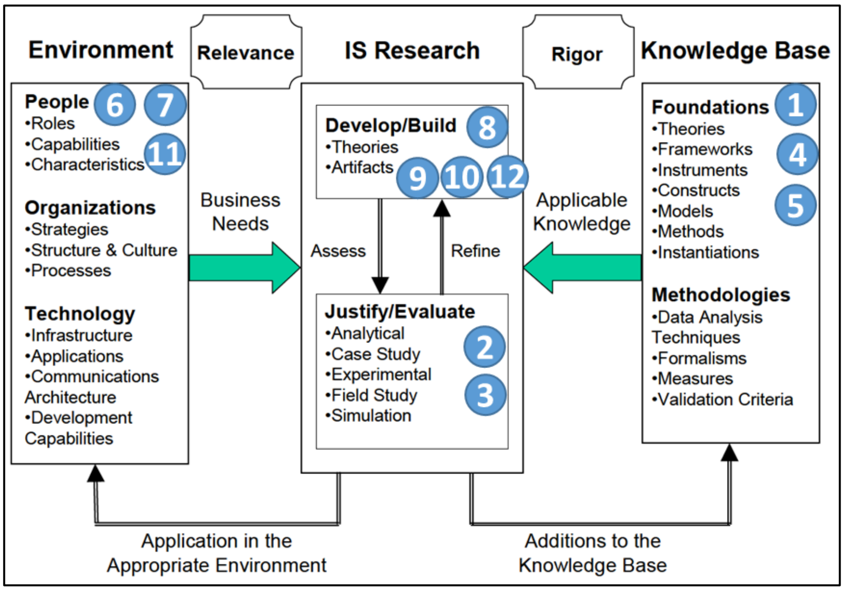


Figure 3. Information Systems Research Framework (Hevner, Park & March, 2004, p. 80)

1.4 Research objective

This research aims at addressing the relevance and rigor of maturity models by incorporating the business needs and using the foundations and methodologies of the knowledge base. The research objective is to develop a multi-criteria decision-making model which can be used to choose an enterprise architecture maturity model which fits the business needs best. These business needs are interpreted as todays context, Industry 4.0. Industry 4.0 is the possible fourth industrial revolution which we are experiencing today. This revolution brings several opportunities and challenges (e.g. technological) for organizations. Effective enterprise architecture practice can help organizations to realize changes with regards to Industry 4.0.

1.5 Research questions

In order to achieve the research objective, the following research questions need answering:

1. Which criteria can be used to compare and decide between multiple enterprise architecture maturity models?

2. What constitutes Industry 4.0?

3. Which criteria should be incorporated to address Industry 4.0?

4. What is the order of importance of these criteria?

1.6 Scientific and practical relevance

There is limited research on the combined fields of Industry 4.0 and enterprise architecture. There is no research on the impact of Industry 4.0 on existing models for measuring enterprise architecture maturity. The research will add value to practitioners in the means of identifying enterprise architecture maturity models which fit the context of Industry 4.0 best. In addition to this, the approach of comparing enterprise architecture maturity models for a specific domain can be used as a foundation for other domains.

Additionally, the exploration on the concept of Industry 4.0 from an Information Systems Research Framework perspective and an industrial revolution in general provides a different view on the concept.

1.7 Thesis outline

The next section provides the literature review on the topics Industry 4.0 and enterprise architecture maturity. The third chapter addresses the research methodology. It addresses the adopted research framework (i.e. Information Systems Research Framework) and research methods. The results of the research are presented in chapter 4. These results are structured by the outcome of the research methods: secondary research, survey and expert interview. This chapter concludes with the developed, demonstrated and evaluated multi-criteria decision-making model. The last chapters provides the discussion and conclusion of the research.

2 Literature review

A literature review has been conducted to evaluate and interpret the existing literature related to the topics Industry 4.0 and enterprise architecture maturity. In order to present a fair evaluation of the research topics, the paper "Procedures for performing systematic reviews" was used as a guideline for the literature review. However, not every aspect was applied due to relevance and added value. The three stages and their accompanied criteria, discussed by Kitchenham (2004), are incorporated in the research:

1. Planning
2. Conducting the review
3. Reporting the review

These stages have not been followed in the exact sequential order, but have been performed iteratively and were refined along the way. For example, during the second stage the initially set inclusion and exclusion criteria were refined based on initial results.

The following sections describes the followed strategy, the selection criteria and procedures, selected studies, and the results.

2.1 Strategy

A strategy has been developed and executed for the literature review[2]. Firstly, sources were identified for the literature review. The suggestions of databases by Leiden University have been taken into consideration. The underlying table shows the suggested databases, the ones that were selected and the reason for in- or exclusion.

Database	Selected (Y/N)	Reason for in- or exclusion
The ACM digital library	No	Results for Industry 4.0 = 44 Results for EA maturity = 0
The DBLP Computer science bibliography	Yes	Results for Industry 4.0 = 239 Results for EA maturity = 11
IEEE Computer Science Society Digital Library	No	A lot of hits, not all relevant, and most articles require payments
CiteSeerX	No	Too many irrelevant search results
Lecture Notes in computer science	No	Not appropriate, books and purchases
SIAM ebooks	No	No relevant results
ArXiv.org	No	No relevant results and no full text option

Table 1. Database search

Google Scholar has been added as a source next to the suggested database from DBLP. Some of the articles on Google Scholar require a subscription or payment. In order to bypass this, the digital library of Leiden University is being consulted to gain free access to these articles. The digital library of Leiden University will not be used as a primary resource because searching generates a lot of irrelevant hits and is not perceived as user friendly.

[2] The search for literature was time boxed, papers made available after 2018 have not been included in the search.

Three meaningful techniques stated by Levy and Ellis (2006) will be used for the search process. These are the keyword search, followed by the backward search and finished by the forward search. For the keyword search it is important to realize that the initial keywords will be updated based on initial results. The initial keywords are: Industry 4.0, Industrie 4.0, the fourth industrial revolution, enterprise architecture, enterprise architecture maturity, and a combination of these words.

The keyword search will be followed by the backward search. The backward search, introduced by Webster and Watson (2002), consists of three sub-steps: backward references search, backward authors search and previously used keywords. The backward references will be applied and involves taking the relevant references in the article into consideration. The backward authors search will not be applied. As the disciplines are relatively young, not a lot of relevant articles by the same author is expected. Exceptions will be there, but if relevant, multiple articles of the same author should come up in the results. The previously used keywords will be used in order to review the used keywords for searching relevant articles. This can lead to new keywords to be incorporated in the keyword search.

The forward search, introduced by Webster and Watson (2002) as well, consists of two sub-steps: forward references search and forward author search. For the same reason as of the backward search, the forward author search will not be adopted. The forward references will be applied in order to look into the articles that referred to the selected articles, and those will be taken into consideration.

After the papers are selected, they will be judged in a structured way. The papers will initially be judged on its title, abstract and keywords. If these are relevant and useful, the introduction and conclusion will be read and evaluated. If all the previous steps are satisfying, the rest of the article will read and evaluated.

2.2 Study selection criteria

In addition to the relevance of the articles, there are also a set of inclusion and exclusion criteria. These criteria are presented in the next two sections.

2.2.1 Inclusion criteria

The following inclusion criteria were applied for the literature review:

- The study defines the concept Industry 4.0, or adapts a definition provided by another study, or adds specific and relevant knowledge to the concept;
- The study defines the concept enterprise architecture maturity, or adapts a definition provided by another study, or adds specific and relevant knowledge to the concept;
- The study covers both topics: Industry 4.0 and enterprise architecture (maturity);

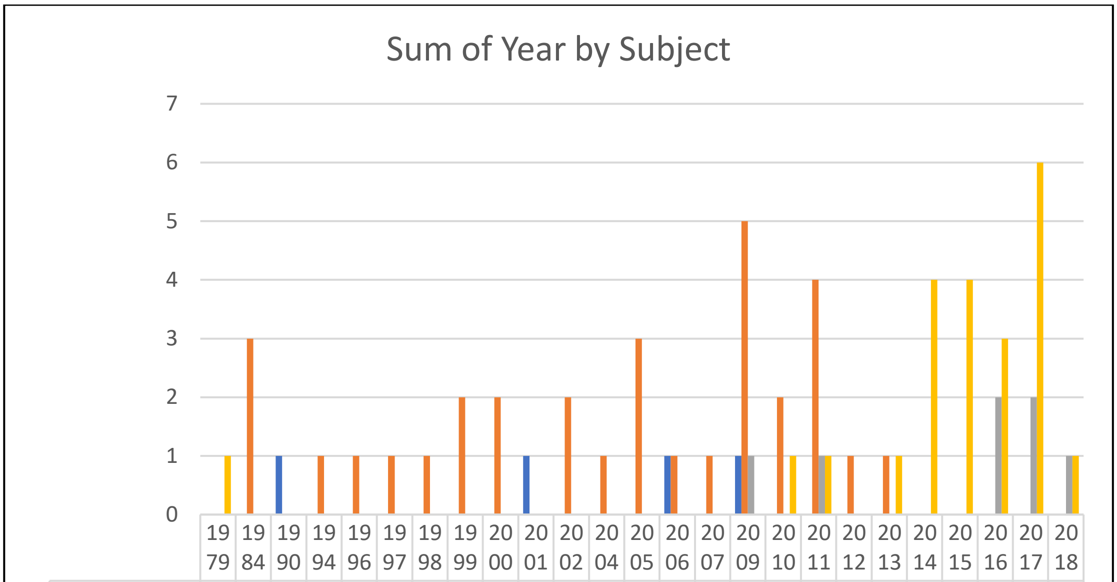
2.2.2 Exclusion criteria

The following exclusion criteria were applied for the literature review:

- The study is not accessible;
- The study focused minimally on one of the topics;
- The study is not published or peer reviewed;
- The study is not in English.

2.3 Selected studies

Based on the strategy and applied criteria, 65 studies have been selected to incorporate in the literature review. These are related to enterprise architecture (EA), enterprise architecture maturity (EAM), Industry 4.0 or both Industry 4.0 and enterprise architecture (i4.0&EA). The selected studies are captured in the graph below.



	1979	1984	1990	1994	1996	1997	1998	1999	2000	2001	2002	2004	2005	2006	2007	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
EA			1							1				1		1									
EAM		3		1	1	1	1	2	2		2	1	3	1	1	5	2	4	1	1					
i4.0&EA																1		1					2	2	1
Industry 4.0	1																1	1		1	4	4	3	6	1

Figure 4. Selected studies for literature review

The next sections presents the outcome of the literature review.

2.4 Industry 4.0

The term Industry 4.0 and the fourth industrial revolution are used interchangeable in academic literature. It refers to both the German initiative and the fourth industrial revolution. The fourth industrial revolution is the first industrial revolution predicted beforehand instead of being acknowledged afterwards (Draft & Horch, 2014).

The term Industry 4.0 was firstly introduced by a German Workgroup in 2011 as previously mentioned (Kagermann, Lukas & Wahlster, 2011). One of the following works of the German Workgroup (Kagermann, Wahlster & Heilbig, 2013) is the most cited reference for Industry 4.0 (Liao, Deschamps, Loures & Ramos, 2017). However, there is still no common agreement on the concept of Industry 4.0 (Hofmann & Rüsch, 2017; Oesterreich & Teuteberg, 2016). The next paragraphs explores different definitions and understandings of the concept Industry 4.0.

To start off with the most referred source on the concept, Kagermann et al. (2013) do not provide a concrete definition for Industry 4.0. However, they state a few things which gives insight in their understanding of Industry 4.0. Kagermann et al. (2013) state the following:

> “The first three industrial revolutions came about as a result of mechanisation, electricity and IT. Now, the introduction of the Internet of Things and Services

into the manufacturing environment is ushering in a fourth industrial revolution.” (p. 5)

“In essence, Industrie 4.0 will involve the technical integration of CPS into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes. This will have implications for value creation, business models, downstream services and work organisation.” (p. 14)

“If German industry is to survive and prosper, it will need to play an active role in shaping this fourth industrial revolution.” (p. 20)

“The fourth industrial revolution (Industrie 4.0) holds huge potential for manufacturing industry in Germany... the implementation of the Industrie 4.0 initiative should aim to leverage the market potential for German manufacturing industry through the adoption of a dual strategy comprising the deployment of CPS in manufacturing on the one hand and the marketing of CPS technology and products in order to strengthen Germany’s manufacturing equipment industry on the other.” (p. 29)

“Industrie 4.0 is a “strategic initiative” of the German government that was adopted as part of the High-Tech Strategy 2020 Action Plan in November 2011. It was launched in January 2011 by the COMMUNICATION Promoters Group of the Industry-Science Research Alliance (FU).” (p. 77)

Based on the first, second and fourth paraphrase, Industry 4.0 and the fourth industrial revolution seem mostly to be evolved around technologies: Internet of Things (IoT), Internet of Services (IoS) and Cyber-Physical Systems (CPS). It also shows the use of both Industry 4.0 and the fourth industrial revolution for similar intentions. The fourth and fifth paraphrase refer to Industry 4.0 as a strategic initiative of Germany. The strategic initiative is adopted in order for the German Industry to maintain competitive and increase their competitive advantage by taking the most out of the Industry 4.0 identified concepts and technologies.

Hofmann and Rüsch (2017) also refer to Industry 4.0 as the fourth industrial revolution and provide the following definition: “The Fourth Industrial Revolution can be best described as a shift in the manufacturing logic towards an increasingly decentralised, self-regulating approach of value creation, enabled by concepts and technologies such as CPS, IoT, IoS, cloud computing or additive manufacturing and smart factories, so as to help companies meet future production requirements.” (p. 33).

The concepts and technologies are in line with the ones mentioned by Kagermann et al. (2013): CPS, IoT, IoS, cloud computing, additive manufacturing and smart factories. Their understanding is mostly focused on manufacturing.

Lu (2017) summarizes the concept on a higher level, “Industry 4.0 can be summarized as an integrated, adapted, optimized, service-oriented, and interoperable manufacturing process which is correlated with algorithms, big data, and high technologies.” (p. 3).

This definition is focused on concepts which emerge from the use of certain technologies and methods, and is focused on the manufacturing process as well. Lu (2017) does not emphasize on the technology IoT in contrary to the other definitions.

Liao, Deschamps, Loures & Ramos (2017) do not provide a definition for Industry 4.0, but they state the following, “the final report of Industry 4.0 working group (Kagermann, Wahlster & Helbig, 2013) can confidently be used as the citation and guidance for identifying the definition of Industry 4.0 … Furthermore, even though the most accepted citation was found, the gap of frequency between it and the other references is still huge.” (p. 3624).

They refer to the report of the German workgroup as a guideline for the understanding of Industry 4.0, but the workgroup does not provide a clear definition or understanding, as they use the concept as a strategic initiative and as the fourth industrial revolution.

2.4.1 Strategic initiatives related to Industry 4.0

As shown in multiple definitions, Industry 4.0 is highly referred to two things, a strategic initiative and the fourth industrial revolution. Liao et al. (2017) identified several similar initiatives as to Germany’s Industrie 4.0 from a government and industrials plans perspective[3]:

Government / Industrial	Strategic initiative	Aim
Germany	Industrie 4.0	Leveraging the market potential for German manufacturing industry through the adoption of a dual strategy comprising the deployment of CPS in manufacturing on the one hand and the marketing of CPS technology and products in order to strengthen Germany’s manufacturing equipment industry on the other.
US	Advanced Manufacturing (AMP)	Using innovative technologies to create existing products and the creation of new products. This can include production activities that depend on information, automation, computation, software, sensing and networking.
France	La Nouvelle France Industrielle – Industrie du Futur	Modernising the French production base and production tools and support the use and integration of digital technologies to transform companies and business models.
United Kingdom	Future of Manufacturing – High Value Manufacturing Catapult	Catalysing future growth and success of UK manufacturing by helping business accelerate and de-risk new concepts to commercial reality.
South Korea	Innovation in Manufacturing 3.0	Creating new value and obtain competitiveness in manufacturing sectors by converging factory and IT to accelerate the smart factory system.
China	Made in China 2025	Upgrading the industrial capability and smart manufacturing by ensuring that innovation, product quality, efficiency, and integration drive manufacturing across 10

[3] These initiatives have been updated and expanded with information on the Digital Transformation Monitor of the European Commission, source: https://ec.europa.eu/growth/tools-databases/dem/monitor/category/national-initiatives?page=1

		key industries such as IT, robotics and aerospace.
Japan	Super Smart Society	Creating a society which resolves various social challenges by incorporating the innovation of the fourth industrial (e.g. IoT, big data, AI, robot, sharing economy) revolution into every industry and social life.
Netherlands	Smart Industry	The far-reaching digitisation of devices, production means and organisations. Through the 'internet of things', these are interconnected, creating new ways of production, business models and sectors. Smart industries have great resource and cost efficiency and they can produce very flexibly, both in terms of product (specifications, quality, design), volume (quantity) and delivery time.
European Commission	Factories of the Future (FoF)	Helping EU manufacturing enterprises, in particular SMEs, to adapt to global competitive pressures by developing the necessary key enabling technologies across a broad range of sectors.
Industrial (AT&T, Cisco, General Electric, IBM and Intel	Industrial Internet Consortium (IIC)	Transforming business and society by accelerating the Industrial Internet of Things (IIoT).

Table 2. Strategic initiatives

All initiatives aim to improve manufacturing and the desired competitive advantage, except for the initiative of Japan. The initiatives are mostly based on applying new concepts and technologies in manufacturing.

2.4.2 The fourth industrial revolution

In addition to a governmental or industrial strategic initiative, Industry 4.0 refers to the fourth industrial revolution. Brettel, Friederichsen, Keller and Rosenberg (2014) state that according to experts from industry and research, the fourth industrial revolution will be triggered by the Internet, which allows communication between humans as well as machines in Cyber-Physical-Systems (CPS) throughout large networks. However, according to Schwab (2017) the fourth industrial revolution is not only about smart and connected machines and systems.

As mentioned in the introduction, there is still no commonly agreed upon understanding of what an industrial revolution comprises (Maynard, 2015). According to Deane (1979) an industrial revolution can be characterized by seven interrelated changes. If these changes are developed together to an sufficient degree this would constitute an industrial revolution. Deane (1979) identified the following seven interrelated changes:

1. Widespread and systematic application of modern science and empirical knowledge to the process of production for the market

2. Specialization of economic activity directed towards production for national and international markets rather than for family or parochial use
3. Movement of population from rural to urban communities
4. Enlargement and depersonalization of the typical unit of production so that it comes to be based less on the family or the tribe and more on the corporate or public enterprise
5. Movement of labour from activities concerned with the production of primary product to the production of manufactured goods and services
6. Intensive and extensive use of capital resources as a substitute for and complement to human effort
7. Emergence of new social and occupational classes determined by ownership of or relationship to the means of production other than land, namely capital

The changes of Deane were identified in the seventies, and are therefore more appropriate with the first industrial revolutions. However, aspects of the changes seem to be applicable to any industrial revolution, as well as the possible fourth industrial revolution.

The widespread and application of modern science is an recurring change in every industrial revolution. Every revolution has been ignited by one or more technologies. Industry 4.0 is according to multiple perspectives evolved around technologies and concepts such as IoT and CPS.

The second change is demonstrated by the focus on manufacturing by several country's initiatives.

Urbanization is estimated to grow from 55,3 percent to 60 percent by 2030 according to studies of the United Nations, Department of Economic and Social Affairs, Population Division (2018).

The fourth change seems to be different for the possible fourth industrial revolution. According to Wang, Ma, Yang and Wang (2017) mass customization has been a trend in recent times, and the technologies and concepts of Industry 4.0 will enable novel forms of personalization.

One of the trends for Industry 4.0 is manufacturing servitization and innovation (Lee, Kao & Yang, 2014). Servitization is the shift from selling products to selling a combination of products and services that delivers value in use (Martinez, Bastl, Kingston & Evans, 2010). This aligns with the fifth change.

The interaction between human and machine is a recurring theme in academic literature on Industry 4.0 (Gorecky, Schmitt & Loskyll, 2014; Lu, 2017; Posada, Toro, Barandiaran, Oyarzun, Stricker, De Amicis & Vallarino, 2015; Roblek, Meško & Krapež, 2016). The tasks and demands of humans will change with the development of Industry 4.0 (Gorecky, Schmitt & Loskyll, 2014). It is likely that simple manual tasks will continue to decline due to the increasing presence of IT, which could pose a threat to semi-skilled workers (Kagermann, Wahlster & Helbig, 2013). The sixth and seventh change seem to be interrelated. The change on workforce by an increase of IT affects occupational classes.

Apart from these seven changes, an industrial revolution has always been associated with a growing population and an increasing annual volume of goods and services produced (Dean, 1979). Lucas (2002) defines an industrial revolution as the onset of sustained income growth. According to Rüßmann et al. (2015) Industry 4.0 will lead to an increase in production and productivity, which will drive the GDP. They used

German manufacturing as an example to quantify the potential impact of Industry 4.0. The numbers are based on the Federal Statistics Office of Germany, expert interviews and Business Consulting Group's analysis. The increase in productivity is acknowledged by Lee , Kao and Yang (2014) as it will reduce costs of machines, labour and energy. Hermann, Pentek and Otto (2016) state that the economic impact of Industry 4.0 is supposed to be huge as it promises substantial increase of operational effectiveness and the development of entire new business models, services and products. In comparison to previous industrial revolutions, the impact on economic development and work organisation will be just as profound (Kagermann, 2015).

The interpretation of the seven changes of Dean (1979) with regards to Industry 4.0 might indicate we are experiencing the fourth industrial revolution today. These seven changes also indicate a broader perspective on an industrial revolution, and not limiting it solely to manufacturing. Therefore, the understanding of Schwab and Davis (2018) on the fourth industrial revolution is adopted. The understanding is based on the book of Schwab (2017) and presented graphically below.

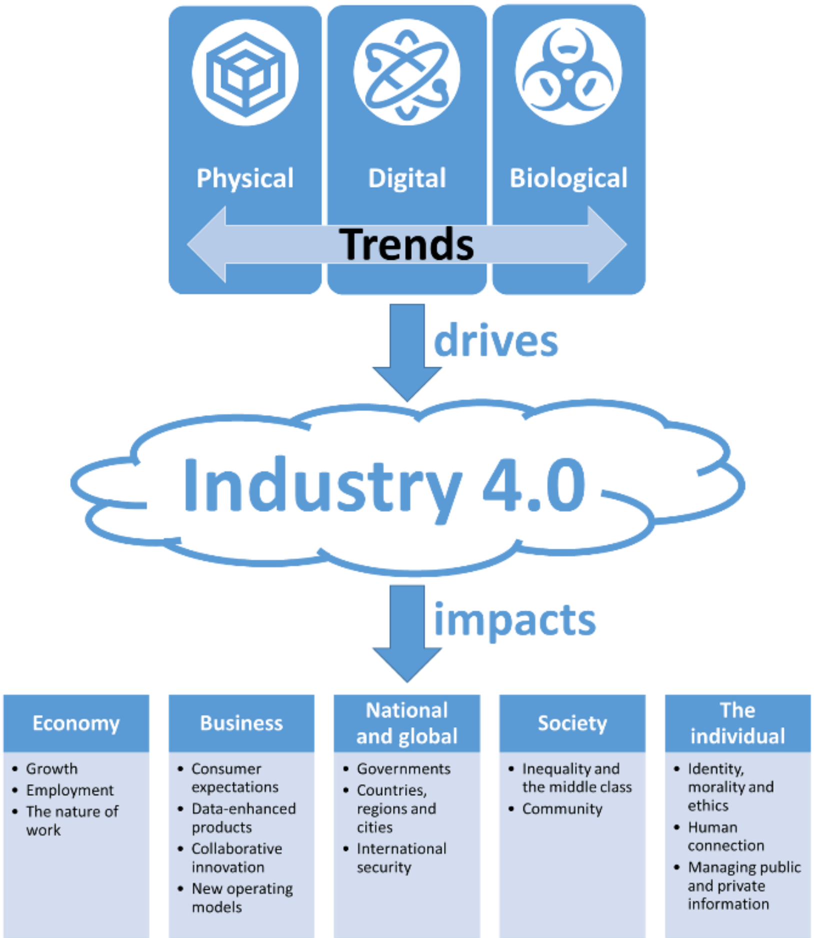


Figure 5. Industry 4.0 according to Schwab (2017)

The fourth industrial revolution's scope encompasses more than just 'industrial' (Schwab & Davis, 2018). A more suitable framing of what industrial encompasses in this matter is the way Thomas Carlyle and John Stuart Mill referred to industry in the 19th century: all activities that flow from human effort (Schwab & Davis, 2018). Most of the strategic initiatives across the world refer to factories, manufacturing and production, when discussing Industry 4.0 or similar terms such as Smart Industry (Netherlands), Advanced Manufacturing (US), and Made in China 2025. Unlike the concept of Industry 4.0, Japan introduced Society 5.0 which is not only restricted to the manufacturing sector, but its goal is to solve social problems through integration of physical and virtual spaces (Skobelev & Borovik, 2017). The fourth industrial revolution is driven by physical, digital and biological megatrends. These megatrends impacts: economy, business, national and global, society, and the individual. Several possible influential technology shifts are presented by Schwab (2017), such as: artificial intelligence, Internet of Things, blockchain, 3D printing and neurotechnologies.

2.5 Enterprise architecture

Every revolution has been associated with technological changes. Several types of technological changes exist. These can be framed using the framework for defining innovation of Henderson and Clark (1990). An innovation can be classified along two dimensions: an innovation's impact on components and the impact on the linkages between components. The accompanied framework is shown below.

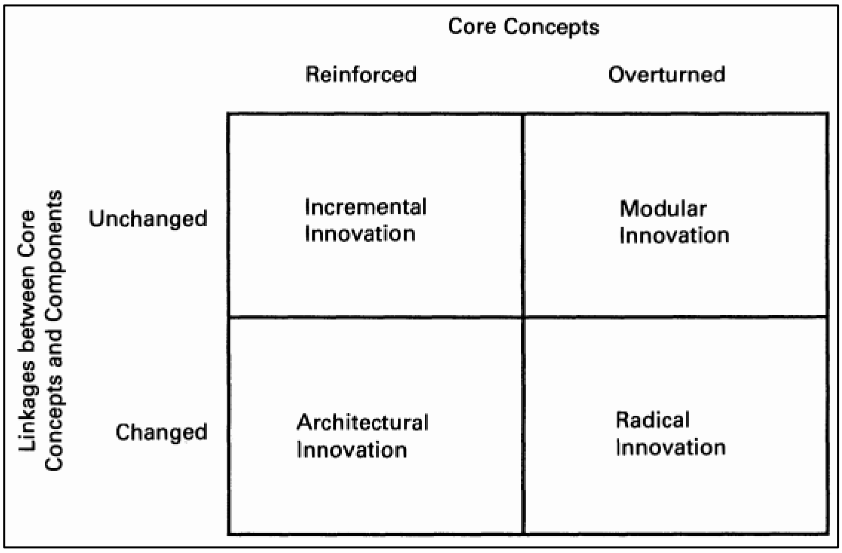


Figure 6. A framework for defining innovation (Henderson & Clark, 1990, p. 12)

An innovation can be placed anywhere on the continuum, from incremental (or evolutionary) to radical (or revolutionary), depending on the impact it has on the components or architecture of a system (Sircar, Nerur & Mahapatra, 2001).

As mentioned in the first chapter, enterprise architecture is “a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise’s organizational structure, business processes, information systems, and infrastructure” (Lankhorst, 2009, p. 3). The framework of Henderson and Clark is useful for exploring the impact of innovations on existing architectures.
Most framework structures enterprise architecture into the following layers according to Winter and Fisher (2006):

- Business architecture, which represents the fundamental organization of the enterprise from a business strategy viewpoint;
- Process architecture, which represents the development, creation and distribution of services;
- Integration architecture, which represents the information systems;
- Software architecture, which represents the software artefacts;
- Technology (or infrastructure) architecture, which represents the computing and telecommunications hardware and networks.

The enterprise architecture layers are similar to the environment of the Information Systems Research Framework. The business and process architectures relate to people and organizations. Whereas, the integration, software and technology architectures relate to technology.

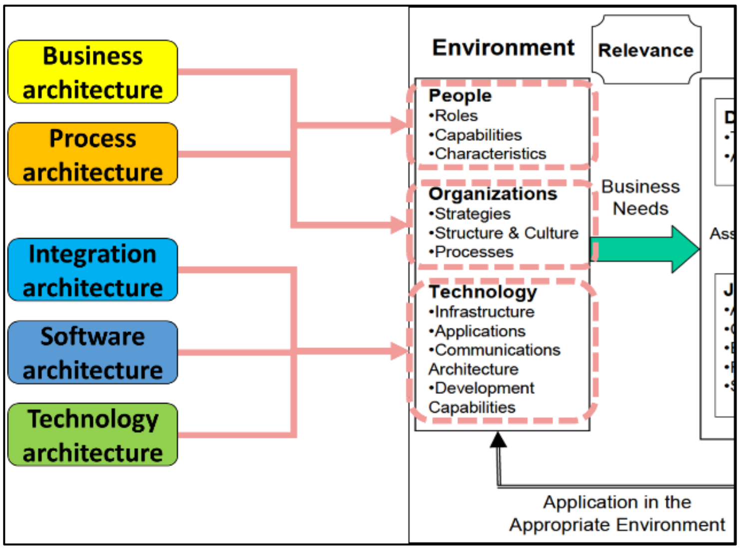


Figure 7. Relation enterprise architecture and Information Systems Research Framework

2.5.1 Enterprise architecture maturity

Besides using existing knowledge, the ability of organizations to deploy their resources to competitive advantage is key for success (Wernerfelt, 1984). Nowadays, organisations must distinguish themselves by how they apply technologies, because technologies are becoming more common and accessible (Steenbergen, Bos, Brinkkemper, van de Weerd & Bekkers, 2013). For applying these technologies, information systems capabilities have to be developed (Montealegre, 2002; Scott, 2007). Maturity models can be a mean to assess these capabilities for a specific discipline, like Information Systems (Cleven, Winter & Wortmann, 2012; Poeppelbuss, Niehaves, Simons & Becker, 2011; Mettler, Rohner & Winter, 2010; Scott, 2007; De Bruin & Rosemann, 2005).

Maturity models became popular with the emergence of the Capability Maturity Model (CMM) (Paulk, 1995; Paulk et al., 1993; de Bruin et al., 2005]). The CMM and its successor, CMM Integration (CMMI), are still the most dominant foundation for maturity models in Information Systems (Poeppelbuss, Niehaves, Simons & Becker, 2011).

The CMM is a staged fixed level model. These levels (i.e. Initial, repeatable, defined, managed, optimizing) provide a layer in the foundation for continuous process improvement. This maturity growth structure is one of the characteristics of a maturity model. Steenbergen (2011) distinguishes three types of characteristics for maturity models:

1. **The maturity growth structure**
   Many models adopt the maturity growth structure of CMM or is similar to it. The number of levels commonly differ from three to six levels. The levels of CMM focus on the degree of process management, other models base there levels on the resulting situation. The model of Ross, Weill & Robertson (2006) consists of four stages (i.e. business silos, standardized technology, optimized core, business modularity) organisations go through, where each

stage results in increasingly effective use of enterprise architecture. Another maturity growth structure are the continuous level models. These models consist of focus areas and each focus area consist of the same amount of levels. The focus area oriented models differ from the other two maturity growth structure. This structure is evolved around focus areas where each focus has its own amount of specific maturity levels.

2. **The application dimension**
   Most models only focus on the process dimension such as the CMM. Other possible dimensions to incorporate could be people and objects, because specific functions involves more dimensions (Bharadwaj, 2000; Feeny & Willcocks, 1998; Mettler & Rohner, 2009; Niazi, Wilson & Zowghi, 2005; Ravichandran & Rai, 2000).
3. **The purpose of the model**
   Models typically have three application-specific purposes: descriptive, prescriptive and comparative (Becker, Knackstedt & Poeppelbuss, 2009; De Bruin, Freeze, Kaulkarni & Rosemann, 2005; Iversen, Nielsen & Norbjerg, 1999; Maier, Moultrie & Clarkson, 2009). Descriptive models are used to assess the current situation. Prescriptive models are used to identify the desirable maturity levels and provides guidelines on improvement measures. Comparative models are used for comparative purposes, which can be for internal or external benchmarking.

Numerous maturity models are available for enterprise architecture. Most of these have been published by government institutions or analyst institutions (e.g. Gartner) (Steenbergen, 2011). Enterprise architecture maturity models are a means to measure and improve the maturity of the enterprise architecture practice, depending on the purpose of the model. Effectiveness of enterprise architecture practice can lead to organizational benefits such as lower costs, higher strategic agility, and a more reliable operating platform (Tamm, Seddon, Shanks & Reynolds, 2011).

The concept of maturity models has been subject to criticism. The framework of Hevner, March, Park and Ram (2004) will be used to position the criticism. The framework has been proposed to understand, execute, and evaluate Information System research combining behavioural-science and design-science paradigms. This framework allows you to position and compare these paradigms.

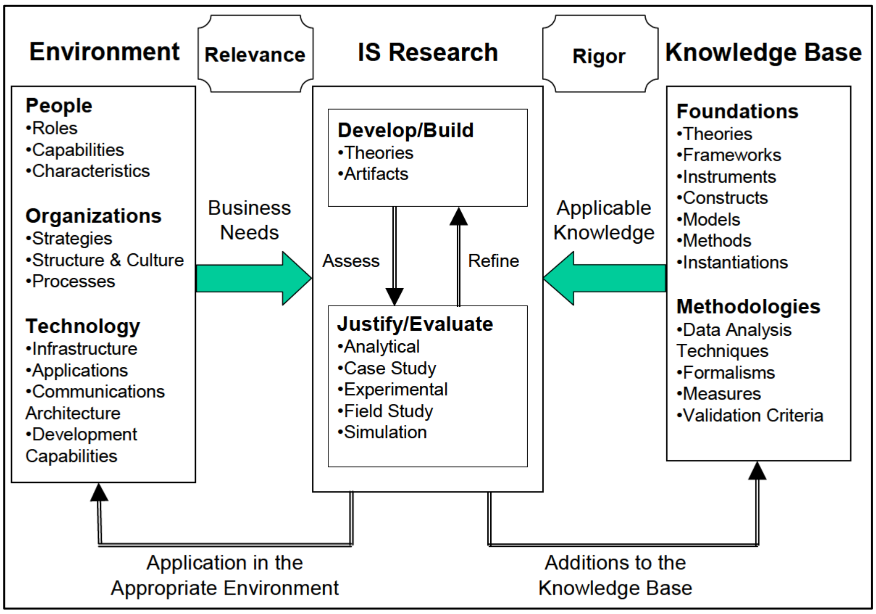


Figure 8. Information Systems Research Framework (Hevner, Park & March, 2004, p. 80)

The environment addresses the problem space which captures the phenomena of the interest. It is composed of people, organisations and technologies, and these translate into business needs. The CMM, foundation for numerous maturity models, has been criticised for overemphasising on processes and disregarding people's capabilities (Bach, 1994). Mettler and Rohner (2009) state that maturity models should be configurable in order to deal with organization's external and internal characteristics, such as the technologies and customer base of organizations. Another subject to criticism has been the outcome for organizations. Maturity tends to neglect multiple equal advantageous paths organizations can go through for improving their maturity (Teo & King, 1997). Besides having multiple paths, maturity should not solely focus on predefined end-states, but on factors which drive evolution and change (King & Kraemer, 1984). According to Pfeffer and Sutton (1999) the purpose of maturity models should be to identify a gap and provide the necessary improvement actions to close this gap. However, a lot of the models do not provide a description on how to perform these actions effectively (Mettler, 2009). A too strong focus on formalizing these improvement actions, accompanied by extensive bureaucracy, can have a negative effect on innovativeness of people (Herbsleb & Goldenson, 1996).

The middle of the Information Systems Research Framework, IS Research, concerns with behavioural science and design science. Behavioural science addresses the development and justification of theories regarding the business needs. Design science addresses the building and evaluation of artefacts to meet the identified business needs. The step by step approach of maturity models is characterized as oversimplified and lacking empirical foundation (Benbasat, Dexter, Drury & Goldstein, 1984; De Bruin, Freeze, Kaulkarni & Rosemann, 2005; King & Kraemer, 1984; McCormack et al., 2009). In addition, the models lack testing in terms of validity, reliability and generalizability, and little documentation on how to design and develop such a model (De Bruin & Rosemann, 2005). Other criticism addresses the multitude of similar maturity models, the lack of documentation on the design process, and a non-reflective adoption of the CMM (Becker, Knackstedt & Poeppelbuss, 2009; Becker, Niehaves, Poeppelbuss & Simons, 2010; Iversen, Nielsen & Norbjerg , 2010). The data collected for the assessment in most models depends on people being asked and thus subject to bias (Mettler, 2009).

The right side of the Information Systems Research Framework covers the knowledge base which provides the raw materials from and through which IS research is accomplished. This is composed of foundations and methodologies. One of the widely known criticism is CMM's lack of a formal theoretical basis. CMM is based on experience from groups of practitioners rather than formal theories (Biberoglu & Haddad, 2002). Mettler (2009) states that there is also a lack of a methodology to design theoretically sound and widely accepted maturity models.

In order to address the criticism Mettler (2009) proposed a phase model for both, development and application of maturity models. The development of a maturity models consists of four phases: (1) Define scope; (2) Design model, (3) Evaluate design; (4) Reflect evolution.

The application of maturity models consists of four phases as well: (1) Select model; (2) Prepare deployment; (3) Apply model; (4) Take corrective actions.

Every phase for both development and application consists of a number of decision parameters and their accompanied characteristics. The model aims to add knowledge on how to design theoretically sound and accepted maturity models.

Another research proposed a framework that identifies design principles for form and function which maturity models should comply with (Poeppelbus Röglinger, 2011). The design principles are grouped into basis principles, descriptive purposes principles and prescriptive purposes principles. This framework aims to provide a checklist that enables to compare alternative maturity models and to disclose in what respect a specific maturity model requires further substantiation.

2.6 Industry 4.0 and Enterprise Architecture (maturity)

Industry 4.0 is closely related to Enterprise Architecture (Lu, 2017). Future trends on enterprise architecture indicate changes on business architectures, information architectures, application architectures and technical architectures: business architecture will emphasis on cross-business processes instances where changes are a normality instead of an exception; information architectures will focus on big data, data analytics and social business intelligence; application architectures will aim at reusable components in order to form an edge application in which multiple services and components (e.g. portals, RSS feeds, gadgets, user interface components and several types of servers) are overlaid or mashed together; technical architectures will aim at strong service orientation which realizes platform-, language- and operating systems independent middleware solutions as promoted by internet computing (Romero & Vernadat, 2016).

Enterprise architecture should be a guiding principle for the design and realization of an enterprise's organizational structure, business processes, information systems, and infrastructure (Lankhorst, 2009). In order to successfully integrate these changes sound architectural practice is necessary. Architectural practice is the whole of activities, responsibilities and actors involved in the development and application of enterprise architecture within the organisation (Steenbergen, 2011). Maturity models can be used as an instrument to support and accelerate the establishment of architectural practice, depending on the purpose of the model, i.e. descriptive, prescriptive and comparative.

However, according to Lapalme et al. (2016) current enterprise architecture is strongly focused on modelling and planning concerns, but should strive to be more considerate to people, society and the environment, and contribute to the development of organization capacity for sense-making and innovation. The striving to be more considerate to people and contribute to innovation is a recurring theme. The critics on maturity models also point out the lack of consideration on people and innovation.

Reference architectures also provide guidance to organisations that evolve or create new architectures. Several reference architecture related to Industry 4.0 have been developed. Some are focused on (industrial) IoT, others on smart factories and others on CPS. The reference architecture which was specifically developed for Industry 4.0 is Reference Architecture Industry 4.0 (RAMI 4.0), which is often compared to the Industrial Internet of Things Reference Architecture (IIRA).

Industry 4.0 has been heavily associated with an service-oriented architecture (SOA). RAMI 4.0 is such an service-oriented architecture. SOA is an architectural style that supports service-orientation. In such an architecture, applications are self-contained and expose themselves as services, which other applications can connect to and use. Besides being adopted by RAMI 4.0, SOA has been heavily associated with Industry 4.0 and seen as a solution for implementing Industry 4.0 concepts and technologies (Xu, L., Xu, E. & Li, 2018).

Nowadays, there is a second iteration on the concept of SOA, which is based on microservices. Microservices architectures have received considerable interest from academic and industry (Shadija, Rezai & Hill, 2017). Figure 5 captures the differences between a ‘traditional’ service-oriented architecture and a microservices architecture (Shadija, Rezai & Hill, 2017). It will be interesting to see the future impact of the development of microservices architecture. As of now, academic literature on both Industry 4.0 and microservices architecture is limited.

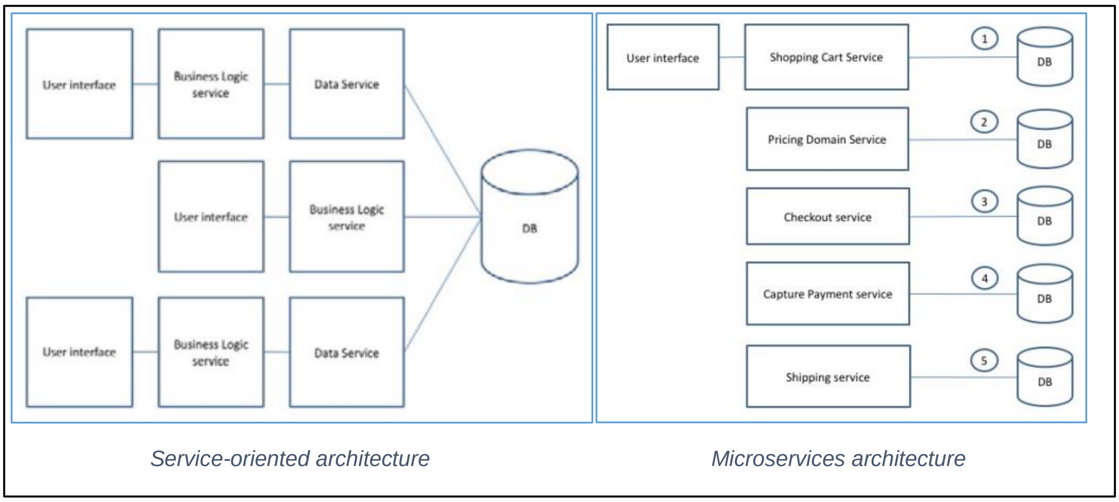


Figure 9. Service-oriented architecture and Microservices architecture (Shadija, Rezai & Hill, 2017)

3 Research methodology

This chapter describes the framework and methodologies that are used to answer the research questions.

3.1 Research approach

The research has an exploratory and interpretive nature. Therefore, a semi-qualitative approach has been adopted for answering the research questions. The approach has been inspired by the Information Systems Research Framework from Hevner, March, Park and Ram (2004).

The Information Systems Research Framework is a conceptual framework for understanding, executing and evaluating information systems research (see figure 3). It combines behavioural-science with design-science paradigms.

Information systems research is conducted in two complementary phases:

1. The development and justification of theories that explain or predict phenomena related to the identified business need;
2. The building and evaluation of artefacts that are designed to meet the identified business need.

The first phase addresses the behavioural science which goal is truth, and the second phase addresses design science which goal is utility. Both of these goals are inseparable in information systems research. The justification and evaluation can identify weaknesses in the theory or artefact. The need to refine and reassess this is typically addressed in future research directions.

The underlying framework is adopted for this research. It is slightly modified from the original framework. Instead of business needs, the business perspective is explored through expert interviews. The justification and evaluation phases has been minimalised to analytical and experimental.

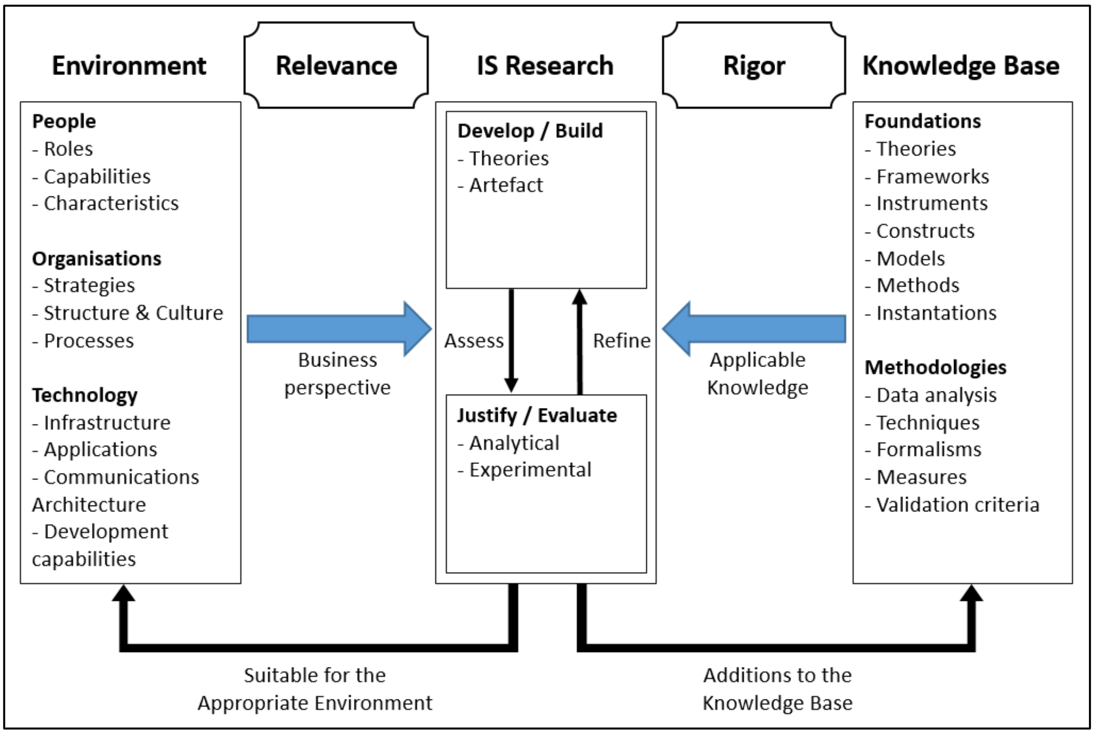


Figure 10. Research framework, adopted from Information Systems Research Framework (Hevner, Park & March, 2004, p. 80)

The incorporation of the environment provides relevance to the research. The appropriate application of existing foundations and methodologies from the knowledge base provides rigor to the research.

The process as described by Peffers et al. (2007) is followed for this research. Gregor and Hevner (2013) find the research process of Peffers et al. compatible with the Information Systems Research Framework. The process consist of the following stages:

1. **Identify problem**
   The problem is described in chapter 1.3.
2. **Define solution objective**
   The research objective is described in chapter 1.4.
3. **Design and development**
   A decision-making model for comparing and selecting enterprise architecture maturity models is designed and developed in this stage. The model is derived from literature and practitioners (expert interviews and survey). The artefact is decision-making model developed in R studio and is based on the Analytical Hierarchy process (AHP) from Saaty (2008). A description of the AHP is provided in the next paragraph.
4. **Demonstration**
   The efficacy of the model is demonstrated by applying it to two existing enterprise architecture maturity models.
5. **Evaluation**
   The seven guidelines of Hevner et al. (2004) are used to evaluate the development of the multi-criteria decision-making model.
6. **Communication**
   The thesis and model will be communicated to the scientific and industry communities by publishing it in the thesis repository of Leiden University.

3.1.1 Analytical Hierarchy Process

The AHP is a multi-criteria decision-making method. It has been used in numerous settings to make decisions (Saaty, 2008). This method structures the decision into a hierarchy: the goal of the decision at top, the criteria (and sub-criteria) which apply to the decision and the alternatives to be rated along the criteria. After the goal is set, weights are developed for all criteria. These weights are obtained by pairwise comparisons of all criteria by experts. For these pairwise comparisons, a scale of absolute judgements is used to determine how many times more important one criteria is over another criteria.

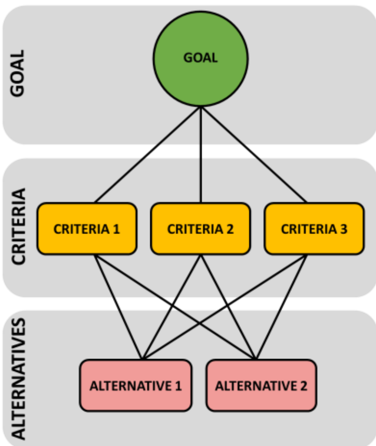


Figure 11. AHP hierarchy tree

Several scales can be used. Saaty (2008) suggested a scale from 1 to 9. 1 means that the criteria are of equal importance, a 9 means that one of the criteria is absolutely more important. 2, 3, 5, 7 are intermediate values. These intermediate values were excluded for this research to limit the variables for the experts. After finishing the pairwise comparisons with 1 to 9 scale, the relative weights are calculated based on the judgement matrix (i.e. pairwise comparisons) and normalized principal eigenvectors. Note that the white squares and light blue squares in the matrix are each other's opposite.

Criteria	C1	C2	C3
C1	1	3	7
C2	1/3	1	4
C3	1/7	1/4	1

Figure 12. Judgement matrix

The AHP allows for slightly inconsistent judgements. Pairwise comparisons of criteria can lead to inconsistencies, because information has to be processed on several simultaneously interacting elements. The AHP measures a consistency ratio (CR) per matrix. The consistency ratio should be 10% or less (Saaty, 1987).

After deriving the weights of the criteria, the alternatives can be rated along these weighted criteria. Alternatives are rated pairwise on every criteria. The 1 to 9 scale can also be used for the rating of alternatives, However, for this research an alternative rating category (i.e. high, medium, low) is adopted, provided by Saaty (2008).

3.2 Research methods

Data is collected through expert interviews, secondary research and a survey. The following paragraphs describe the application of these methods.

3.2.1 Expert interviews

The expert interviews serve to obtain the business perspective on Industry 4.0, enterprise architecture and enterprise architecture maturity. The interviews are conducted with six experienced professionals with a managerial or architectural position from different sectors.

Sector	Role
Public	Enterprise Architect
Private	Managing director
Private (consultancy)	Technology Architect
Public	Enterprise Architect
Financial	Head of CIO Office
Private	Process Information Manager Manufacturing-IT

Table 3. Interviewees

The interviews are qualitative and semi-structured. The same general areas of information are discussed with each interviewee. Appendix A contains the structure of the interview. Using the same general areas provides focus, but still allows a degree of freedom and adaptability in getting the information from the interviewee. For example, Industry 4.0 is a relatively young disciple and the experience with and knowledge of Industry 4.0 differs between the interviewees. Besides that, some of the interviewees are more experienced in enterprise architecture (maturity) than others. The freedom and adaptability of this form of interview will allow to adapt where needed and having the freedom to explore certain areas more in depth.

The interviews are recorded[4] and transcribed. A thematic analysis will be conducted for the analysis of the interviews and integration with theory. A deductive approach is adopted for the thematic analysis. The Environment in the Information Systems Research Framework (figure 5) provides the themes for the theoretical framework and consists of: people, organizations and technology. The process is inspired by Braun and Clarke (2006), and consists of five steps:

1. Familiarizing with the data
2. Generating initial codes
3. Defining themes based on the Information Systems Research Framework
4. Reviewing themes
5. Producing the theory

[4] Consent for the recording of the interviews is asked in accordance with the General Data Protection Regulation (GDPR).

3.2.2 Secondary research

Secondary research is used to define the criteria for comparing and selecting enterprise architecture maturity models. Existing foundations in the knowledge base are inventoried and refined for defining the criteria.

3.2.3 Survey

A survey is carried out to weigh the defined criteria. This survey is sent to 24 architects. The survey consists of an Excel-sheet where respondents perform a pairwise comparison of all criteria. The Analytical Hierarchy Process from Saaty, is used for weighting the criteria. A 1-9-1 scale is used to determine the importance of the criteria. The intensity of importance and the Excel-sheet to fill in by the respondents are shown in the tables below.

A	B	A or B?	How much more important?
Criteria1	Criteria2		
Criteria1	Criteria3		
Criteria2	Criteria3		

Intensity of importance	Numerical value
Equal important	1
Somewhat more important	3
Much more important	5
Very much more important	7
Absolutely more important	9

Table 4. Pairwise comparison matrix & scale

3.3 Research overview

The figure below presents a graphical view on the research. In summary, the research stages lead to the research methods, resulting in the model, which is evaluated and afterwards published. The contribution of the research methods to the research questions is shown on the right.

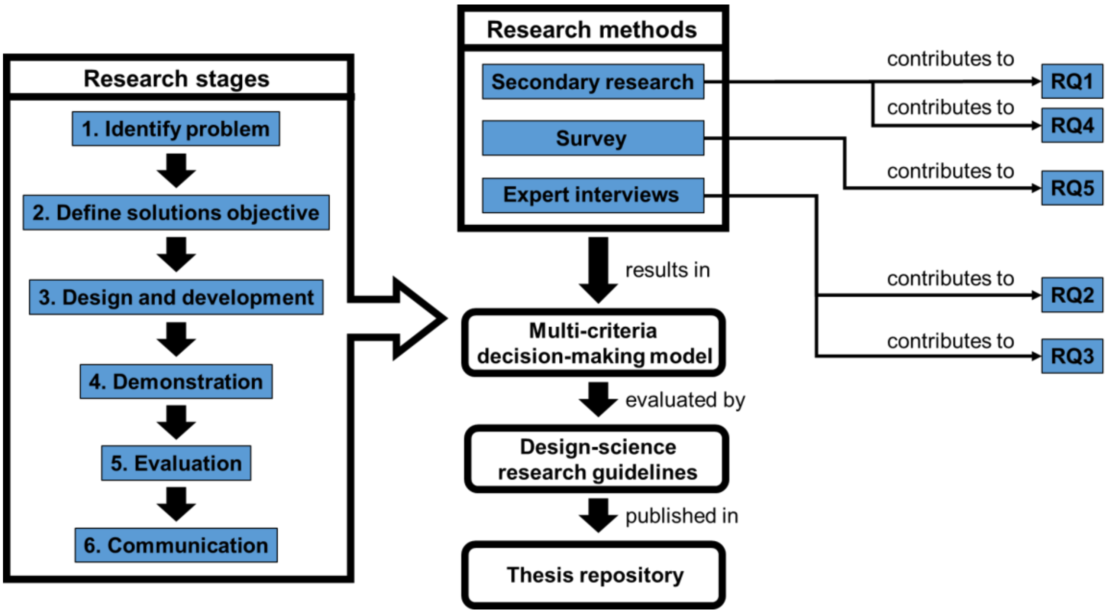


Figure 13. Research overview

4 Results

The results are structured into the outcomes of the secondary research, survey and expert interviews. Afterwards the resulting multi-criteria decision-making model is presented, demonstrated and evaluated.

4.1 Results of the secondary research

The secondary research resulted in three papers which were used as a foundation for defining the criteria for comparing and selecting enterprise architecture maturity models. These papers were chosen on relevancy through a Google Scholar search. Three searches were executed:

1. Selecting “maturity model”;
2. Criteria “maturity model”;
3. Design principles “maturity model”.

The first 30 results on every search were explored on relevancy. This resulted in three relevant papers out of 90 explored papers:

1. Mettler, T. (2009). A design science research perspective on maturity models in information systems.
2. Poeppelbuss, J., & Roeglinger, M. (2011, June). What makes a useful maturity model? a framework of general design principles for maturity models and its demonstration in business process management. In *Ecis* (p. 28).
3. Van Looy, A., De Backer, M., Poels, G., & Snoeck, M. (2013). Choosing the right business process maturity model. *Information & Management*, *50*(7), 466-488.

The following three sections addresses the usefulness of these papers. The fourth section describes the chosen criteria based on these papers.

4.1.1 Metller – A design science research perspective on maturity models in information systems

Mettler (2009) proposed a phase model for both development and application of maturity models. The phase for application of maturity models is relevant for this research, because it contains decision parameters for selecting a model.

#	Decision parameter	Description
M1	**Origin**	Whether it has its source from academia or practice.
M2	**Reliability**	How well the maturity model has been evaluated.
M3	**Practicality**	Whether the recommendations are problem-specific or more general in nature and hence need more detailing.
M4	**Accessibility**	If it is free for use or not.
M5	**Design mutability**	Convertibility of model elements and ease of integration in existing organisational model base.
M6	**Application method**	Self-assessment or an appraisal by certified professionals.

Table 5. Decision parameters (Mettler, 2009)

Mettler (2009) acknowledges the lack of a classification or reference database of maturity models in the knowledge base. The decision parameters are all valuable for selecting a maturity model. However, they do not provide guidance for the content or context with regards to the maturity model. In addition, it lacks the desired outcomes or the importance of the decision parameters. Maturity models have been criticized for numerous aspects. What if none of the maturity models satisfy the decision parameters? Which maturity model will be selected? Which maturity model fits the organization or context best? Or will this lead to organizations making their own maturity model or modifying an existing maturity model?

4.1.2 Poeppelbuss & Roeglinger – What makes a useful maturity model?

Poeppelbuss and Roeglinger (2011) developed a framework of general design principles for form and function which maturity models should comply with. Compliance with these principles results in useful models for the application domain and purpose of use.

Poeppelbuss and Roeglinger (2011) structured their design principles into three groups: basic, descriptive and prescriptive. The descriptive and prescriptive principles reflect the purpose of use. The basic principles should apply to all maturity models. The descriptive principles only apply if the model is being applied as a diagnostic tool. If the purpose is prescriptive, both basic and descriptive principles apply. A prescriptive purpose is if a model indicates how to identify desirable maturity levels and provides guidelines on improvement measures, and specific and detailed courses of action. The principles are captured in the table below.

Group	#	Design Principles
Basic	P1	**1.1 Basic information:** (a) application domain and prerequisites for applicability, (b) purpose of use, (c) target group, (d) class of entities under investigation, (e) differentiation from related maturity models, (f) design process and extent of empirical validation.
	P2	**1.2 Definition of central constructs related to maturity and maturation:** (a) maturity and dimensions of maturity, (b) maturity levels and maturation paths, (c) available levels of granularity of maturation, (d) underpinning theoretical foundations with respect to evolution and change.
	P3	**1.3 Definition of central constructs related to the application domain**
	P4	**1.4 Target group-oriented documentation**
Descriptive	P5	**2.1 Intersubjectively verifiable criteria for each maturity level and level of granularity**
	P6	**2.2 Target group-oriented assessment methodology:** (a) procedure model, (b) advice on the assessment of criteria, (c) advice on the adaptation and configuration of criteria, (d) expert knowledge from previous application.
Prescriptive	P7	**3.1 Improvement measures for each maturity level and level of granularity**
	P8	**3.2 Decision calculus for selecting improvement measures:** (a) explication of relevant objectives, (b) explication of relevant factors of influence, (c) distinction between an external reporting and an internal improvement perspective.
	P9	**3.3 Target group-oriented decision methodology:** (a) procedure model, (b) advice on the assessment of variables, (c) advice on the concretization and adaption of the improvement measures, (d) advice on the adaptation and configuration of the decision calculus, (e) expert knowledge from previous application.

Table 6. Design principles (Poeppelbuss & Roeglinger, 2011)

In contrary to Metller's model, the framework of Poeppelbuss and Roeglinger address the content and context of maturity models. It also gives guiding principles with regards to the purpose of use.

However, the focus of the framework is to compare maturity models and identify gaps in order to improve the maturity models, guided by the design principles. This can be useful for the developers of maturity models. For consumers of maturity models, only some of the design principles are relevant for choosing a maturity model. They might not have the expertise and experience to develop a maturity model or improve an existing maturity model.

4.1.3 Van Looy, de Backer, Poels & Snoeck – Choosing the right business process maturity

Van Looy et al. (2013) built a decision tool for selecting a business process maturity model. The tool consists of a questionnaire with 14 decision criteria. These criteria were defined by an international Delphi study, and weighed by the Analytical Hierarchy Process. The criteria can be grouped into assessment criteria, improvement criteria and non-design criteria.

Group	#	Criteria	Description
Assessment criteria	V1	**Rating scale**	The type of data that is collected during an assessment.
	V2	**Data collection technique**	The way information is collected during an assessment.
	V3	**Assessment duration**	The maximal duration of a particular assessment.
	V4	**Assessment availability**	Whether the assessment items and level calculation are publicly available (instead of only known to the assessors).
	V5	**Functional role of respondents**	The explicit recognition to include people from outside the assessed organisation(s) as respondents.
	V6	**Number of assessment items**	The maximal number of questions to be answered during an assessment.
Improvement criteria	V7	**Presence of capabilities**	The business process capability areas to be assessed and improved.
	V8	**Architecture type**	The possibility to define a road map per capability and/or a road map for overall maturity.
	V9	**Architecture details**	The degree of guidance that a maturity model gives on your journey towards higher maturity.
	V10	**Type of business processes**	Whether the maturity model addresses specific process types (e.g. supply chains or collaboration processes) or can be applied to any process type.
	V11	**Number of business processes**	The number of business processes to be assessed and improved.
Non-design criteria	V12	**Purpose**	The purpose for which the maturity model is intended to be used.
	V13	**Validation methodology**	Evidence that the maturity model is able to assess maturity and helps to enhance the efficiency and effectiveness of business processes.
	V14	**Direct costs**	The direct costs to access and use a maturity model.

Table 7. Criteria (Van Looy et al., 2013)

The decision tool is very specific for business process maturity models, demonstrated by most of the improvement criteria. Most of the other criteria are valuable for this research. However, the criteria are not discussed into detail. Therefore, it is difficult to see the relevance of some of the criteria, such as the duration of an assessment and the number of questions to be answered. The weight to these criteria are among the lowest, each one is less than 4%. The costs received the lowest weight, 3.42%. They state that when choosing between business process maturity models with good guidance, costs become more important. At the current design, this is not factored in. A benefits to costs ratio afterwards might seem more useful, if costs should be a criteria to be included.

Another thing which might cause concern is the amount of criteria (14!) they included. All of these 14 criteria even contain a sub-level of possible outcomes which were weighted as well. Miller (1956) conjectured that there is a limit on our capacity to process information on simultaneously interacting elements. This limit is seven plus or minus two according to Miller. Otherwise it could negatively affect the reliable accuracy and validity. Saaty and Ozdemir (2003) state that this limit should be even less, that it should be no more than seven in order to serve both consistency and redundancy. Van Looy et al. did address this by monitoring fatigue and stopping participants if fatigue occurred.

For future research Van Looy et al. suggest investigating whether their methodology allows theory building on other decision tools, e.g. for selecting other maturity models. The use of AHP for structuring the decision into a hierarchy tree and the pairwise comparisons of criteria is applied to this research as well. They also incorporated the guidelines of Hevner et al. (2004) for evaluation purposes.

4.1.4 Selected and defined criteria from secondary research

The secondary research on the papers has resulted into ten criteria for comparing an selecting enterprise architecture maturity models. The combination of these papers captures design and non-design criteria, but also the application context. In order to serve reliable accuracy and validity, the criteria are minimized to 9, which is the maximum number of interacting elements we are able to process simultaneously according to Miller (1956).

#	Criteria	Description	Refers to:
1	**Origin**	The origin of the model. Whether it has its source from academia or practice.	M1, P2d
2	**Reliability**	The reliability of the model. Whether the model is untested, verified or validated.	M2, P1f, V13
3	**Practicality**	The outcome of the assessment. Whether it provides general or specific recommendations and improvement actions which guides toward the desired maturity.	M3, P5-P9, V9
4	**Accessibility**	The accessibility of the model. Whether access to the model is free, charged or confidential (i.e. whether the assessment items and calculation are available).	M4, V4
5	**Design mutability**	The mutability of form and functioning of the model.	M5, P6c, P6d
6	**Application method**	The application method of the model. The way and type of data (e.g. interviews, data from systems) that is collected, and by whom (i.e. self-assessment, third party or certified professionals).	M6, P6a, P9a, V1, V2, V5

7	**Application dimensions**	The dimensions the model assesses. Whether it incorporates the business, information, application and infrastructure/technology layers of the organization.	P1d, V7, V10, V11
8	**Maturity growth structure**	The maturity growth structure of the model (e.g. staged fixed-level, continuous fixed-levels, focus areas).	P2a, P2b, P2c, V8
9	**Application domain**	The incorporation of the application domain of the model. Whether it incorporates characteristics of the organization (e.g. sector, size, type of organization) and context (e.g. Industry 4.0). The context, Industry 4.0, will be further specified based on the expert interviews.	P1a, P1c, P3, P4, P8b

Table 8. Selected and defined criteria

Two design principles and four criteria are excluded from the papers of Poeppelbuss & Roeglinger and Van Looy et al.: P1b, P1e, V3, V6, V12, V14.

The costs (refers to V14) of a maturity model are positioned as the tenth criteria. This criteria is separated from the other criteria, because the best model according to the non-cost related criteria could be much more expensive. Therefore, after applying the non-cost related criteria, a benefit-cost ratio can be performed. This will avoid selecting a model which might be too expensive for the organization, even though it scores the best on the non-cost related criteria.

The purpose of use (refers to P1b and V12) is excluded from the criteria. Instead, this is reflected into the goal of the hierarchical tree, because the purpose of use initiates the comparing and selection of maturity models, and the purpose will also be reflected in the rating of alternatives.

The differentiation from related maturity models (refers to P1e) is excluded, because the differences between maturity models will be the result of the multi-criteria decision-making model.

The assessment duration (refers to V3) and number of assessment items (refers to V6) are excluded from the criteria as well. These criteria do not seem solely determined by the assessor, but also by the consumer of an assessment. The budget, scope and availability of the consumer determines the duration and number of items to be assessed.

The resulting AHP hierarchy is presented below.

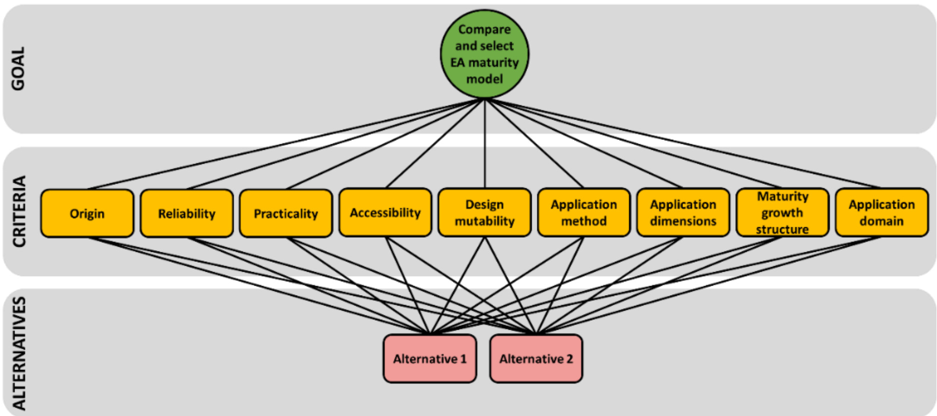


Figure 14. AHP hierarchy for comparing and selecting EA maturity model

4.2 Results of the survey

The survey was sent to 24 architects in the Netherlands, it resulted in two responses. Appendix B contains screenshots of these responses. The model is built flexibly, additional weighting of other experts can be added in the future.

The first pairwise comparison of criteria resulted into the underlying matrix. Note that the white squares and light blue squares are each other's opposite. The inconsistency ratio was 13,5%, which means it is above the tolerated 10% inconsistency (Saaty, 1987). Therefore, the judgements were re-examined to achieve an inconsistency of no more than 10%. An online software tool for calculating priorities provided three suggestions in order to achieve the tolerated inconsistency (Goepel, 2018). These suggestions are shown in the right pairwise comparison matrix below.

	Origin	Reliability	Practicality	Accessibility	Design mutability	Application method	Application dimensions	Maturity growth structure	Application domain
Origin	1	1/7	1/5	3	1/5	1/5	1/5	1/5	1/7
Reliability	7	1	1/5	5	3	5	1	3	1
Practicality	5	5	1	5	3	5	1	3	1
Accessibility	1/3	1/5	1/5	1	1/5	1/5	1/5	1	1/5
Design mutability	5	1/3	1/3	5	1	1	1/5	3	1/5
Application method	5	1/5	1/5	5	1	1	1/5	1/3	1/5
Application dimensions	5	1	1	5	5	5	1	5	1
Maturity growth structure	5	1/3	1/3	1	1/3	3	1/5	1	1/5
Application domain	7	1	1	5	5	5	1	5	1

Figure 15. Initial pairwise comparisons of first respondent with suggestions

Origin-accessibility has been changed to equal importance (i.e. 1), and reliability-practicality has been changed to practicality being somewhat more important (i.e. 1/3) than reliability. These changes resulted in an inconsistency ratio of 8,7%, which is tolerable.

	Origin	Reliability	Practicality	Accessibility	Design mutability	Application method	Application dimensions	Maturity growth structure	Application domain
Origin	1	1/7	1/5	1	1/5	1/5	1/5	1/5	1/7
Reliability	7	1	1/3	5	3	5	1	3	1
Practicality	5	3	1	5	3	5	1	3	1
Accessibility	1	1/5	1/5	1	1/5	1/5	1/5	1	1/5
Design mutability	5	1/3	1/3	5	1	1	1/5	3	1/5
Application method	5	1/5	1/5	5	1	1	1/5	1/3	1/5
Application dimensions	5	1	1	5	5	5	1	5	1
Maturity growth structure	5	1/3	1/3	1	1/3	3	1/5	1	1/5
Application domain	7	1	1	5	5	5	1	5	1

Figure 16. Adjusted pairwise comparisons of first respondent

This resulted in the following weights per criteria after pairwise comparisons:

1. Application domain: 20.1%
1. Practicality: 20.1%
2. Application dimensions: 19.6%
3. Reliability: 16.0%
4. Design mutability: 7.6%
5. Maturity growth structure: 5.9%
6. Application method: 5.6%
7. Accessibility: 2.9%
8. Origin: 2.2%

The second pairwise comparison of criteria resulted into the underlying matrix. The inconsistency ratio was 29%, which means it is above the tolerated 10% inconsistency (Saaty, 1987). Therefore, the judgements were re-examined to achieve an inconsistency of no more than 10%. The online software tool of Goepel (2018) for calculating priorities provided suggestions in order to achieve the tolerated inconsistency. A minimum of six adjustments was necessary to achieve a tolerated inconsistency ratio. The necessary adjustments are highlighted in the matrix on the right.

	Origin	Reliability	Practicality	Accessibility	Design mutability	Application method	Application dimensions	Maturity growth structure	Application domain
Origin	1	3	1/9	1/7	3	3	1/3	3	1/3
Reliability	1/3	1	1/5	1/3	1/3	1/3	1/3	1/3	1/3
Practicality	9	5	1	5	5	1/3	5	7	5
Accessibility	7	3	1/5	1	3	1/3	1/3	1	1/5
Design mutability	1/3	3	1/5	1/3	1	1/3	1/3	1/3	1/3
Application method	1/3	3	3	3	3	1	1/3	1/3	1/3
Application dimensions	3	3	1/5	3	3	3	1	1/3	1/3
Maturity growth structure	5	1/3	1/3	1	1/3	3	1/5	1	1/5
Application domain	7	1	1	5	5	5	1	5	1

Figure 17. Initial pairwise comparisons of second respondent with suggestions

Six adjustments have been made: (1) origin-accessibility into 1, (2) origin-maturity growth structure into 1, (3) practicality-application method into 3, (4) practicality-application domain into 3, (5) accessibility-application method into 1, and (6) application dimensions-maturity growth structure into 1. These changes resulted in an inconsistency ratio of 9%, which is tolerable.

	Origin	Reliability	Practicality	Accessibility	Design mutability	Application method	Application dimensions	Maturity growth structure	Application domain
Origin	1	3	1/9	1	3	3	1/3	1	1/3
Reliability	1/3	1	1/5	1/3	1/3	1/3	1/3	1/3	1/3
Practicality	9	5	1	5	5	3	5	7	3
Accessibility	7	3	1/5	1	3	1	1/3	1	1/5
Design mutability	1/3	3	1/5	1/3	1	1/3	1/3	1/3	1/3
Application method	1/3	3	3	3	3	1	1/3	1/3	1/3
Application dimensions	3	3	1/5	3	3	3	1	1	1/3
Maturity growth structure	5	1/3	1/3	1	1/3	3	1/5	1	1/5
Application domain	7	1	1	5	5	5	1	5	1

Figure 18. Adjusted pairwise comparisons of second respondent

This resulted in the following weights per criteria after pairwise comparisons:

1. Practicality: 35.5%
2. Application domain: 18.1%
3. Application dimensions: 11.3%
4. Maturity growth structure: 8.3%
5. Origin: 7.5%
6. Accessibility: 6.3%
7. Application method: 6.0%
8. Design mutability: 3.9%
9. Reliability: 3.1%

The combined pairwise comparisons results in the following weight per criteria:

1. Practicality: 27.8%
2. Application domain: 19.1%
3. Application dimensions: 15.5%
4. Reliability: 9.5%
5. Maturity growth structure: 7.1%
6. Application method: 5.8%
6. Design mutability: 5.8%
8. Origin: 4.8%
9. Accessibility: 4.6%

The combined results have a tolerable inconsistency ratio of 8.9%. Practicality is the most important criteria, which is aligned with the selected papers. Application domain is the second most important criteria, which is interesting as it is an important aspect of this research: assessing the suitability of enterprise architecture maturity models in the context of Industry 4.0. In addition, the application domain is not included as a criteria in the decision tool for business process maturity models of Van Looy et al. (2013). Another important criteria is the application dimensions the model assesses. The weight, 15.5%, is similar to the weight (14.28%) of Van Looy et al. (2013). The accessibility and origin does not seem very important according to the weighing, which might state that if the model fits the context and organization, covers the desired dimensions, and provides an reliable outcome, the origin or accessibility of the model is less relevant.

4.3 Results of the expert interviews

The other results were derived from the expert interviews. Six interviews were conducted with experienced practitioners which are active in the public, private and financial sector. The interviewees have the following role in their organisation: enterprise architect, technology architect, managing director, head of CIO Office, process information manager.

Interviewee	Sector	Role	More affiliation with I4.0 or EA
Int1	Public	Enterprise-architect ICT - CIO Office	Enterprise architecture
Int2	Private	Managing Director Divisions Digital Factory and Process Industries & Drives	Industry 4.0
Int3	Private (consultancy)	Technology Architect	Enterprise architecture
Int4	Public	Concern Architect/Chief Enterprise Architect	Enterprise architecture
Int5	Financial	Head of CIO Office	Enterprise architecture
Int6	Private	Process Information Manager Manufacturing-IT	Enterprise architecture

Table 9. Affiliation interviewees

4.3.1 Familiarizing with the data

The interviews have been transcribed and read several times to get familiar with the data. These transcripts have resulted into approximately 53,000 words.

4.3.2 Generating initial codes

The transcript resulted into 594 initial codes. The codes are added to transcripts and included in Appendix C.

Interviewee	Nr. of codes
Int1	176
Int2	119
Int3	107
Int4	49
Int5	126
Int6	17

Table 10. Number of initial codes per interview

Analysis of the initial codes by breaking them down into single values led to insights in patterns and recurring themes. The following tables captures values which were mentioned more than four times. Most of the values are concerned with enterprise architecture (maturity), Industry 4.0, data and technologies. Other values of interest are government, business/companies, agile and DevOps. The remaining values are concerned with organization’s strategy, structure, operations and change.

#	Value	Amount
1	EA	46
2	Maturity	43
3	Industry	34
4	Data	33
5	Smart	31
6	IT	27
7	I4.0	25
8	Architecture	24
9	Services	24
10	Blockchain	23
11	Technology	23
12	Technologies	22
13	Models	21
14	Business	18
15	Cloud	15
16	Government	15
17	Model	15
18	AI	14
19	Machine	14
20	Micro	14
21	Development	13
22	Challenge	12
23	Devops	12
24	Customer	11
25	IoT	10
26	Change	9
27	Digital	9
28	Flexible	9
29	Traditional	9
30	Companies	8
31	Future	8
32	Principles	8
33	Processes	8
34	Software	8
35	Time	8
36	World	8
37	DYA	7
38	Energy	7
39	Everything	7
40	Optimal	7

#	Value	Amount
41	Public	7
42	Security	7
43	Value	7
44	AT	6
45	Automation	6
46	Delivery	6
47	Demand	6
48	Developments	6
49	Disruptive	6
50	Flexibility	6
51	Impact	6
52	Journey	6
53	Level	6
54	Organization	6
55	Product	6
56	Production	6
57	Projects	6
58	Role	6
59	SCM	6
60	Service	6
61	Systems	6
62	Work	6
63	Agile	5
64	Alexia	5
65	Changes	5
66	Control	5
67	Disruption	5
68	Feedback	5
69	Human	5
70	Information	5
71	Innovations	5
72	People	5
73	Reliable	5
74	Rules	5
75	Sensoring	5
76	Strategy	5
77	Things	5
78	Transformation	5
79	Transition	5

Table 11. Values derived from initial codes

4.3.3 Defining and reviewing of themes

The themes are based on the environment of the Information Systems Research Framework: people, organizations and technology. The transcripts and codes are explored and categorized to fill in the elements within the environment. Data has been added to organizations as it turned out to be an important theme which did not fit any of the other categories. Industry 4.0 and enterprise architecture (EA) maturity model have also been added as separate categories, if none of the environment elements fit. The 594 initial codes resulted into 215 categorized themes. Appendix D contains all themes.

Category	Sub-category	Nr. of themes
People	Roles	7
People	Capabilities	13
People	Characteristics	1
Organizations	Strategies	21
Organizations	Structure and culture	16
Organizations	Processes	16
Organizations	Data	12
Technology	Infrastructure	15
Technology	Applications	18
Technology	Communications architecture	12
Technology	Development capabilities	10
Industry 4.0		46
EA maturity model		28

Table 12. Defined themes

4.3.4 Produced theory

People

The digital transformation of organizations is creating a possible digital gap in society. The role of IT is changing jobs, but also customer interaction, services and channels. Jobs will be substituted or complemented by technologies. This will require more IT and digital skills from IT professionals, but also non-IT professionals. Finding and educating personnel will be a challenge. The government and education should play a significant role to close the knowledge and skills gap, but also the gap between academics and practitioners. A relevant matter is also to realize more R&D, therefor it is necessary to bring more industry to the country.

Organization

The role of IT in the strategic alignment of Business and IT is growing rapidly with the digitalization and development of technologies. Organizations have to address this matter with an IT strategy which utilizes architecture, but also focuses on innovation.

The structure and culture of organizations should evolve into agile and dynamic teams in order to deliver fast and individualized services and products to customers. These expectations are not only expected from business, but also from governments. Therefore, the operations (business) should also be convinced of these new ways of working and technologies. The cultural aspect of this matter can be a challenge, from a skills and knowledge perspective, but also from a change management perspective.

New concepts and technologies are changing existing and future processes. The incorporation of robots, AI and algorithms will automate both activities and decision-making. This will also affect the manufacturing and supply chain management processes. These will be transformed by the collaborating between human and machine, and IT-OT, but also by integration of the entire supply chain management through shared processes and data.

The availability, accessibility, and producing of data plays a vital role in the future. This does not only concern historic data, but also real-time data and non-structured data. These will provide (real-time) insights, patterns and prediction regarding the organizations, customers and citizens. In order to utilize this, data collection and analytics processes will increase in numbers and relevance. Besides presenting value, privacy and security of data becomes more important. Either by new laws, regulations and standards, otherwise by expectations of the society.

Technologies
As mentioned, several technologies are emerging and becoming more relevant by the day, such as: AI, VR, AR, CPS, blockchain, robotics, algorithms, IoT, virtual assistant, and further down the line neurotechnologies and quantum computing.

These technologies rely on modern, scalable, reliable and flexible infrastructures such as cloud, blockchain and containers. This requires a hyper converged architecture which is accommodated by microservices and API's. For the realization of these infrastructures and technologies, new development capabilities should be adopted that incorporates DevOps, agile, automated testing and low coding.

Other big trends include the reducing of CO2, excess capacity, the use of natural resources, and the waste of energy.

Enterprise architecture maturity models
Enterprise architecture maturity models could be of added value if they provide guidance for continuous improvement and if they can serve as a reference. The maturity models should be flexible, dynamic and follow developments such as agile. They should cover the enterprise architecture, but also incorporate experimentation and innovation. Existing maturity models are perceived as outdated, inflexible and too heavily focused on IT and waterfall development.

4.4 Multi-criteria decision-making model

The multi-criteria decision-making model is developed in R[5] and is based on the AHP package of Glur (2018). Multiple other packages need to be installed and loaded besides the AHP package: shiny, shinyAce, shinythemes, shinyjs, testthat, knitr and markdown.

After loading the packages, the AHP input file needs to be created and loaded in YAML[6]. The AHP input file is in essence a hierarchy tree, which follows the structure and rules of AHP. The underlying hierarchy tree is coded in YAML.

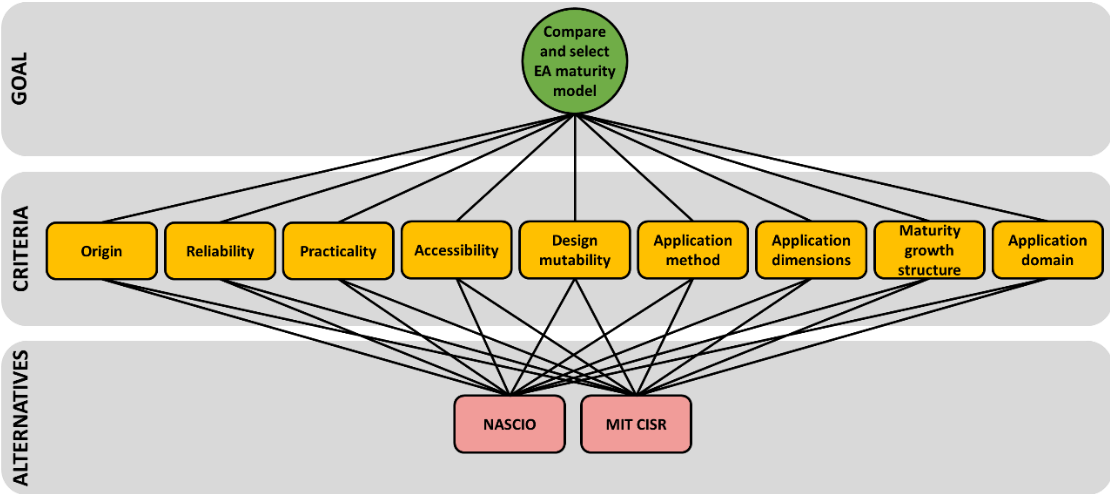


Figure 19. Final AHP hierarchy tree

At top is the goal of the multi-criteria decision-making model:
Compare and select EA maturity model.

The next layers consists the criteria which were defined in chapter 4.1.4. The last layer contains the alternatives to be compared in the next section (4.4.1). The grey textbox on the next page is a trimmed-down version of the AHP input. It only captures the pairwise comparison of the criteria 'Origin' and the rating of the alternatives with regards to the criteria 'Origin'. The complete AHP file is included in Appendix E.

The code starts with the selected alternatives (NASCIO and MIT CISR) and their characteristics. More alternatives can be added, and qualitative or quantitative characteristics can be added to each alternative. These characteristics can be used to rate the alternatives with functions. This is not used for this research.

The alternatives are followed by the goal and decision-makers (i.e. Resp1 and Resp2). In this context, the decision-makers are the survey respondents who weighted the criteria.

The next lines in the code contains the pairwise comparisons of the criteria, which was the results of the survey (chapter 4.2).

The last section captures the rating of the alternatives alongside the criteria. The decision-makers in the AHP package are used to weigh the criteria, but also to rate the alternatives. Decision-makers can have different voting powers. For this research

[5] A software environment for statistical computing and graphics.
[6] A data serialization standard for all programming languages.

the decision-makers (survey respondents) have equal voting powers (0.5). The decision-makers do not rate the alternatives for this demonstration. This is done by the researcher. In order to achieve this without modifying the package, the rating of the alternatives is performed by the researcher but assigned to the respondents in the code.

```
Version: 2.0
Alternatives: &alternatives
  NASCIO:
    owner: NASCIO
    year: 2003
  MIT CISR:
    owner: MIT CISR
    year: 2003
Goal:
  name: Compare and select EA maturity model
  decision-makers:
    - Resp1: 0.5
    - Resp2: 0.5
  preferences:
    Resp1:
      pairwise:
      - [Origin, Reliability, 1/7]
      - [Origin, Practicality, 1/5]
      - [Origin, Accessibility, 1]
      - [Origin, Design mutability, 1/5]
      - [Origin, Application method, 1/5]
      - [Origin, Application dimensions, 1/5]
      - [Origin, Maturity growth structure, 1/5]
      - [Origin, Application domain, 1/7]
    Resp2:
      pairwise:
      - [Origin, Reliability, 3]
      - [Origin, Practicality, 1/9]
      - [Origin, Accessibility, 1]
      - [Origin, Design mutability, 3]
      - [Origin, Application method, 3]
      - [Origin, Application dimensions, 1/3]
      - [Origin, Maturity growth structure, 1]
      - [Origin, Application domain, 1/3]
  children:
    Origin:
      preferences:
        Resp1:
          pairwise:
            - [NASCIO, MIT CISR, 1/3]
        Resp2:
          pairwise:
            - [NASCIO, MIT CISR, 1/3]
      children: *alternatives
```

After finishing the AHP input file, it can be loaded in R to perform the pairwise comparisons of criteria, rating of alternative, analysis and presentation of the results.

Loading the AHP input file is performed with the following code:

```
library(ahp)
ahpFile <- system.file("extdata", "ea03.ahp", package="ahp")
ea03Ahp <- Load(ahpFile)
```

Exploring the AHP input file in R is performed by:

```
cat(readChar(ahpFile, file.info(ahpFile)$size))
```

Presenting the hierarchy tree is performed by:

```
library(data.tree)
print(ea03Ahp, filterFun = isNotLeaf)
```

This results in:

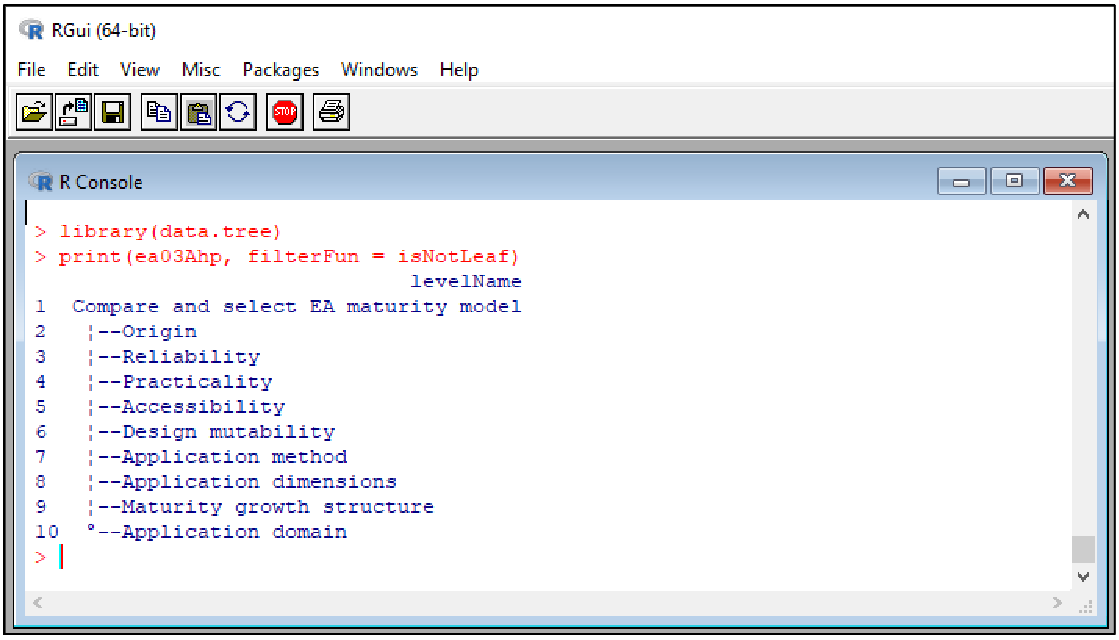


Figure 20. Hierarchy tree in R

The hierarchy tree can also be visualized in a browser by:

```
Visualize(ea03Ahp)
```

This results in:

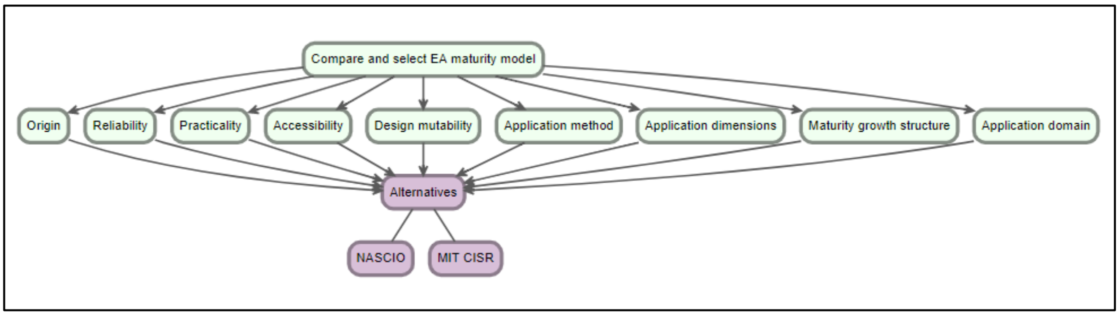


Figure 21. Visualization of hierarchy tree in browser

Calculating the AHP and presenting the results is performed by:

```
Calculate(ea03Ahp)
Analyze(ea03Ahp)
```

This results in:

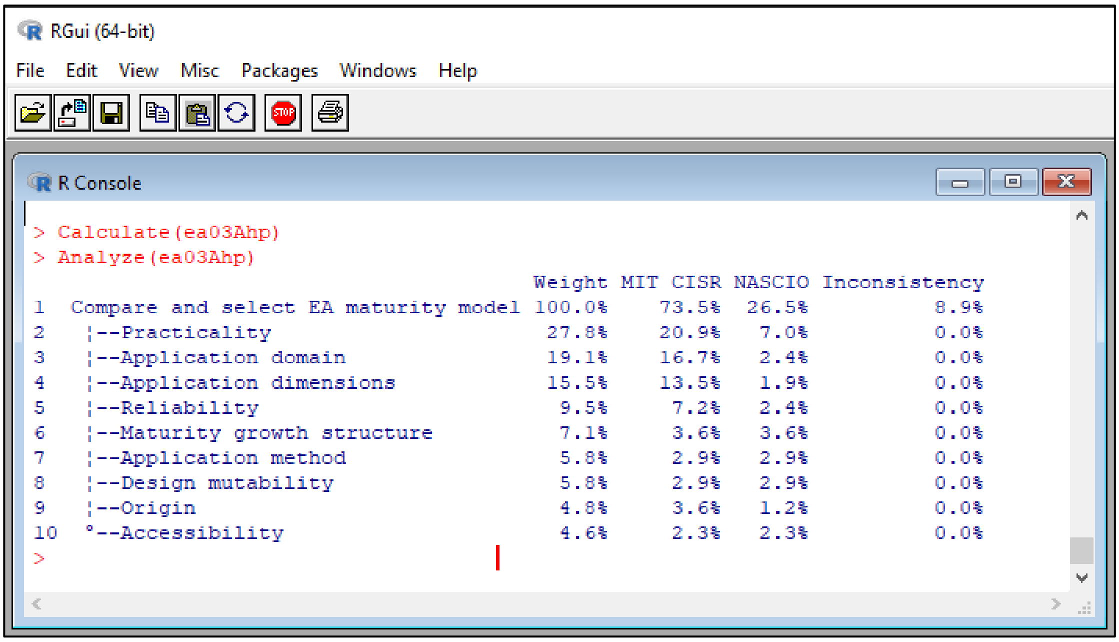


Figure 22. Results of AHP in R

The results can also be presented in a browser by:

```
Calculate(ea03Ahp)
AnalyzeTable(ea03Ahp)
```

This results in:

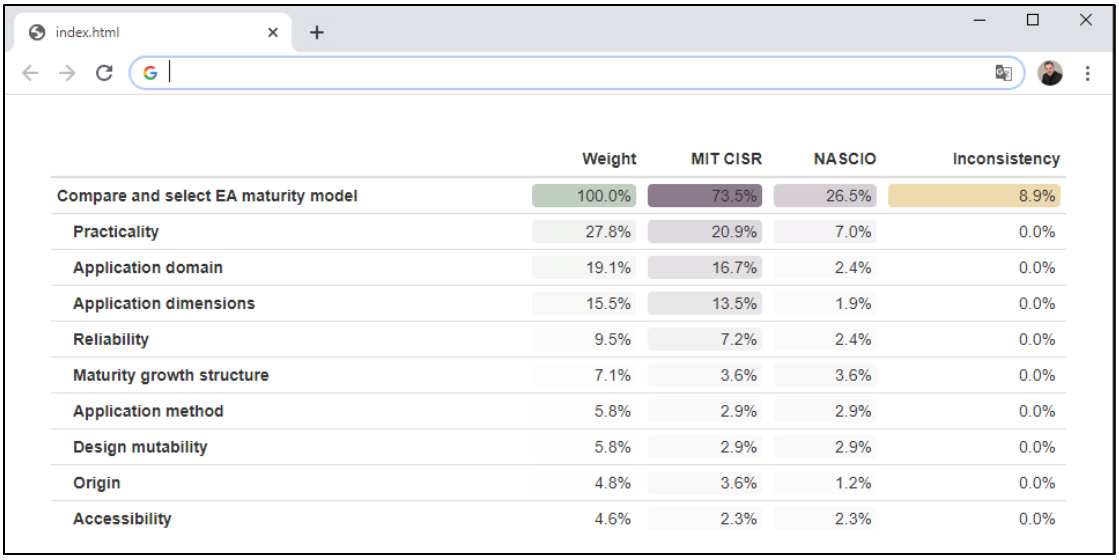
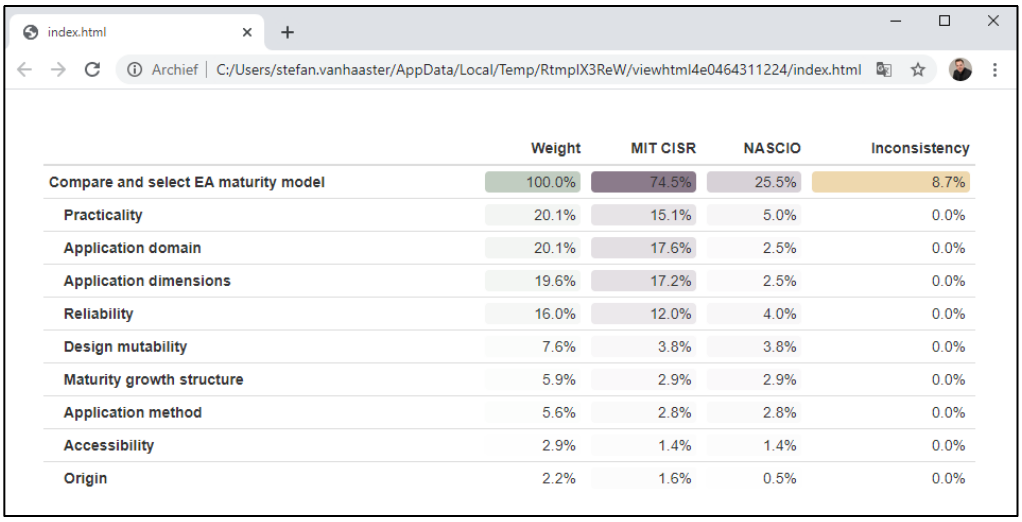


Figure 23. Results of AHP in browser

The results can also be filtered, such as filtering on only one respondent:

```
AnalyzeTable(ea03Ahp, decisionMaker = "Resp1")
```

This results in:



	Weight	MIT CISR	NASCIO	Inconsistency
Compare and select EA maturity model	100.0%	74.5%	25.5%	8.7%
Practicality	20.1%	15.1%	5.0%	0.0%
Application domain	20.1%	17.6%	2.5%	0.0%
Application dimensions	19.6%	17.2%	2.5%	0.0%
Reliability	16.0%	12.0%	4.0%	0.0%
Design mutability	7.6%	3.8%	3.8%	0.0%
Maturity growth structure	5.9%	2.9%	2.9%	0.0%
Application method	5.6%	2.8%	2.8%	0.0%
Accessibility	2.9%	1.4%	1.4%	0.0%
Origin	2.2%	1.6%	0.5%	0.0%

Figure 24. Filtered results of AHP in browser

The AHP input file and results can also be processed through a graphical user interface (GUI) in your browser by:

```
RunGUI(port = getOption("shiny.port"))
```

Running the function above results in a browser with four tabs: (1) Model, (2) Visualize, (3) Analyze, (4) More.

The tab 'Model' is used to define an AHP input file or to load an existing AHP input file. A loaded AHP input file can also easily be modified and saved in this tab.

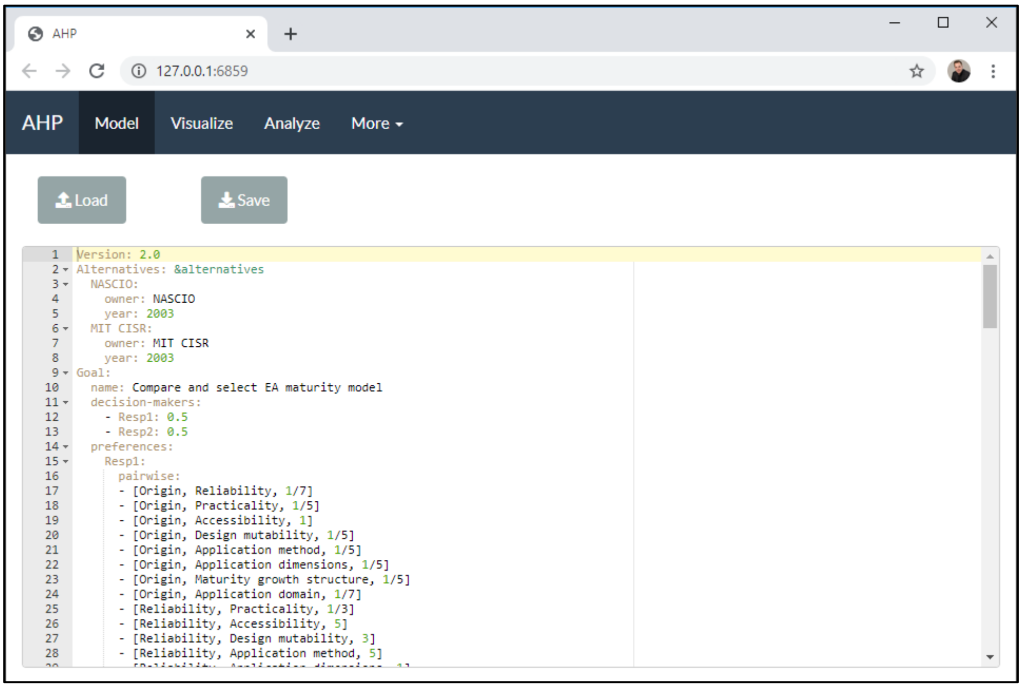


Figure 25. GUI AHP - Model

After defining or uploading an AHP input file, the model can be visualized in the tab 'Visualize'.

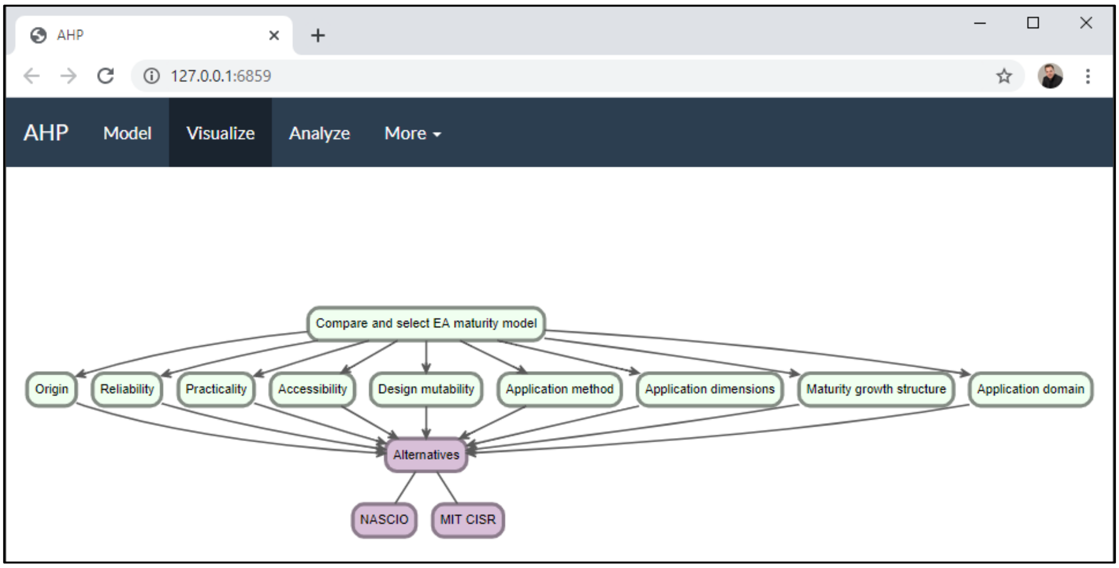


Figure 26. GUI AHP - Visualize

The third tab 'Analyze' shows the results of the AHP input file in a table. The results can be filtered on variables, decision-makers, weight contribution and levels. Filtering on levels could be relevant if multiple sub-criteria are added as new levels. Besides filtering the results, the calculation can be adjusted to calculating the mean of normalized values or the geometric mean if another calculation method is preferred over the Eigenvalues calculation method. The AHP method of Saaty suggests to use the Eigenvalues calculation method.

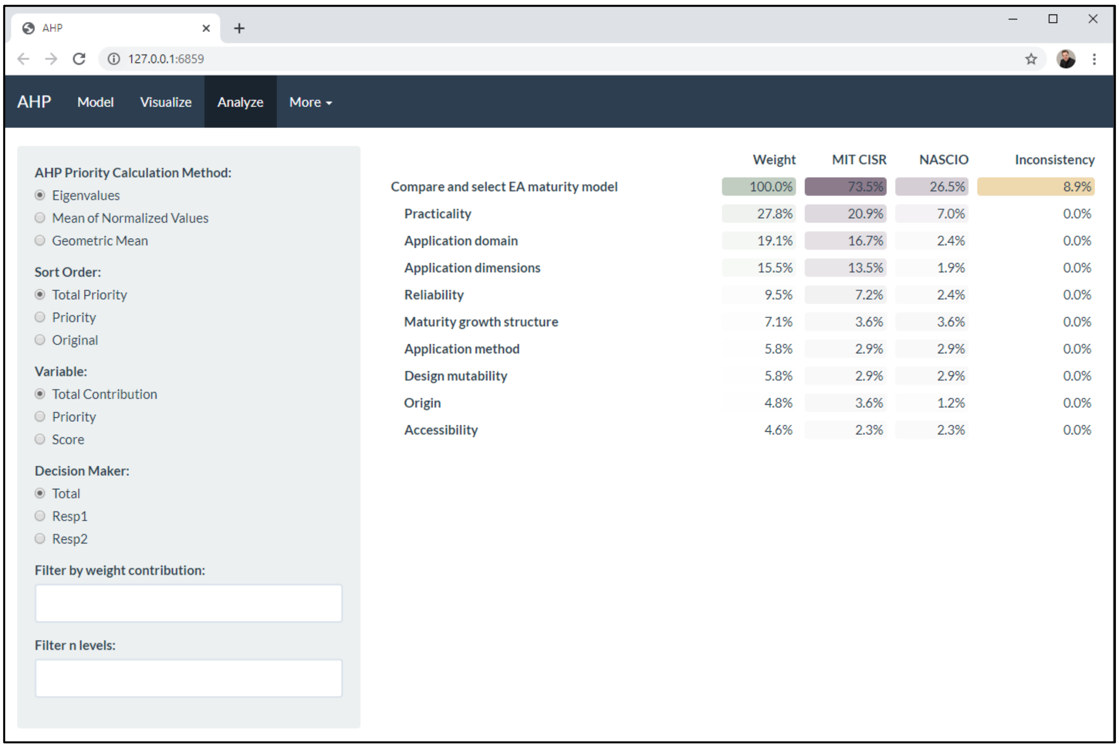


Figure 27. GUI AHP - Analyze

The fourth tab 'More' contains additional information on the AHP package.

4.4.1 Demonstration

The efficacy of the model is demonstrated by applying it to two existing enterprise architecture maturity models.

The selection of the maturity models is based on references by two of the most cited books on enterprise architecture, and two papers which focuses on enterprise architecture maturity models. The underlying table captures the books and papers, and the referred enterprise architecture maturity models.

Reference of the book/paper	Enterprise architecture maturity models
Lankhorst, M. (2009). *Enterprise architecture at work* (Vol. 352). Berlin: Springer.	• NASCIO (2003). NASCIO Enterprise Architecture Maturity Model.
Ross, J. W., Weill, P., & Robertson, D. (2006). *Enterprise architecture as strategy: Creating a foundation for business execution*. Harvard Business Press.	• Ross, J. W. (2003). Creating a strategic IT architecture competency: Learning in stages.
Meyer, M., Helfert, M., & O'Brien, C. (2011). An analysis of enterprise architecture maturity frameworks. *Perspecti ves in business informatics research*, 167-177.	• Curley, M. (2007, June). Introducing an IT capability maturity framework. In International Conference on Enterprise Information Systems (pp. 63-78). Springer, Berlin, Heidelberg. • NASCIO (2003). NASCIO Enterprise Architecture Maturity Model. • Luftman, J. (2004). Assessing Business-IT Allignment Maturity. In Strategies for information technology governance (pp. 99-128). Igi Global. • Busby, M., Buttles-Valdez, P., Byrnes, P., Hayes, W., Khetan, R., Kirkham, D., ... & Stall, A. (2011). Standard CMMI Appraisal Method for Process Improvement (SCAMPI) A, Version 1.3: Method Definition Document (No. CMU/SEI-2011-HB-001). CARNEGIE-MELLON UNIV PITTSBURGH PA SOFTWARE ENGINEERING INST.DoC (Department of Commerce). 2007. Enterprise Architecture Capability Maturity Model Version 1.2. US Department of Commerce. • GAO (U.S. Government Accountability Office). 2010. Organizational transformation: A Framework for Assessing and Improving Enterprise Architecture Management Version 2.0. U.S. Government Accountability Office. • OMB. (2009). Improving Agency Performance Using Information and Information Technology (Enterprise Architecture Assessment Framework v3.1) • IT Governance Institute (ITGI). (2007). Control Objectives for Information and Related Technology (COBIT) 4.1. • IT Governance Institute. (2008). Enterprise Value: Governance of IT Investments, the Val IT Framework, Version 2. 0. ISACA.
Vallerand, J., Lapalme, J., & Moïse, A. (2017). Analysing enterprise architecture maturity models: a learning perspective. *Enterpris*	• Gartner, I. (2012). Itscore Overview for Enterprise Architecture. Gartner, Inc., Stamford, CT. • Cullen, A., DeGennaro, T. (2011). Forget EA Nirvana: Assessing EA Maturity. Forrester. • NASCIO (2003). NASCIO Enterprise Architecture Maturity Model. • DoC (2007). Enterprise Architecture Capability Maturity Model. • Ross, J. (2004). Enterprise Architecture: Depicting a vision of the

e Information Systems, *11*(6), 859-883.	firm. CISR Research Briefing, 4(1B), 1-3. • GAO (2010). Organizational transformation: A Framework for Assessing and Improving Enterprise Architecture Management Version 2.0.
Steenbergen, M. V. (2011). *Maturity and effectiveness of enterprise architecture* (Doctoral dissertation, Utrecht University).	• GAO (2003). A framework for assessing and improving enterprise architecture management. • NASCIO (2003). NASCIO Enterprise Architecture Maturity Model. • Weiss, D. (2006). Enterprise Architecture Measurement Program, Part 1: Scoping. ID Nr G00142314. • Ross, J. W., Weill, P., & Robertson, D. (2006). *Enterprise architecture as strategy: Creating a foundation for business execution*. Harvard Business Press. • Raadt, B. van der, Slot R. and Vliet, H. van (2007). Experience report: assessing a global financial services company on its enterprise architecture effectiveness using NAOMI. In *Proceedings of the 40th Annual Hawaii International Conference on System Sciences* (HICSS'07). • Van Steenbergen, M., Schipper J., Bos, R. and Brinkkemper, S. (2010). The Dynamic Architecture Maturity Matrix: Instrument Analysis and Refinement. In Dan, A., Gittler, F. and Toumani, F. (Eds.), *ICSOC/ServiceWave 2009*, LNCS 6275, 48-61. Springer-Verlag Berlin Heidelberg.

Table 13. Selected books and papers on enterprise architecture

The three most referred to enterprise architecture maturity models are: NASCIO (four times), Ross (three times), GAO (three times). The enterprise architecture maturity models from NASCIO and Ross are chosen. Even though the model from Ross and GAO are both referred three times in the selected books and papers, Ross (i.e. MIT CISR) is chosen because it is well known by the scientific community and it has a different take on architecture maturity. The model from GAO is similar to NASCIO, whereas Ross also focuses on the organizational benefits from enterprise architecture.

NASCIO – Enterprise architecture maturity model

The National Association of State Chief Information Officers (NASCIO) is a non-profit organization. It represents state chief information officers, IT executives and manager of various states and territories in the US.

The enterprise architecture maturity model provides a path for architecture and procedural improvements. The model intents to be used for benchmarking the effectiveness of the enterprise architecture programs. Expected benefits from progress in enterprise architecture maturity are:

- Reduced software and data redundancy;
- Enhanced enterprise information sharing;
- Reduced information systems complexity;
- Better alignment of business strategy and system development;
- Greater reliability at implementations & updates;
- Reduced dependency on key resources;
- Improved accuracy in scheduling software development / implementation;
- More accurate forecasting of development and support costs;
- More efficient deployment of technology solutions;
- Greater ability to set realistic goals;
- Improved alignment of IT solutions with business strategy;
- Increased traceability.

The maturity model is based on the same concept of the Capability Maturity Model from the Software Engineering Institute (SEI). The maturity growth structure consists of six maturity levels:

- Level 0 - No Program;
- Level 1 - Informal Program;
- Level 2 - Repeatable Program;
- Level 3 - Well-Defined Program;
- Level 4 - Managed Program;
- Level 5 - Continuously Improving Vital Program.

Each level contains eight statements that indicate the enterprise architecture program at that level:

- Administration – governance roles & responsibilities;
- Planning – enterprise architecture program roadmap and implementation plan;
- Framework – processes and templates used for enterprise architecture;
- Blueprint – collection of the actual standards and specifications;
- Communication – education and distribution of enterprise architecture and blueprint detail;
- Compliance – adherence to published standards, processes and other enterprise architecture elements, and the processes to document and track variances from those standards;
- Integration – touch-points of management processes to the enterprise architecture;
- Involvement – support of the enterprise architecture program throughout the organization.

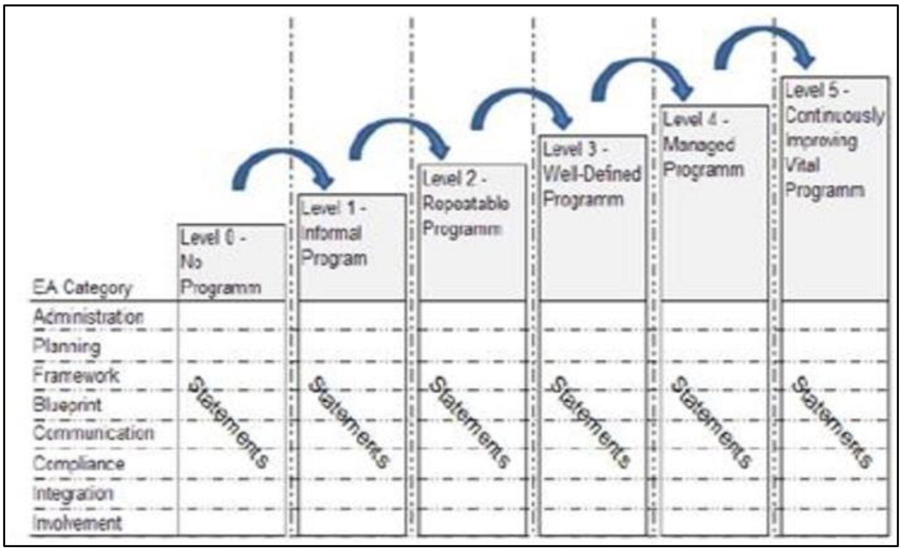


Figure 28. NASCIO enterprise architecture maturity model (Lakhrouit & Baïna, 2013)

According to NASCIO, architecture is an iterative and on-going process. The enterprise architecture framework should be reviewed every one or two years at a minimum, or when a noticeable shift in the business or IT strategy occurs.

MIT CISR – Enterprise architecture maturity model

The MIT Center for Information Systems Research (MIT CISR) performs practical empirical research on how firms generate business value from IT. MIT conducts research related to the management and use of IT, and the research portfolio includes enterprise architecture among others. Ross, a principal research scientist, has published several books and papers related to the maturity model.

A greater architecture maturity leads to:

- Lower IT costs;
- Shorter IT development times;
- Greater discipline in their business processes;
- More strategic benefits from IT such as customer intimacy, product leadership and strategic agility.

These benefits were derived from a survey of 103 firms, where specific data on investments patterns and management practices related to the four stages of architecture maturity was acquired.

The four architecture maturity stages are:

- Business silos;
- Standardized technology;
- Optimized core;
- Business modularity.

These stages are directly related to value of IT for the business. The first stage, business silos, leads to local or functional optimizations. The second stage, standardized technology, leads to IT efficiency. The third stage, optimized core, leads to operational efficiency. The fourth stage, business modularity, leads to strategic agility. Another dimension on the maturity model relates architecture maturity stages to investments in IT. A greater maturity leads to less local applications, more enterprise systems and more shared data. Besides receiving value from IT and changing investments of IT, a greater architecture maturity also shows evolving management practices for designing and protecting architecture.

Rating of NASCIO and MIT CISR maturity models

The NASCIO and MIT CISR enterprise architecture maturity models are compared for each criteria, based on rating categories. The rating categories is an alternative for pairwise comparison of alternatives (Saaty, 2008). The rating categories are high, medium and low. This results in the following matrix:

Criteria	High	Medium	Low
High	1	3	7
Medium	1/3	1	4
Low	1/7	1/4	1

Table 14. Rating categories for comparing alternatives

Origin

The origin of the model. Whether it has its source from academia or practice.

MIT CISR is preferably over NASCIO, because its origin is in research and practice. NASCIO has its origin solely in practice.

Origin	NASCIO	MIT CISR
NASCIO	1	1/3
MIT CISR	3	1

Table 15. Rating origin

Reliability
The reliability of the model. Whether the model is untested, verified or validated.

Both of the models are validated. MIT CISR is however preferably over NASCIO, as it is validated by a bigger group and also in the scientific community. The maturity levels are based on these validations as well. NASCIO only reports validation from CIO's and IT architect from 22 states.

Reliability	NASCIO	MIT CISR
NASCIO	1	1/3
MIT CISR	3	1

Table 16. Rating reliability

Practicality
The outcome of the assessment. Whether it provides general or specific recommendations and improvement actions which guides toward the desired maturity.

Neither of the models provide specific recommendations and improvement actions. The desired maturity level might vary among the consumers, this is not reflected in either maturity model. The MIT CISR maturity does provide levels which reflect the value of IT for the business, whereas NASCIO solely focuses on the enterprise architecture program. Therefore, MIT CISR is preferred.

Practicality	NASCIO	MIT CISR
NASCIO	1	1/3
MIT CISR	3	1

Table 17. Rating practicality

Accessibility
The accessibility of the model. Whether access to the model is free, charged or confidential (i.e. whether the assessment items and calculation are available).

For both models several documentations and papers are available. However, exact calculation and detailed assessment items are not (freely) accessible. It is unclear if this information will be provided after payment.

Accessibility	NASCIO	MIT CISR
NASCIO	1	1
MIT CISR	1	1

Table 18. Rating accessibility

Design mutability
The mutability of form and functioning of the model.

Neither of the models seem to be suitable for mutating the form or function of the model. The models are built on fixed levels and related aspects. Mutating these does not seem a suitable solution.

Design mutability	NASCIO	MIT CISR
NASCIO	1	1
MIT CISR	1	1

Table 19. Rating design mutability

Application method
The application method of the model. The way and type of data (e.g. interviews, data from systems) that is collected, and by whom (i.e. self-assessment, third party or certified professionals).

Neither of the models elaborate on the way and type of data that is collected for an assessment. Both of the models seem to rely on interviews and documents such as policies, blueprints, processes and models. A third party would be necessary for the assessments of both models, as knowledge and expertise on the levels and assessed items is necessary.

Application method	NASCIO	MIT CISR
NASCIO	1	1
MIT CISR	1	1

Table 20. Rating application method

Application dimensions
The dimensions the model assesses. Whether it incorporates the business, information, application and infrastructure/technology layers of the organization.

NASCIO mainly focuses on the EA program, and to some extent business and technology. Whereas, MIT CISR also focuses on business, processes, data and infrastructure. Therefore, MIT CISR is highly preferable.

Application dimensions	NASCIO	MIT CISR
NASCIO	1	1/7
MIT CISR	7	1

Table 21. Rating application dimensions

Maturity growth structure
The maturity growth structure of the model (e.g. staged fixed-level, continuous fixed-levels, focus areas).

Both models have a similar level based maturity growth structure, with several element per level.

Maturity growth structure	NASCIO	MIT CISR
NASCIO	1	1
MIT CISR	1	1

Table 22. Rating maturity growth structure

Application domain
The incorporation of the application domain of the model. Whether it incorporates characteristics of the organization (e.g. sector, size, type of organization) and context (e.g. Industry 4.0).

Both of the models do not incorporate specific characteristics for organizations such as sector and size. Both are proposed as a one-size fits all. The context however is addressed by the model of MIT CISR, and not in the model of NASCIO. The levels of MIT CISR are based on the value IT delivers for the business. Maturation of architecture results in business silos with local applications to shared resources, infrastructure and data. Besides sharing, business processes will be standardized and applications become smaller and reusable. Some of this is still relevant today, however, not everything. The emergence of cloud services and potentially blockchain indicate another kind of infrastructure: decentralized.

Application domain	NASCIO	MIT CISR
NASCIO	1	1/7
MIT CISR	7	1

Table 23. Rating application domain

After adding the data and configuring the multi-criteria decision-making model in R, it results in the scores below. The tool has been successfully demonstrated for the pairwise comparisons of multiple criteria by multiple experts and ratings of multiple alternatives.

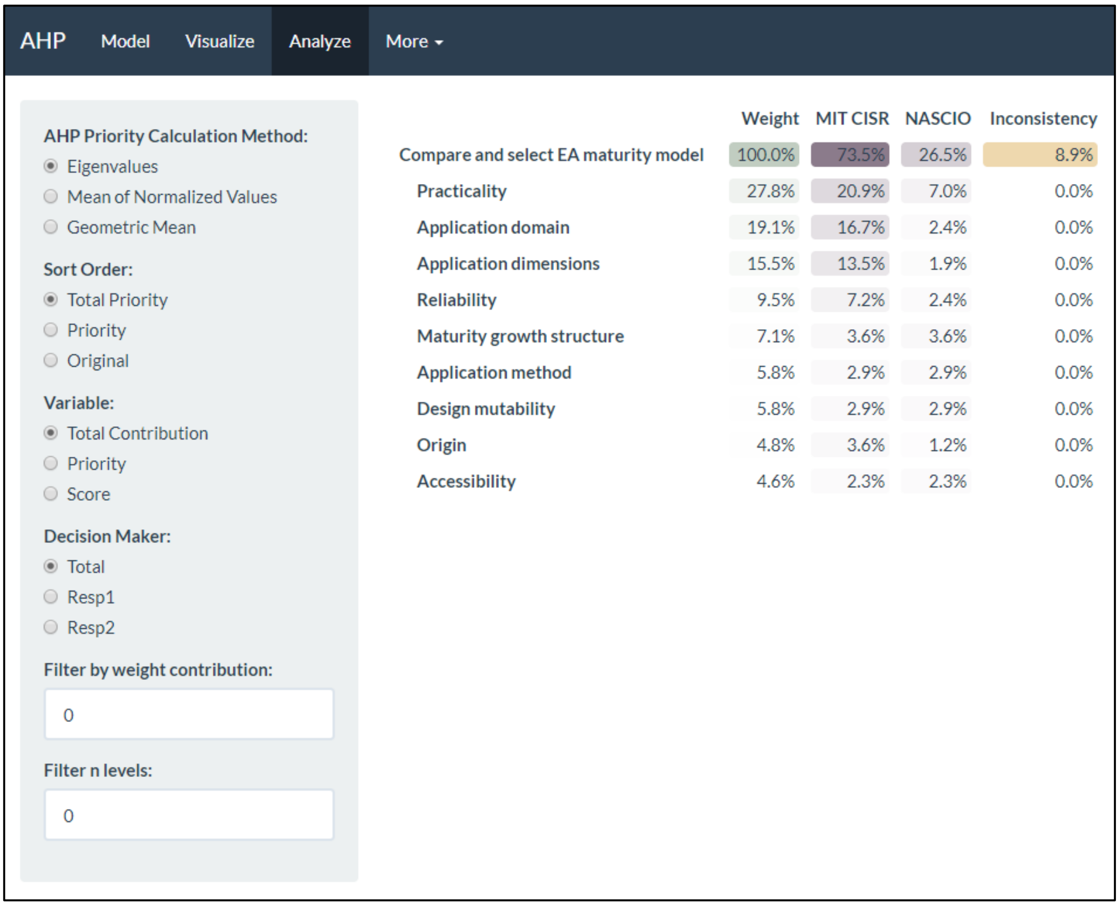


Figure 29. Results of demonstration

As mentioned in chapter 4.1.4, the costs are included afterwards by performing a cost-benefits ratio. The costs of an assessment with the maturity models could not be retrieved. This would require a quotation from an organization, but the quotation depends on multiple factors (e.g. size, scope, purpose). However, based on the scores it can be concluded that MIT CISR scores 2.774 times better than NASCIO (73.5% / 26.5% = 2.774). Therefore, NASCIO will only have a better score with regards to the cost-benefits ratio if it is more than 2.774 times less expensive.

4.4.2 Evaluation

The seven guidelines of Hevner et al. (2004) are used to evaluate the development of the multi-criteria decision-making model. The following table is adopted from Hevner et al. (2004) and describes the seven guidelines.

Guideline	Description
Guideline 1: Design as an artefact	Design-science research must produce a

	viable artefact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies.
Guideline 5: Research rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.
Guideline 6: Design as a search process	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Table 24. Guidelines of Hevner et al. (2004)

The following table provides the evaluation per guideline.

Guideline	Evaluation
Guideline 1: Design as an artefact	The multi-criteria decision-making model is a viable model which can be used for comparing and selecting an enterprise architecture maturity model. The model can also be used for other type of maturity models. The development in the open source tool R ensures the model can be used by everyone, but it also allows modifications of the model.
Guideline 2: Problem relevance	The relevance of the provided solutions is provided in chapter 1.
Guideline 3: Design evaluation	The model has been demonstrated successfully by comparing two existing maturity models.
Guideline 4: Research contributions	The model is a practical solution for comparing and selecting maturity models. The inclusion of the context, Industry 4.0, is unique and provides relevance to the model, but also to the young research discipline of Industry 4.0. The combination of utilizing existing foundations and a business perspective provides a new addition to the knowledge base.
Guideline 5: Research rigor	Several frameworks, methods and

	techniques have been applied for the development of the model (e.g. Information Systems Research Framework, AHP, thematic analysis, expert interviews, survey).
Guideline 6: Design as a search process	Existing foundations from the knowledge base have been used effectively for the development of the criteria and for demonstrating the model.
Guideline 7: Communication of research	This research is presented to be used by the scientific community and industry. The scientific community can develop the model further, but can also explore the application of the model in other domains. Industry can use the model for comparing and selecting a maturity model. The criteria can also be used as guidelines for the development of new or existing maturity models.

Table 25. Evaluation per guideline

5 Discussion

Numerous maturity models are available in the knowledge base for several domains. A search on “maturity model” in the title of a paper on Google Scholar results in almost 3000 papers. Google Scholar captured more than 400 papers in 2018 with maturity model in the title. This suggests that numerous new maturity models will be added to the knowledge base in the future.

Besides the availability of numerous maturity models, numerous criticism is expressed regarding the relevance and rigor of these maturity models. Instead of developing new maturity models, existing maturity models should be critically assessed. However, the critics should be constructive and serve as a catalyst for improving the existing maturity models. New problems and developments will occur in the future, and newly developed maturity models might provide guidance or serve as a solution. However, developing a new maturity model is not necessary for every new problem, development or domain. Existing and validated maturity models, maybe even from other domains, can serve as a solid foundation for a new iteration on the maturity model. Therefore, it is important to rigorously dig through the knowledge base for suitable maturity models, before considering to design a new maturity model.

Every research should provide relevance to the environment, whether it is the scientific community or industry. To provide relevance to this research, Industry 4.0 has been explored as today’s context. Industry 4.0 has been used interchangeable in research as a strategic initiative and as the fourth industrial revolution. There is still no common understanding on what it is, and the interchangeable use of the concept does not contribute either. Instead of predicting the next industrial revolutions, shouldn’t we focus on what an industrial revolution comprises? So that we can monitor trends with the immense amount of data which is available, and which continuously increases. The work of Deane (1979) can serve as a foundation for this matter, as discussed in the literature review.

Regarding the scope and impact of an industrial revolution, is industry in today’s digital and connected world solely the traditional making (i.e. manufacturing) industry or does it also include the ‘manufacturing’ of digital products? Many refer to it as the interconnectedness between human and (smart) machine, but this is not only a trend in the making industry, but in all industries.

Another item for debate is, whether Industry 4.0 is a ‘just’ an evolution of the third industrial revolution (i.e. the digital revolution). Important identified drivers and trends for Industry 4.0 are the Internet of Things (IoT) and Cyber-Physical Systems (CPS). Is the application of sensors (IoT) revolutionary or evolutionary? Sensors are being used for decades and are evolving continuously, mostly by the connectivity, creation and using of data. Krämer (2014) referred to CPS as a possible buzzword in 2014. He stated among others that Norbert Wiener was already elaborating on the concept of CPS in 1948: feedback between men and machines with mechanisms in technical, biological and social systems.

And nowadays, research and industry is already focusing on Industry 5.0, the fifth *and* second *ex ante* industrial revolution…

5.1 Significance

The multi-criteria decision-making model can serve as a tool for the analysis of maturity models in the knowledge base, and can be used to find the best maturity models and use those as examples, for improving and reusing existing maturity models, but also as an inspiration for new models.

Furthermore, the tool can serve as a foundation for comparing and selecting maturity models from other domains. The critics of AHP can also use the retrieved data and criteria with other (preferred) calculation methods. The tool already provides two alternative calculation methods: mean of normalized values and the geometric mean.

Consumers (i.e. organizations, environment) of maturity models have a practical tool to compare different maturity models. Instead of relying on third parties using their own or preferred models, without fitting it to the context and needs of the consumers. It also provides guidance to relevant aspects of a maturity model.

The practicality of the tool and literature-based criteria should satisfy both academics and industry.

5.2 Limitations

The research has its limitations. Firstly, data has been retrieved through expert interviews and a survey. The answers and analysis of the interviews and survey can be subject to bias. The retrieved data are beliefs, perspectives and expert opinions of individuals. The qualitative and interpretive nature of the data also leads to an interpretive analysis of the data. To perform the analysis as sound as possible, a well-proven and known method, thematic analysis as proposed by Braun and Clarke (2006), has been applied for the analysis. In addition, the Information Systems Research Framework and guidelines of Hevner et al. (2004) were adopted to ensure rigor and relevant research. Furthermore, the amount of subjects was limited to eight experienced professionals in the Netherlands. More subjects would enrichen the data, especially for the survey. Only 2 out of 24 architects participated in the survey.

Secondly, the AHP method has received criticism from the scientific community. These are mainly concerned with the measurement scale, rank reversal and transitivity of preferences (Gass, 2005). Most of the critics have been refuted in theoretical, methodological, and practical terms. Other than that, the AHP is being used worldwide in several settings and applications for more than three decades. Additionally, the AHP is easy to use and present as it structures a complex decision into a hierarchical model, and it also analyses the consistency of judgements.

Thirdly, the multi-criteria decision-making model consists of 9 criteria on a single layer. As mentioned in chapter 4.1.3, Miller (1956) conjectured that there is a limit on our capacity to process information on simultaneously interacting elements. This limit is seven plus or minus two according to Miller. Otherwise it could negatively affect the reliable accuracy and validity. Saaty and Ozdemir (2003) state that this limit should be even less, that it should be no more than seven in order to serve both consistency and redundancy. An inconsistent judgement was shown in the survey of the second respondent. This was fairly more than the tolerated inconsistency ratio. The exact reason for the inconsistency was not obtained, it could be the amount of criteria to be compared, but this was not proven. A possible solution could be the incorporation of the Delphi technique, a structured method for congregating expert opinions through a series of iterative questionnaires, with a goal of coming to a group consensus. Another solution is to group or remove criteria. Criteria could be grouped by adding another layer of sub-level criteria.

6 Conclusion

This chapter concludes the research. It presents and integrates the findings, and positions them in relation to existing literature. Furthermore, future research directions are suggested based on the findings and limitations of the research.

6.1 Multi-criteria decision-making model

This research proposed a multi-criteria decision-making model for comparing and selecting enterprise architecture maturity models. To arrive at a relevant and rigor model the Information Systems Research Framework and guidelines of Hevner et al. (2004) have been adopted.

The model is based on the Analytical Hierarchy Process (AHP) from Saaty (2008). It consists of three layers: (1) goal; (2) nine weighted criteria; (3) two alternatives. The underlying figure shows the structure of the multi-criteria decision-making model.

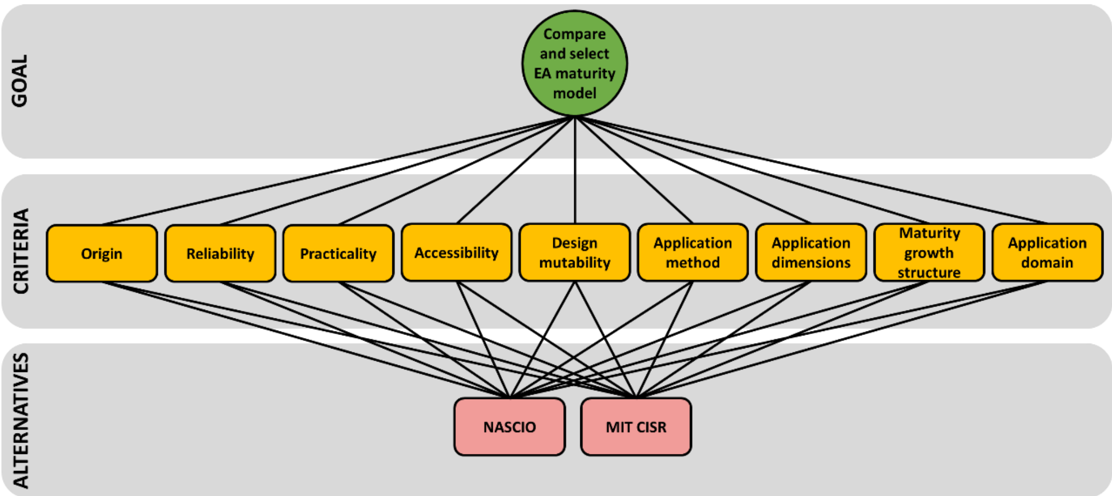


Figure 30. Final AHP hierarchy tree

The criteria were derived through secondary research on existing literature in the knowledge base (Mettler, 2009; Poeppelbuss & Roeglinger, 2011; Van Looy et al., 2013). The weighting of these criteria were performed by experts with the pairwise comparison technique of the AHP. These weighted criteria are set out in the table below. The cost-benefits ratio is included separately as discussed in chapter 4.1.4.

#	Criteria	Description	Weight
1	**Practicality**	The outcome of the assessment. Whether it provides general or specific recommendations and improvement actions which guides toward the desired maturity.	**27.8%**
2	**Application domain**	The incorporation of the application domain of the model. Whether it incorporates characteristics of the organization (e.g. sector, size, type of organization) and context (Industry 4.0).	**19.1%**
3	**Application dimensions**	The dimensions the model assesses. Whether it incorporates the business, information, application and infrastructure/technology layers of the organization.	**15.5%**
4	**Reliability**	The reliability of the model. Whether the model is untested, verified or validated.	**9.5%**
5	**Maturity growth structure**	The maturity growth structure of the model (e.g. staged fixed-level, continuous fixed-levels, focus areas).	**7.1%**

6	**Application method**	The application method of the model. The way and type of data (e.g. interviews, data from systems) that is collected, and by whom (i.e. self-assessment, third party or certified professionals).	**5.8%**
6	**Design mutability**	The mutability of form and functioning of the model.	**5.8%**
8	**Origin**	The origin of the model. Whether it has its source from academia or practice.	**4.8%**
9	**Accessibility**	The accessibility of the model. Whether access to the model is free, charged or confidential (i.e. whether the assessment items and calculation are available).	**4.6%**

Table 26. Weighted criteria

The second most important criteria, application domain, is an outstanding finding of this research. A similar research proposed a multi-criteria model for selecting a business process maturity model (Van Looy et al., 2013). It has similar criteria, but did not incorporate the application domain, in contrary to this research. In addition, the multi-criteria decision-making model followed the intent from Mettler (2009), and Poeppelbuss and Roeglinger (2011) to design criteria which are generalizable for all maturity models, and not focusing solely on one functional domain such as Business Processes. The descriptions of the application domain and application dimensions were made specific for enterprise architecture, but could be interpreted and described in a general manner.

The model, however, has a minus in comparison to Van Looy et al. (2013). It only has one layer of criteria, whereas the model of Van Looy et al. (2013) has three layers. The first layers structures the criteria into assessment criteria, improvement criteria and non-design criteria. A similar design could have been adopted for this research by structuring the criteria on design, assessment and application domain criteria. The structured and normalized criteria are set out in the table below.

Design criteria	47.3 %	Assessment criteria	33.6%	Application domain criteria	19.1%
Application dimensions	32.8%	Practicality	82.7%	Application domain	100%
Reliability	20.1%	Application method	17.3%		
Maturity growth structure	15%				
Design mutability	12.3%				
Origin	10.1%				
Accessibility	9.7%				

Table 27. Structured criteria

The weights of the design, assessment and application domain were derived by summing the underlying criteria, and subsequently normalizing the underlying criteria. For a rigor weighting, another pairwise comparison should be performed by experts on this new layer. This would be challenging for the respondents as it requires even more information to process on different levels. It could however be easier and more consistent to perform pairwise comparison within the groups, as they are more similar to each other. Van Looy et al. (2013) did not perform a weighting for the top layer of criteria, instead they summed up the underlying criteria, which is not corresponding with the AHP method of Saaty (2008). In this matter it only adds structure to the criteria.

In comparison to the decision parameters and design principles of Mettler (2009), and Poeppelbuss and Roeglinger (2011), the derived criteria of this research are more complete and guiding. This was arrived by combining and refining their findings, and by generating the order of importance for the derived criteria. In addition, a practical tool was developed in R to use the model in practice. However, for designing or modifying a maturity model, their papers provide more guidance, as it is more focused on the development of useful and sound maturity models. Therefore, the use of this research in combination with their papers is ideal for improving existing maturity models. This research can be used for identifying the best maturity models, and their strengths and weaknesses. Subsequently, their papers can be used for modifying the selected maturity model to a useful and sound maturity model.

The model addresses multiple issues which were identified in the problem statement and literature review on maturity models. This is discussed in the following paragraphs.

Maturity models lack a formal theoretical foundation (Biberoglu & Haddad, 2002), empirical foundation (Benbasat, Dexter, Drury & Goldstein, 1984; De Bruin, Freeze, Kaulkarni & Rosemann, 2005), and testing in terms of validity, reliability and generalizability (De Bruin & Rosemann, 2005). The multi-criteria decision-making model has been based on existing foundations, incorporated the environment and is tested on two models. However, more tests should be performed to address this.

Documentation of the design process is lacking for existing maturity models (Becker, Knackstedt & Poeppelbuss, 2009; Becker, Niehaves, Poeppelbuss & Simons, 2010; Iversen, Nielsen & Norbjerg, 2010). This has also been a problem with the demonstrated maturity models of NASCIO and MIT CISR. The design process of the multi-criteria decision-making model is fully documented in this thesis. The framework and guidelines of Hevner et al. (2004) have been used to develop a sound artefact.

From a practical perspective, maturity models have been criticized for multiple matters. Firstly, maturity models are overemphasising on processes and disregarding people's capabilities (Bach, 1994). This has been addresses by the criteria application dimensions. The focus of a maturity model can be rated on which dimensions it includes.

Secondly, maturity models neglects multiple equal advantageous paths organizations can go through for improving their maturity (Teo & King, 1997), focus on predefined end-states instead of factors which drive evolution and change (King & Kraemer, 1984), and lack of a description on how to perform the necessary improvement actions (Mettler, 2009). The criteria practicality and maturity growth structure governs these matters.

Thirdly, they tend to be subject to bias, because how and which data is obtained (Mettler, 2009). Rating the application method of alternatives is added as a criteria to address this issue.

Lastly, maturity models are not configurable in order to deal with organization's external and internal characteristics, such as the technologies and customer base of organizations (Mettler & Rohner, 2009). A key focus of this research was to understand the context of organizations by exploring Industry 4.0. This has been included in the criteria application domain. Other characteristics of organizations (e.g.

sector, size) were not addressed in this research. The next subchapter concludes the concept of Industry 4.0 with regards to the criteria ‘Application domain’.

6.2 Industry 4.0

The concept of Industry 4.0 has been explored through literature review and expert interviews. Industry 4.0 is discussed in literature as a strategic initiative and as the ex-ante fourth industrial revolution. It is mostly targeted towards the manufacturing industry. The findings of the expert interviews largely corresponded with the understanding of Schwab (2017) on Industry 4.0.

According to Schwab (2017), Industry 4.0 is driven by megatrends: physical, digital and biological. The biological trends were minimally acknowledged by the interviewed experts. The physical and digital trends are expected to impact all organizations, national and international, but also the individual. Schwab (2017) minimally addressed the impact of Industry 4.0 on education and research. This was a key finding from the expert interviews.

The discussion in the literature review on the seven changes of Deane (1979) shows promise for identifying an industrial revolution. The findings of the expert interviews touched on five of the seven changes. The following paragraphs captures the findings in literature and expert interviews regarding these seven changes.

1. **Widespread and systematic application of modern science and empirical knowledge to the process of production for the market**
   Previous revolution were characterized by one or two drivers, The first industrial revolution is known for the introduction of water and steam-powered mechanical production facilities; the second industrial revolution started in the 1870’s and was centred around electrification and the division of labour; the third industrial revolution, also referred as the digital revolution, started in the 1970’s and led to further automation of production processes with the incorporation of advanced electronics and information technology (Hermann, Pentek & Otto, 2016).

   In literature most refer to IoT and CPS as the drivers for Industry 4.0. The findings of the expert interviews did not acknowledge these drivers as the most important drivers. However, the most important driver(s) could not be derived from the expert interviews, and has yet to be determined. However, the availability and usage of data was a recurring theme in the findings. This could potentially be the main driver for the fourth industrial revolution. Other identified trends by the experts are: AI, robotics, Blockchain, IoT, CPS, cloud services, 3D printing, neurotechnologies, and reducing $CO2$, excess capacity, the use of natural resources, and the waste of energy.

2. **Specialization of economic activity directed towards production for national and international markets rather than for family or parochial use**
   The second change is demonstrated by the focus on manufacturing by several country’s initiatives, as discussed frequently in literature. Key initiatives were set out in chapter 2.4.1 of the literature review.

3. **Movement of population from rural to urban communities**
   Urbanization is estimated to grow from 55,3 percent to 60 percent by 2030 according to studies of the United Nations, Department of Economic and Social Affairs, Population Division (2018).

4. **Enlargement and depersonalization of the typical unit of production so that it comes to be based less on the family or the tribe and more on the corporate or public enterprise**
   The fourth change seems to be different for the possible fourth industrial revolution. According to Wang, Ma, Yang and Wang (2017) mass customization has been a trend in recent times, and the technologies and concepts of Industry 4.0 will enable novel forms of personalization.

   Findings from the interviews indicate the same pattern with regards to previous industrial revolution, i.e. individualized mass production and services.

5. **Movement of labour from activities concerned with the production of primary product to the production of manufactured goods and services**
   One of the trends for Industry 4.0 is manufacturing servitization and innovation (Lee, Kao & Yang, 2014). Servitization is the shift from selling products to selling a combination of products and services that delivers value in use (Martinez, Bastl, Kingston & Evans, 2010). This trend has also been identified by the experts and perceived as relevant for other sectors as well.

6. **Intensive and extensive use of capital resources as a substitute for and complement to human effort**
   The interaction between human and machine is a recurring theme in academic literature on Industry 4.0 (Gorecky, Schmitt & Loskyll, 2014; Lu, 2017; Posada, Toro, Barandiaran, Oyarzun, Stricker, De Amicis & Vallarino, 2015; Roblek, Meško & Krapež, 2016). The tasks and demands of humans will change with the development of Industry 4.0 (Gorecky, Schmitt & Loskyll, 2014). It is likely that simple manual tasks will continue to decline due to the increasing presence of IT, which could pose a threat to semi-skilled workers (Kagermann, Wahlster & Helbig, 2013). The sixth and seventh change seem to be interrelated. The change on workforce by an increase of IT affects occupational classes.

   The experts discussed trending technologies such as robots, CPS and AI which will be a substitute for and complement to human effort in the future.

7. **Emergence of new social and occupational classes determined by ownership of or relationship to the means of production other than land, namely capital**
   In contrary to most literature, Schwab (2017) discussed this change in depth and expects major changes to business, national and global, but the society and individual as well due to the megatrends of the fourth industrial revolution. The findings from the expert interviews corresponded with this understanding, and added education and research as impacted parties. Servitization, digitalization and automation of processes requires a different ICT-landscape and new capabilities of people and organizations. The government, industry and education plays a major role in this.

The figure on the next page visualizes an integrated theory on Industry 4.0, which captures both literature and findings from the expert interviews. The numbered circles reflect the seven changes. In the centre are the trends which drives the fourth industrial revolution. The impact of these trends is shown on the right.

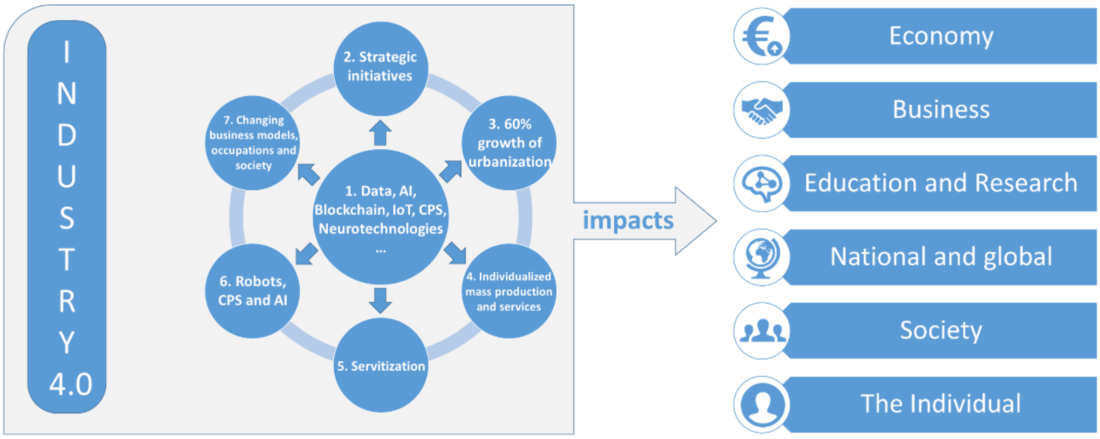


Figure 31. Integrated theory on Industry 4.0

To arrive at a sound theory, a thematic analysis was adopted for the analysis of the expert interviews. The themes were centred around the environment of the well-known and used Information Systems Research Framework of Hevner et al. (2004).

The framework was found useful for capturing the context and application domain of this research, Industry 4.0. The environment served as a guidance for defining the themes. However, linking the codes from the transcripts to the themes was challenging at first. Adding data as a new element to the environment was necessary to ensure sound and fitting themes for the codes. Therefore, adding data to the environment is recommended for modernization of the framework. A modernized version of the framework is presented below. Further specification on the element 'Data' was not necessary for this research, and therefore not performed, but could be explored in future research.

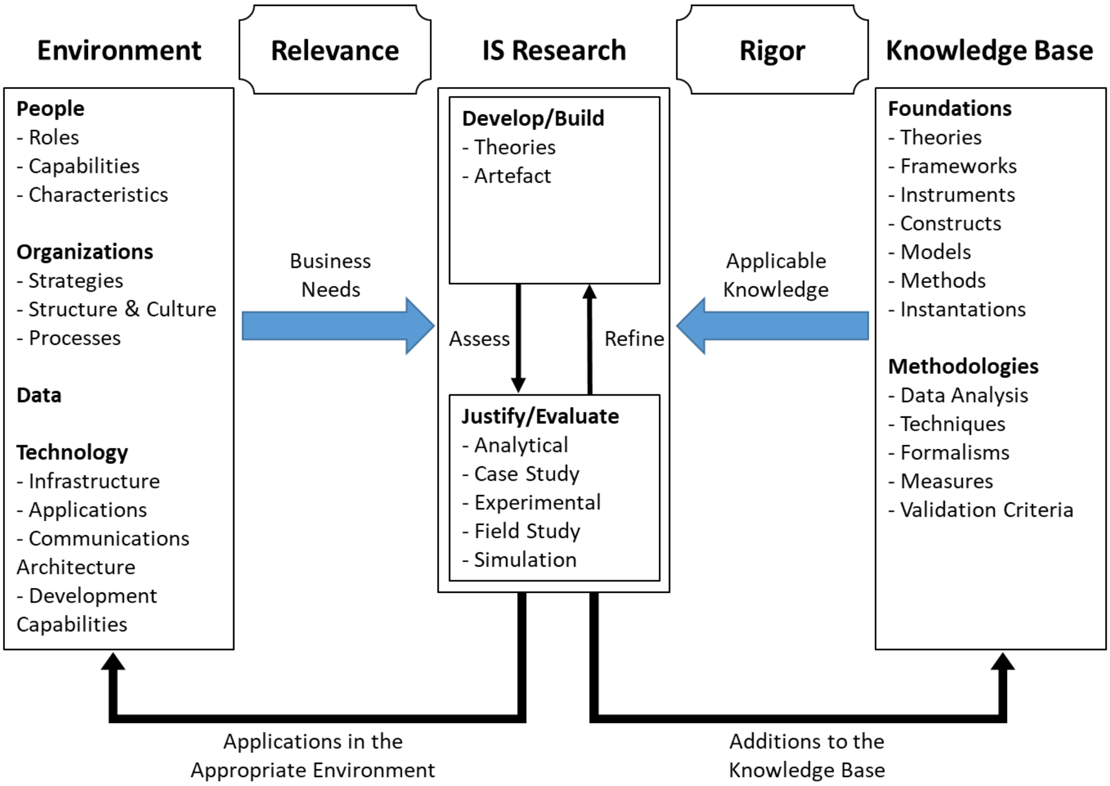


Figure 32. Modernized Information Systems Research Framework (Hevner et al., 2004)

6.3 Future research

Future research directions are suggested for the developed model, enterprise architecture maturity and industrial revolutions.

6.3.1 Multi-criteria decision-making model

Another layer of sub-criteria can be added in order to minimize the main level of criteria to a maximum of seven to serve consistency. A brief exploration of adding another layer is presented in chapter 6.1.

The nine criteria could be decomposed into possible outcomes, for example: adding another level for maturity growth structure which consists of staged fixed-level, continuous fixed-levels and focus areas. After adding a level, research should be conducted to derive the advantages and disadvantages of the outcomes and calculate weights. This could vary depending of the purpose of use and application domain.

More pairwise comparisons of the criteria should be performed to increase the validity of the outcomes. The pairwise comparisons in this research had a similar outcome with regards to the importance of criteria. Will this still be the case after adding a significant number of additional pairwise comparisons? If not, should the criteria be reviewed for completeness and relevance? A Delphi method would be the preferred method over a regular survey.

Testing the model on additional enterprise architecture maturity models is necessary to increase the validity of the model as well, and to test the practicality of the developed tool in R.

The AHP package in R could be adjusted so that the weighting of criteria and rating of alternatives can be performed by separate persons easier, instead of bypassing the original intent of the package.

Exploring the usage of the multi-criteria decision-making model for other domains. This would require testing the model in different functional domains and refine the criteria if necessary.

AI techniques could potentially be used for classifying and analysing maturity models with the defined criteria. Appearance of words and sentences could possibly be used to automatically rate alternatives. For example, recognizing the usage of design principles in a paper on the maturity model, or finding patterns in the maturity growth structure of the model based on images.

6.3.2 Enterprise architecture maturity

The enterprise architecture maturity model of MIT CISR is potentially a suited model in today's context, as demonstrated with the multi-criteria decision-making model. It does lack in accessible documentation on the design process and maturity growth structure, but the incorporation of the application domain adds significant relevance to the model in contrary to other models. Most of the concepts of the maturity models are still valid:

- The architecture maturity stages which evolves from business silos, standardized technology, operational efficiency and finally to business modularity.
- The value of IT which evolves from local/functional optimizations to IT efficiency, operational efficiency and finally to strategic agility.

However, one of the dimensions of the model captures the investments of firms in IT, which is structured into:

- Local applications, 15% is spent on local application in the most mature stage.
- Enterprise systems, 34% is spent on enterprise systems in the most mature stage.
- Shared infrastructure, 33% is spent on shared infrastructure in the most mature stage.
- Shared data, 18% is spent on shared data in the most mature stage.

Future research could use the maturity model of MIT CISR as a foundation for a new iteration on IT investments. The enterprise systems and shared infrastructure is based on older concepts such as traditional ERP-systems and an on-premise infrastructure, and does not address the emerging cloud applications and services. In addition to that, data is becoming more relevant and valuable, easier to access and process, creates new business (models), and with the development of AI will be of even more value.

The evolving management practices seem to be outdated as well, as they imply traditional governance structures and project methods. Developments such as agile and modern business structures (e.g. flatter hierarchy, empowering of individuals, faster, innovativeness) should be reflected in the evolving management practices.

6.3.3 Industrial revolutions

The seven changes of Deane (1979) can be explored in depth to determine what an industrial revolution comprises by using historical data, papers and documents to identify trends and patterns of an industrial revolution. If this confirms the theory, existing data and predictive data can be used to determine whether the fourth industrial revolution is truly a revolution or just an evolution of the third industrial revolution. Subsequently, it can be used for identifying the possible fifth industrial revolution.

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Appendix
A: Interview structure

Introduction
The research is concerned with two topics: Industry 4.0 and enterprise architecture. All the concepts and technologies of Industry 4.0 have a significant impact on the existing enterprise architecture of organizations. This comes with several challenges regarding integration, capabilities, governance, process management and so on. This research focuses on evaluating existing models for measuring EA maturity in the context of Industry 4.0. The existing maturity models will be evaluated based on criteria for EA maturity models in general, and criteria for Industry 4.0.

One part of the data collection from the research will be through interviews with practitioners in the field of Industry 4.0 and/or EA. The interviews will be open and semi-structured, in order to gain multiple perspectives, experiences and opinions on the two interrelated topics. The topics and questions of the interview are as followed:

Interviewee/organization
- Name, organization, function, experiences, expertise
- Can you tell something about the organization, regarding mission/vision, purpose, structure and customers?
- What is the department you work at?
- What is your role within the department?
- What is the strategic direction of the organization and department?

Industry 4.0
- What is your experience with Industry 4.0 and are you currently involved with Industry 4.0?
- How would you define/describe Industry 4.0?
- What are the biggest changes due to Industry 4.0?
- What are the critical success factors and necessary requirements for adopting Industry 4.0?
- What are the biggest challenges integrating Industry 4.0 concepts and technologies?

Enterprise architecture
- What is your experience with enterprise architecture and are you currently involved with enterprise Architecture?
- How about enterprise architecture Maturity?

Industry 4.0 & enterprise architecture
- How do Industry 4.0 & EA relate and influence each other?
- What are the biggest changes and factors to deal with integrating Industry 4.0 concepts and technologies in the existing EA of organizations?
- What needs to be monitored/measured/assessed regarding EA maturity with the upcoming changes of Industry 4.0?
- Are there existing models suitable for assessing EA maturity in general, and how about Industry 4.0?

Follow-up questions, additional comments and notes
At the end of the interview there will be room for additional questions and comments based on the earlier provided answers/perspectives/opinions from the interviewee.

B: Survey responses

The received response from the first respondent is shown below. The next page contains the response from the second respondent.

	A	B	A or B?	How much more or equal?	Intensity of importance	Criteria	Explanation
2	Origin	Reliability	b	Very much more important	Equal importance	Origin	The origin of the model: academic, practitioner-based.
3	Origin	Practicality	b	Much more important	Somewhat more important	Reliability	The reliability of the model: untested, verified, validated.
4	Origin	Accessibility	a	Somewhat more important	Much more important	Practicality	The outcome / results of the assessment: no recommendations, generic recommendations, specific improvement actions.
5	Origin	Design mutability	b	Much more important	Very much more important	Accessibility	The accessibility of the model: free, charged, confidential.
6	Origin	Application method	b	Much more important	Absolutely more important	Design mutability	The mutability of form (e.g. the underlying meta-model or model schema of the maturity model) and functioning (e.g. the way how maturity is assessed) of the model: none, form, functioning, form & functioning.
7	Origin	Application dimensions	b	Much more important		Application method	The application method of the model: self-assessment, third party, licenced party, interview-driven, data-driven.
8	Origin	Maturity growth structure	b	Much more important		Application dimensions	The dimensions the model assesses: business, data, application, infrastructure.
9	Origin	Application domain	b	Very much more important		Maturity growth structure	The maturity growth structure: levels (e.g. CMM), focus areas (e.g. DYA).
10	Reliability	Practicality	b	Much more important		Application domain	The incorporation of characteristics of the organization (e.g. needs, type, size, sector) and / or context (e.g. digital transformation, Industry 4.0, data-driven) in the model. For example, the enterprise architecture maturity model from Ross, Weill and Robertson in the book Enterprise Architecture as Strategy which incorporates elements such as centralization, standardization, rationalization.
11	Reliability	Accessibility	a	Much more important			
12	Reliability	Design mutability	a	Somewhat more important			
13	Reliability	Application method	a	Much more important			
14	Reliability	Application dimensions		Equal importance			
15	Reliability	Maturity growth structure	a	Somewhat more important			
16	Reliability	Application domain		Equal importance			
17	Practicality	Accessibility	a	Much more important			
18	Practicality	Design mutability	a	Somewhat more important			
19	Practicality	Application method	a	Much more important			
20	Practicality	Application dimensions		Equal importance			
21	Practicality	Maturity growth structure	a	Somewhat more important			
22	Practicality	Application domain		Equal importance			
23	Accessibility	Design mutability	b	Much more important			
24	Accessibility	Application method	b	Much more important			
25	Accessibility	Application dimensions	b	Much more important			
26	Accessibility	Maturity growth structure		Equal importance			
27	Accessibility	Application domain	b	Much more important			
28	Design mutability	Application method		Equal importance			
29	Design mutability	Application dimensions	b	Much more important			
30	Design mutability	Maturity growth structure	a	Somewhat more important			
31	Design mutability	Application domain	b	Much more important			
32	Application method	Application dimensions	b	Much more important			
33	Application method	Maturity growth structure	b	Somewhat more important			
34	Application method	Application domain	b	Much more important			
35	Application dimensions	Maturity growth structure	a	Much more important			
36	Application dimensions	Application domain		Equal importance			
37	Maturity growth structure	Application domain	b	Much more important			

	A	B	A or B?	How much more or equal?	Intensity of importance	Criteria	Explanation
1	A	B	A or B?	How much more or equal?	Intensity of importance	Criteria	Explanation
2	Origin	Reliability	A	Somewhat more important	Equal importance	Origin	The origin of the model: academic, practitioner-based.
3	Origin	Practicality	B	Absolutely more important	Somewhat more important	Reliability	The reliability of the model: untested, verified, validated.
4	Origin	Accessibility	B	Very much more important	Much more important	Practicality	The outcome / results of the assessment: no recommendations, generic recommendations, specific improvement actions.
5	Origin	Design mutability	A	Somewhat more important	Very much more important	Accessibility	The accessibility of the model: free, charged, confidential.
6	Origin	Application method	A	Somewhat more important	Absolutely more important	Design mutability	The mutability of form (e.g. the underlying meta-model or model schema of the maturity model) and functioning (e.g. the way how maturity is assessed) of the model: none, form, functioning, form & functioning.
7	Origin	Application dimensions	B	Somewhat more important		Application method	The application method of the model: self-assessment, third party, licenced party, interview-driven, data-driven.
8	Origin	Maturity growth structure	A	Somewhat more important		Application dimensions	The dimensions the model assesses: business, data, application, infrastructure.
9	Origin	Application domain	B	Much more important		Maturity growth structure	The maturity growth structure: levels (e.g. CMM), focus areas (e.g. DYA).
10	Reliability	Practicality	B	Much more important		Application domain	The incorporation of characteristics of the organization (e.g. needs, type, size, sector) and / or context (e.g. digital transformation, Industry 4.0, data-driven) in the model. For example, the enterprise architecture maturity model from Ross, Weill and Robertson in the book Enterprise Architecture as Strategy which incorporates elements such as centralization, standardization, rationalization.
11	Reliability	Accessibility	B	Somewhat more important			
12	Reliability	Design mutability	B	Somewhat more important			
13	Reliability	Application method	B	Somewhat more important			
14	Reliability	Application dimensions	B	Somewhat more important			
15	Reliability	Maturity growth structure	B	Somewhat more important			
16	Reliability	Application domain	B	Somewhat more important			
17	Practicality	Accessibility	A	Much more important			
18	Practicality	Design mutability	A	Much more important			
19	Practicality	Application method	B	Somewhat more important			
20	Practicality	Application dimensions	A	Much more important			
21	Practicality	Maturity growth structure	A	Very much more important			
22	Practicality	Application domain	A	Much more important			
23	Accessibility	Design mutability	A	Somewhat more important			
24	Accessibility	Application method	B	Somewhat more important			
25	Accessibility	Application dimensions	B	Somewhat more important			
26	Accessibility	Maturity growth structure	A	Somewhat more important			
27	Accessibility	Application domain	B	Much more important			
28	Design mutability	Application method	B	Somewhat more important			
29	Design mutability	Application dimensions	B	Somewhat more important			
30	Design mutability	Maturity growth structure	B	Somewhat more important			
31	Design mutability	Application domain	B	Somewhat more important			
32	Application method	Application dimensions	B	Somewhat more important			
33	Application method	Maturity growth structure	B	Somewhat more important			
34	Application method	Application domain	B	Somewhat more important			
35	Application dimensions	Maturity growth structure	B	Somewhat more important			
36	Application dimensions	Application domain	B	Somewhat more important			
37	Maturity growth structure	Application domain	B	Somewhat more important			

C: Transcripts and initial codes of the interviews

This part of the appendix is delivered separately.

D: Derived themes from interviews

Category	Sub-category	Theme
People	Roles	Data scientist
People	Roles	Finding the right people
People	Roles	IT role is changing
People	Roles	Less role fixed
People	Roles	Role of IT and human are changing
People	Roles	Roles will disappear because of IT
People	Roles	Solving automating jobs
People	Capabilities	Decision-making
People	Capabilities	Digital skills
People	Capabilities	Education should evolve based on developments
People	Capabilities	Flexibility depends on organization
People	Capabilities	IT skills
People	Capabilities	Limited knowledge on application in industrial market
People	Capabilities	Managing standardization
People	Capabilities	Need to develop competences of employees
People	Capabilities	Solving complex issues
People	Capabilities	Technical and soft skills
People	Capabilities	Technical skills
People	Capabilities	Understanding and using architecture
People	Capabilities	Working with IT
People	Characteristics	Risk for creating digital gap in society
Organizations	Strategies	AI strategy
Organizations	Strategies	Custom and flexible services
Organizations	Strategies	Dependence of IT
Organizations	Strategies	Efficiency through centralization
Organizations	Strategies	From business to technology oriented
Organizations	Strategies	Governmental experimentation with technologies
Organizations	Strategies	Growing role of IT in strategic alignment
Organizations	Strategies	Innovations stimulated by government
Organizations	Strategies	I-strategy
Organizations	Strategies	IT is an asset
Organizations	Strategies	IT should contribute to organizational goals
Organizations	Strategies	IT strategy derived from business strategy
Organizations	Strategies	I-vision
Organizations	Strategies	Long-term distinctive capability
Organizations	Strategies	Organization-wide approach necessary
Organizations	Strategies	Outside in approach in stead of (inside-ou) push

Organizations	Strategies	Outsourcing if not distinctive
Organizations	Strategies	Strategic flexibility
Organizations	Strategies	Translating strategy to target landscape
Organizations	Strategies	Two track policy
Organizations	Strategies	Using architecture is part of IT strategy
Organizations	Structure & culture	Agile
Organizations	Structure & culture	Change management
Organizations	Structure & culture	Combination of human and machine
Organizations	Structure & culture	Combine business and technology experts
Organizations	Structure & culture	Convincing operations on i4.0
Organizations	Structure & culture	Culture is a challenge for adapting technologies
Organizations	Structure & culture	DevOps is not only technology
Organizations	Structure & culture	Digital government
Organizations	Structure & culture	Dynamic teams
Organizations	Structure & culture	Flexible organization
Organizations	Structure & culture	Innovation phased
Organizations	Structure & culture	Lean
Organizations	Structure & culture	Minimize suppliers
Organizations	Structure & culture	Trusting teams
Organizations	Structure & culture	Virtual assistant (e.g.) will change our behaviour and work
Organizations	Structure & culture	Work will change due to automation
Organizations	Processes	Automatic decision-making
Organizations	Processes	Automating processes
Organizations	Processes	Automating task activities
Organizations	Processes	Autonomous decisions with AI
Organizations	Processes	Building processen on data
Organizations	Processes	Centralization and standardization of processes
Organizations	Processes	Decision-making with deep learning and self-learning network
Organizations	Processes	DevOps is not only technology
Organizations	Processes	I4.0 is not only technology, but an entire process of implementation, support and continous improvement
Organizations	Processes	Managing energy transition
Organizations	Processes	Managing traffic streams
Organizations	Processes	Not automating is not an option
Organizations	Processes	Predicting
Organizations	Processes	Predicting and preventing failure with algorithms
Organizations	Processes	Shared processess
Organizations	Processes	Supply chain management
Organizations	Data	Big data
Organizations	Data	Data

Organizations	Data	Data analytics
Organizations	Data	Data collection
Organizations	Data	Experimentation with data collection and processing
Organizations	Data	Historic and real time data
Organizations	Data	Non-structured data
Organizations	Data	Predictive analysis
Organizations	Data	Real-time analytics
Organizations	Data	Real-time insights and opportunities with data
Organizations	Data	Security and privacy
Organizations	Data	Shared data
Technology	Infrastructure	Blockchain
Technology	Infrastructure	Blockchain might not be as disruptive as suggested
Technology	Infrastructure	Cloud
Technology	Infrastructure	Conscious cloud
Technology	Infrastructure	Container
Technology	Infrastructure	Container technolgy
Technology	Infrastructure	Hyper converged architecture
Technology	Infrastructure	IoT
Technology	Infrastructure	Maintainability
Technology	Infrastructure	Platform development
Technology	Infrastructure	Quantum computing
Technology	Infrastructure	Reliable IT
Technology	Infrastructure	Scalability
Technology	Infrastructure	Sensoring
Technology	Infrastructure	Standardization of platforms
Technology	Applications	AI
Technology	Applications	AR
Technology	Applications	Automatic and autonoomous decisions for safety
Technology	Applications	Deep learning
Technology	Applications	Energy systems based on IoT
Technology	Applications	Intelligent algorithms
Technology	Applications	IoT
Technology	Applications	Machine learning
Technology	Applications	Neural technologies
Technology	Applications	Reliable IT
Technology	Applications	Secure and reliable IT
Technology	Applications	Security
Technology	Applications	Security by design
Technology	Applications	Supervised learning
Technology	Applications	Virtual assistant (e.g. Alexa) in public services
Technology	Applications	Virtual assistant (e.g. Alexa) remove interfaces of devices

Technology	Applications	Virtual assistant (e.g. Alexa) will have big impact on society)
Technology	Applications	VR
Technology	Communications architecture	API
Technology	Communications architecture	API centric architecture
Technology	Communications architecture	Data access control
Technology	Communications architecture	Digital channels
Technology	Communications architecture	Distinctive client interaction
Technology	Communications architecture	Easy to use userinterface with user experience
Technology	Communications architecture	Flexible architecture to avoid legacy in the future
Technology	Communications architecture	Hybrid architecture
Technology	Communications architecture	Integrating operations with API's
Technology	Communications architecture	Microservices
Technology	Communications architecture	Replacing interface such as keyboard
Technology	Communications architecture	Seamless interface
Technology	Development capabilities	Agile
Technology	Development capabilities	Algorithm development
Technology	Development capabilities	Automated testing
Technology	Development capabilities	Build for reuse
Technology	Development capabilities	Data lab
Technology	Development capabilities	DevOps
Technology	Development capabilities	Experimentation
Technology	Development capabilities	Experimentation with innovation
Technology	Development capabilities	Innovation
Technology	Development capabilities	Low code
EA maturity model		Added value unknow
EA maturity model		DIA is somewhat outdated
EA maturity model		DYA
EA maturity model		DYA felt behind of market development
EA maturity model		DYA is based on functional areas
EA maturity model		DYA is focused on software development
EA maturity model		DYA measures making and using of EA
EA maturity model		Dynamic and agile
EA maturity model		EA is more than IT and projects
EA maturity model		EA maturity is of added value
EA maturity model		EA maturity models are focused on IT, not enterprise architecture

EA maturity model		EA maturity models are mostly based on waterfall methods
EA maturity model		EA maturity models are not flexible
EA maturity model		EA maturity models are outdated
EA maturity model		EA maturity models should adopt agile
EA maturity model		EA maturity models should evolve and follow developments
EA maturity model		Gartner maturity model
EA maturity model		Gartner maturity model focuses on projects and IT
EA maturity model		Guidance
EA maturity model		No funding
EA maturity model		No suitable EA maturity models
EA maturity model		Not static
EA maturity model		Reference
EA maturity model		Room for experimenting
EA maturity model		SAFE framework is useful
EA maturity model		Specific reference EA maturity
EA maturity model		The purpose of EA maturity model should be for continous improvement
EA maturity model		TOGAF maturity model
Industry 4.0		Automation is a recurring theme in industrial revolutions
Industry 4.0		Chain integration
Industry 4.0		CO2 reduction is megatrend
Industry 4.0		Creating new jobs with industry
Industry 4.0		Data-driven supply chain management
Industry 4.0		Different takes on Industry 4.0 in multiple countries
Industry 4.0		Digital and connected product design
Industry 4.0		Digital twin
Industry 4.0		Digitizing
Industry 4.0		Efficiency
Industry 4.0		Faster delivery is megatrend
Industry 4.0		Field labs, stimulated by government
Industry 4.0		Flexible processing
Industry 4.0		Government recognizes industry
Industry 4.0		Government should involve in data

		privacy and cyberresilience
Industry 4.0		Government should involve in fit of education and business
Industry 4.0		Government should not involve in supply and demand
Industry 4.0		Improve and integrate supply chain management
Industry 4.0		Individualized mass production
Industry 4.0		Industry 4.0 affects society, people and things
Industry 4.0		Industry 4.0 goes beyond industry
Industry 4.0		Industry 4.0 is digital transformation
Industry 4.0		Industry 4.0 themes are disruptive, destructive and fast
Industry 4.0		Industry necessary for R&D
Industry 4.0		Integration of real world and virtual world
Industry 4.0		IT and OT
Industry 4.0		Lack of R&D lead to poor fit with academic
Industry 4.0		Living labs
Industry 4.0		Management execution systems
Industry 4.0		Multiple understandings of Industry 4.0
Industry 4.0		New business models
Industry 4.0		No waste of energy
Industry 4.0		Optimal use of resources
Industry 4.0		Platformization is the big change in Industry 4.0
Industry 4.0		Reducing CO2
Industry 4.0		Reducing excess capacity/inventory
Industry 4.0		Revolutionary is determined afterwards
Industry 4.0		Short time to market
Industry 4.0		Shortage of natural sources is megatrend
Industry 4.0		Smart city
Industry 4.0		Smart energy
Industry 4.0		Smart industry
Industry 4.0		Smart industry from a chain perspective
Industry 4.0		Smart loses its content
Industry 4.0		Technology can break business models
Industry 4.0		Workforce is not digital native

E: AHP input file

```
Version: 2.0
Alternatives: &alternatives
  NASCIO:
    owner: NASCIO
    year: 2003
  MIT CISR:
    owner: MIT CISR
    year: 2003
Goal:
  name: Compare and select EA maturity model
  decision-makers:
    - Resp1: 0.5
    - Resp2: 0.5
  preferences:
    Resp1:
      pairwise:
      - [Origin, Reliability, 1/7]
      - [Origin, Practicality, 1/5]
      - [Origin, Accessibility, 1]
      - [Origin, Design mutability, 1/5]
      - [Origin, Application method, 1/5]
      - [Origin, Application dimensions, 1/5]
      - [Origin, Maturity growth structure, 1/5]
      - [Origin, Application domain, 1/7]
      - [Reliability, Practicality, 1/3]
      - [Reliability, Accessibility, 5]
      - [Reliability, Design mutability, 3]
      - [Reliability, Application method, 5]
      - [Reliability, Application dimensions, 1]
      - [Reliability, Maturity growth structure, 3]
      - [Reliability, Application domain, 1]
      - [Practicality, Accessibility, 5]
      - [Practicality, Design mutability, 3]
      - [Practicality, Application method, 5]
      - [Practicality, Application dimensions, 1]
      - [Practicality, Maturity growth structure, 3]
      - [Practicality, Application domain, 1]
      - [Accessibility, Design mutability, 1/5]
      - [Accessibility, Application method, 1/5]
      - [Accessibility, Application dimensions, 1/5]
      - [Accessibility, Maturity growth structure, 1]
      - [Accessibility, Application domain, 1/5]
      - [Design mutability, Application method, 1]
      - [Design mutability, Application dimensions, 1/5]
      - [Design mutability, Maturity growth structure, 3]
      - [Design mutability, Application domain, 1/5]
      - [Application method, Application dimensions, 1/5]
      - [Application method, Maturity growth structure, 1/3]
      - [Application method, Application domain, 1/5]
      - [Application dimensions, Maturity growth structure, 5]
      - [Application dimensions, Application domain, 1]
      - [Maturity growth structure, Application domain, 1/5]
    Resp2:
      pairwise:
      - [Origin, Reliability, 3]
      - [Origin, Practicality, 1/9]
```

```yaml
      - [Origin, Accessibility, 1]
      - [Origin, Design mutability, 3]
      - [Origin, Application method, 3]
      - [Origin, Application dimensions, 1/3]
      - [Origin, Maturity growth structure, 1]
      - [Origin, Application domain, 1/3]
      - [Reliability, Practicality, 1/5]
      - [Reliability, Accessibility, 1/3]
      - [Reliability, Design mutability, 1/3]
      - [Reliability, Application method, 1/3]
      - [Reliability, Application dimensions, 1/3]
      - [Reliability, Maturity growth structure, 1/3]
      - [Reliability, Application domain, 1/3]
      - [Practicality, Accessibility, 5]
      - [Practicality, Design mutability, 5]
      - [Practicality, Application method, 3]
      - [Practicality, Application dimensions, 5]
      - [Practicality, Maturity growth structure, 7]
      - [Practicality, Application domain, 3]
      - [Accessibility, Design mutability, 3]
      - [Accessibility, Application method, 1]
      - [Accessibility, Application dimensions, 1/3]
      - [Accessibility, Maturity growth structure, 1]
      - [Accessibility, Application domain, 1/5]
      - [Design mutability, Application method, 1/3]
      - [Design mutability, Application dimensions, 1/3]
      - [Design mutability, Maturity growth structure, 1/3]
      - [Design mutability, Application domain, 1/3]
      - [Application method, Application dimensions, 1/3]
      - [Application method, Maturity growth structure, 1/3]
      - [Application method, Application domain, 1/3]
      - [Application dimensions, Maturity growth structure, 1]
      - [Application dimensions, Application domain, 1/3]
      - [Maturity growth structure, Application domain, 1/3]
  children:
    Origin:
      preferences:
        Resp1:
          pairwise:
            - [NASCIO, MIT CISR, 1/3]
        Resp2:
          pairwise:
            - [NASCIO, MIT CISR, 1/3]
      children: *alternatives
    Reliability:
      preferences:
        Resp1:
          pairwise:
            - [NASCIO, MIT CISR, 1/3]
        Resp2:
          pairwise:
            - [NASCIO, MIT CISR, 1/3]
      children: *alternatives
    Practicality:
      preferences:
        Resp1:
          pairwise:
            - [NASCIO, MIT CISR, 1/3]
```

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    Resp2:
      pairwise:
        - [NASCIO, MIT CISR, 1/3]
  children: *alternatives
Accessibility:
  preferences:
    Resp1:
      pairwise:
        - [NASCIO, MIT CISR, 1]
    Resp2:
      pairwise:
        - [NASCIO, MIT CISR, 1]
  children: *alternatives
Design mutability:
  preferences:
    Resp1:
      pairwise:
        - [NASCIO, MIT CISR, 1]
    Resp2:
      pairwise:
        - [NASCIO, MIT CISR, 1]
  children: *alternatives
Application method:
  preferences:
    Resp1:
      pairwise:
        - [NASCIO, MIT CISR, 1]
    Resp2:
      pairwise:
        - [NASCIO, MIT CISR, 1]
  children: *alternatives
Application dimensions:
  preferences:
    Resp1:
      pairwise:
        - [NASCIO, MIT CISR, 1/7]
    Resp2:
      pairwise:
        - [NASCIO, MIT CISR, 1/7]
  children: *alternatives
Maturity growth structure:
  preferences:
    Resp1:
      pairwise:
        - [NASCIO, MIT CISR, 1]
    Resp2:
      pairwise:
        - [NASCIO, MIT CISR, 1]
  children: *alternatives
Application domain:
  preferences:
    Resp1:
      pairwise:
        - [NASCIO, MIT CISR, 1/7]
    Resp2:
      pairwise:
        - [NASCIO, MIT CISR, 1/7]
  children: *alternatives
```