Chapter 4
Development of Smart Grid Architectures

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Abstract. Because of new producer-, storage- and demand-side management systems which are introduced for a Smart Grid, new data pools, interfaces and processes, arise. Existing legacy systems have to interact with new systems, therefore, the functional and process logic of the power system will be distributed in a more complex way. Information and communication technologies will be required to realize these complex interactions. Developing such a complex system architecture requires a structured approach, which considers the various stakeholders' concerns. Accordingly, a fundamental architecture management of the system landscape as well as a process overview needs to be established by energy suppliers. This chapter presents an introduction and basics on this topic.

4.1 Motivation for Architecture Development

The development of large-scale systems—like the Smart Grid—is a complex task. It involves numerous stakeholders along the value chain, as for instance producers, utilities or consumers, as well as manufacturers, ICT-experts or even stakeholders from the automotive sector regarding electrical vehicles. These systems usually consist of various interrelated elements themselves and also relate to other, equally complex and heterogeneous systems. Therefore, they are hard to understand as a whole for individuals. In addition, the time from development to realization and operation spans over a long period of time and involves great costs. These facts lead to the assumption that a well-planed development of these systems is advisable. Each system's architecture has to be managed to support the development of a complex system like the Smart Grid.

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Since the term *system* can relate to various subjects, as for instance devices, software or enterprises, and systems can be composed of subordinate systems, the meaning of the term architecture is dependent on the current context. In this sense, “Smart Grid architecture” comprises a wide range of architectures regarding the systems involved in the realization of a smart grid—a term which is not even clearly defined and whose subjects are often dependent from company-specific or regional goals. Therefore, existing recommendations for Smart Grid architectures differ regarding the level of detail, regional focus and organizational scope. Examples are the NIST conceptual models defined in [10], the Smart Grid Architecture Model (SGAM) defined in [3] or the Smart Grid Standards Architecture as defined in IEC 62357 [5].

Enterprises representing actors in a Smart Grid producing, trading, distributing and selling electricity, are now encouraged to put the Smart Grid into practice. However, the artifacts of the architecture models named above are not directly applicable for enterprises, i.e. they must be adapted to enterprise-specific requirements and require to be applied thoughtfully using a methodology which can leverage the already defined structures. Within the enterprise-specific context, several factors, depicted in Figure 4.1, lead to changes in different architecture views. Changes in the business context, as for instance changed business processes due to enterprise-external requirements (e.g. automated meter reading vs. manual meter reading) also affect other parts, like (software) applications and underlying technology. In this case, software applications must offer functionality supporting this process. Moreover, when reading meter data every 15 minutes, corresponding solutions able to process the large amount of data must be available. However, data will not be available unless the underlying technology provides them, i.e. in terms of meters. This requires the availability of reliable, digital solutions. Not only do innovations in business influence technology, but also new technology or applications can influence the business. Managing this process requires a holistic development approach, from requirements engineering to developing architectural building blocks and finally selecting (where applicable) and implementing solutions.

This chapter addresses the foundations of architecture and its description in Section 4.2, and presents these aspects in the enterprise context in Section 4.3. These architecture basics lay the foundation for a holistic architecture development method for enterprise architecture and its application in the context of Smart Grids, which is outlined in Section 4.4. Finally, this chapter ends with a conclusion and an outlook on the extended context in Section 4.5.

4.2 On Architecture

There are various definitions of system- and software architecture, and in practice the term is used manifoldly. Empirical research [12] identified at least four different metaphors associated with architecture. These are “architecture as a blueprint”, “architecture as literature”, “architecture as language” and “architecture as decision”. In the first case this means according to [12], that architecture is a working implementation, where its description contains high-level concepts and serves as a plan for the structure to be implemented. The second meaning implies, that architecture is the solution or the collection of solutions made in the past and its description is seen as documentation oriented towards future readers to serve as reference and contains collected solutions. The third metaphor focuses on architecture as a common understanding, where its description serves as a common basis for communication among stakeholder groups and for achieving common high-level structures about the system. Finally, the fourth metaphor understands architecture as the basis for rational decision-making and its description captures the decisions about the structure of the system.

As can be seen, depending on the meaning of architecture—which differs among stakeholders—the contents of its description and its level of detail varies. The ISO/IEC/IEEE standard 42010 "Systems- and software engineering — Architecture description" [8] captures and integrates concepts around architecture and its description, and provides several terms used in this context, which are used in this chapter. These terms are valuable for discussing and creating architecture (descriptions), and facilitate the understanding of existing work. The architecture of a system according to [8] is described as "fundamental concepts of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution". Every system has an architecture, which may not always be made explicit or documented. Figure 4.2 shows a conceptual model of an architecture description's contents, which is presented in the following.

A system is built to achieve one or more specific purposes, which are realized by several parts (even other systems) that are interacting with each other. Systems can be of different natures, as for instance hardware, software-products or enterprises, and may be used in various domains. Everything outside a system is considered as its environment and can in particular influence the system and vice versa. In other words, this means that a system's boundary is defined by its environment.

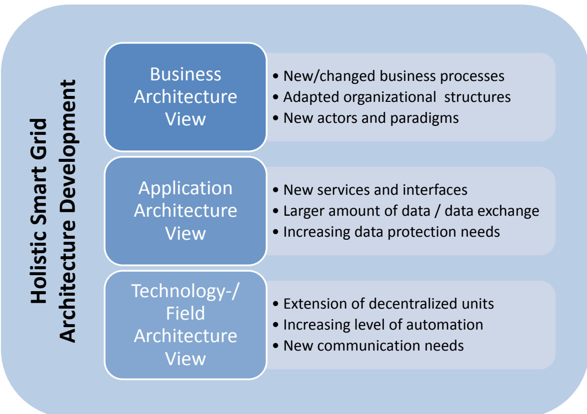

Fig. 4.1 Exemplary issues in Smart Grid architecture management on different layers

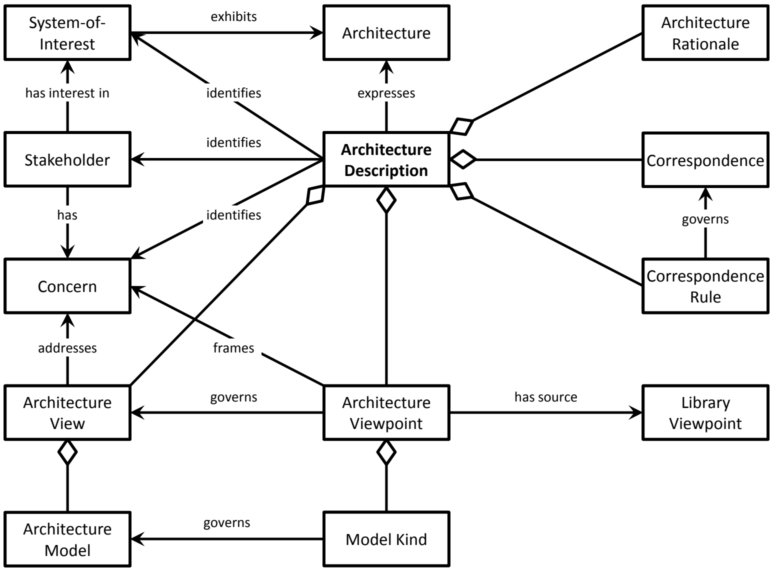

Fig. 4.2 Conceptual model for architecture description following [8]

The *system-of-interest* exhibits an *architecture*, which must not be necessarily documented. *Stakeholders* of a system have interests in this particular system. These could for example be contractees, developers, users or maintainers, who have different, in some cases even opposing architecture-related *concerns* and usually expect the *system-of-interest* to fulfill specific purposes. The main interest of a user will be, for instance, the functionality of the system to achieve a specific task, while developers are more interested in components and technical implementation details of the system.

An *architecture description* (in the upper center of Figure 4.2) is a work product that documents the *architecture* of a system. It is an outcome of *architecting*, which is described in [8] as the "process of conceiving, defining, expressing, documenting, communicating, certifying proper implementation of, maintaining and improving an architecture throughout a system's life cycle". This process can also be subsumed as architecture management. Depending on its focus, *architecture descriptions* can for instance serve as a prescriptive blueprint for a system to be developed, as a basis for development project resource planning, as documentation of an already built system, or be used in tools for simulation and analysis (see different meanings of architecture above, [12, 8]). Such an *architecture description* contains multiple *architecture views* which address one or more of the *stakeholders*' *concerns*; *concerns* can also be covered by multiple *architecture views*. Each *architecture view* depicts relevant parts of the *system-of-interest* as required for the underlying *concerns*. A "complete" view of the system's architecture will then be the consolidation of all architecture views which address the relevant stakeholder concerns. However, architecture descriptions in general are to present the key concepts which are relevant for the stakeholders at a specific point in time and so do not cover the complete complexity of systems and their architectures, but rather reduce it to relevant aspects.

An *architecture view* is governed by an *architecture viewpoint* which frames particular *concerns* (and identifies *stakeholders* for which these are relevant). Moreover an *architecture viewpoint* defines how to model in order create *architecture views*. This can, according to [8], include "languages, notations, *model kinds*, design rules and/or modeling methods, analysis techniques and other operations on views". *Model kinds* govern the *architecture models* which are used in (different) *architecture views*.

Architecture viewpoints can be defined to document a specific *architecture*, but they can also be defined outside the context of a specific *architecture description*. In the latter case, they are applicable in many architecture descriptions and are referred to as *library viewpoints*. Choosing *architecture viewpoints* for an architecture description—and creating respective *architecture views*—basically depends on the concerns/stakeholders.

Beyond the already identified elements, an *architecture rationale* is part of the *architecture description*. Here, the architecture rationale covers multiple aspects, like a rationale for each architecture viewpoint (e.g., its stakeholders, concerns and model kinds), a rationale for key architecture decisions and a rationale for choices made considering alternatives. In addition, an *architecture description* defines *correspondences* between elements used to construct the *architecture description* (AD elements). Identifying correspondences between AD elements documents consistencies and inconsistencies across multiple views and models. *Correspondences* should be governed by *correspondence rules* that allow the identification and analysis of consistencies and inconsistencies. Further recommendations for contents of architecture descriptions can be found directly in [8].

When repeatedly architecting systems of the same nature (e.g. software) within the same domain, it seems evident to reuse existing work products and best practices regarding the process as well as established viewpoints for architecture description. *Architecture frameworks* address this topic. Following [8], frameworks provide "conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders". *Architecture frameworks* are, e.g., useful for creating architecture descriptions, communicating about architecture, and implementing tools to support development. In general, they provide an aligned set of viewpoints, with respective information (stakeholders, concerns, model kinds, etc.). Examples of frameworks include the 4+1 View Model [9], The Open Group Architecture Framework (TOGAF) [13] or the Reference Model for Open Distributed Processing (RM-ODP) [7]. This can simplify the design and development of multi-stakeholder architectures.

The contents of architecture *frameworks* are shown in Figure 4.3. An *architecture framework* identifies several *stakeholders* which are relevant for the particular application domain as well as their *concerns*. In order to give recommendations on how to describe architectures in this domain, these *concerns* are framed by

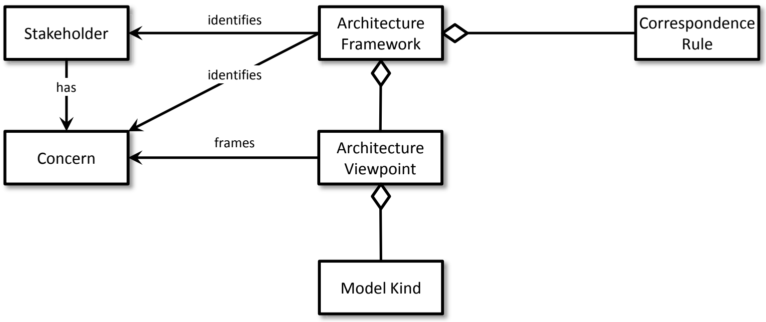

Fig. 4.3 Contents of an architecture framework following [8]

architecture viewpoints. Analogous to the previous explanation, *model kinds* are defined for *architecture viewpoints* in order to create architecture models. *Correspondence rules* define restrictions on relations between AD elements (e.g. *stakeholders*, *concerns*, *viewpoints*) and allow to analyze correspondences. Additionally, the ISO/IEC/IEEE 42010 standard [8] defines further criteria for *architecture frameworks*, their adherence to *architecture descriptions* and architecture description languages which are not discussed here in more detail. As the Smart Grid means increased use of ICT for enterprises, these foundations about architecture shall now be illustrated in the context of enterprises and Smart Grid models.

4.2.1 Enterprise Architecture in the Context of Smart Grids

The functions of enterprises in the Smart Grid context differ from country to country, mainly depending of the type of market and regulations. Examples of such roles, which are taken on by enterprises, are network operators, suppliers, traders, electricity generators or measurement service providers. Due to new roles and functionalities introduced with Smart Grids, enterprises are required to exchange various information with others and to adapt their business processes as well as their supporting information technology. A particular future challenge for distribution system operators for example is represented by the integration and management of their field/operational technologies. Such integration efforts are required and will become more common in context of the increasing amount of distributed generation. As already mentioned, new functionality can also mean new opportunities for the business, i.e. in terms of products or services. This provides a reason for enterprises to take more consideration of the efficient operation of their business- and IT in order to realize new opportunities quickly.

Enterprise architecture deals with the system "enterprise" and so with typical stakeholders and concerns within an enterprise and its environment. There are various definitions of the term "enterprise architecture" available, but there is no generally accepted definition. The understanding of "enterprise architecture" can vary from modeling the enterprise (in terms of architecture description), over implementing architectures within enterprises to a professional discipline or method to manage the enterprise architecture (architecting and managing the architecture). Regardless of the understanding, the subjects of "enterprise architecture" often regard artifacts from the business strategy, organizational issues, business and IT integration as well as software and technical infrastructure [1].

According to the definition given in [8], the term enterprise architecture is understood in the following as defined up to this point with the enterprise representing the system-of-interest. In the context of enterprises, which are socio-technical systems, it is especially important to align the information technology (IT) used (e.g. data entities or information system services) with the respective functions of the business (e.g. business goals, business processes) and organization in order to efficiently operate the business. This alignment process is a focus of enterprise architecture, which holistically considers the system "enterprise". Without a defined/documented enterprise architecture, it will be difficult to consider and meet the stakeholders' concerns and requirements. Viewpoints for enterprise architecture shall allow to express such concerns.

4.3 Viewpoints for Enterprise Architecture

There are several frameworks for enterprise architecture available, which provide different sets of viewpoints. In the late 80s, Zachman [15] provided first foundations for stakeholders and architecture viewpoints with his "framework for information systems architecture", which is often referred to in the context of enterprise architecture. He addressed the six basic concerns (what, how, where, who, when, why) for different stakeholders (strategists, executive leaders, architects, engineers, technicians, workers) and arranged them in a matrix where each cell is addressed by one or more viewpoints (which roughly conforms to the definition of an architecture framework). However, Zachman, providing a fixed set of viewpoints which are assumed to be complete, did not provide a process how to apply the framework. Basically, its application can lead much documentation and leaves it to the user to specify the model kinds and notations to use.

The Open Group Architecture Framework (TOGAF) [13] is a wide-spread and mature enterprise architecture framework which is elaborated by several large industry players as members of The Open Group. TOGAF provides three high-level architecture viewpoints for enterprise architecture, which are called "business architecture", "information systems architecture" and "technology architecture". The "information systems architecture" viewpoint is further subdivided into "application architecture" and "data architecture". According to [13] the following information artifacts and stakeholders are addressed by these viewpoints:

Business Architecture Business strategy, governance, organization, and key business processes information, as well as the interaction between these concepts are part of the business architecture. This viewpoint addresses the concerns of users, planners, and business management.

Data Architecture The structure of an organization's logical and physical data assets and data management resources. It addresses the concerns of database designers, database administrators, and system engineers.

Application Architecture A description of the major logical grouping of capabilities that manage the data objects necessary to process the data and support the business. Here, the concerns of system and software engineers are addressed.

Technology Architecture The logical software and hardware capabilities that are required to support deployment of business, data, and application services. This includes IT infrastructure, middleware, networks,communications, processing, and standards. Acquirers, operators, administrators, and managers are relevant stakeholders for this viewpoint.

TOGAF tries to incorporate the ISO 42010 as far as possible, but the word "architecture" here suggests, that there are four (independent) systems (business, data, application and technology) that have an architecture. In terms of ISO 42010, enterprise architecture is considered as a holistic conception, which can be observed from multiple viewpoints. These "architectures" are here understood as viewpoints, which frame respective concerns regarding business, applications, data, and technology, and so show decompositions of the enterprise.

Within each of these generic viewpoints, TOGAF identifies several exemplary viewpoints which can serve as a starting point to address particular concerns. These viewpoints are divided into three types: Catalogs, Matrices and Diagrams. Catalogs provide lists of information regarding architecture building blocks, matrices are to display relationships between them and diagrams are richer, graphical representations of these information and thus being more suited for stakeholder communication. More detailed "business architecture" viewpoints are for instance "Driver/-Goal/Objective Catalog" or "Actor/Role Matrix", more detailed "data architecture" viewpoints are "Data Entity/Data Component Catalog" or "Data Entity/Business Function Matrix". The TOGAF specification still recommends to take the stakeholder's concerns into account in order to create the architecture description. This also means, that not all of the proposed viewpoints may always be applicable and new ones may have to be developed to cover the concerns.

Not particularly enterprise-specific but Smart-Grid-specific architecture viewpoints are defined within the work of the EU Mandate M/490 CEN/CENELEC/ETSI Working Group "Reference Architecture" [3]. There, the so-called Smart Grid Architecture Model (SGAM) framework is defined, which allows a cross-domain localization of systems. This is a very important aspect in the context of Smart Grids, as it allows to identify interfaces between participating Smart Grid stakeholders. Thus it can enable interoperability between them which is a key to efficiently realize such a complex system. It consists of several layers representing a business viewpoint, a function viewpoint, an information viewpoint, a communication viewpoint and a component viewpoint. Each layer defines a matrix that allows the identification of a Smart Grid domain (one of Generation, Transmission, Distribution, Distributed Energy Resources (DER) or Customer Premise) and the identification of information management zones (one of Market, Enterprise, Operation, Station, Field or Process). The SGAM is described in more detail in the context of requirements engineering in Chapter 2.

The articulation of an enterprise architecture is the basis for its planning, management and evolution. To develop an enterprise architecture description—for instance for planning, management, or just documentation purposes — a well-structured method considering stakeholders, their needs and the organization of created artifacts is required. TOGAF provides these structures and a method for the development, implementation and management of enterprise architectures, independent of any particular business domain. The basics of this approach will be outlined in the following to provide foundations for the enterprise architecture management in the energy sector.

4.4 An Approach for Enterprise Architecture Development and Its Management

The definition of an architecture basically requires to break down a system into its parts, and then to proceed in the same way with its parts until a sufficient granularity for description depending on the objectives of the architecture is reached. This assumes hierarchically structured systems, which are composed of interrelated subsystems, i.e. "nearly decomposable systems" according to [11]. The decomposition of a particular problem area helps to make the complexity of large systems more manageable. Having only to consider parts of a system reduces the complexity of each part and in principle requires only to consider defined relationships. Particular parts of related functionality (e.g. in the form of building blocks) interacting with each other, realize the overall system. In addition, these building blocks provide a basis for work and resource planning, e.g., for scheduling and timing of work tasks, cost analysis or risk management.

One single enterprise already involves various aspects to be taken into account in enterprise architecture. Regarding the integration and information exchange across multiple enterprises with heterogeneous systems, the development can even become more complex. In order to align the changing business and IT-environments and their large numbers of systems, a continuous enterprise architecture management practice has to be established. Since Smart Grid concepts and unbundling provisions in the energy sector mean change to the business of several enterprises and require more information exchange, an established approach, like provided by TOGAF [13], seems reasonable. TOGAF provides methods and tools to develop, implement, use and maintain an enterprise architecture and also includes best practices in the form of a content framework as well as guidelines and techniques.

4.4.1 A Method for Enterprise Architecture Development

The central method of TOGAF is called Architecture Development Method (ADM). It provides a proven and repeatable process for developing architectures. The ADM defines ten phases which can be executed in different iterative cycles, continuously defining and realizing the architecture to a certain extent. Figure 4.4 depicts the phases of the ADM, which are adapted and described in brief in the following text.

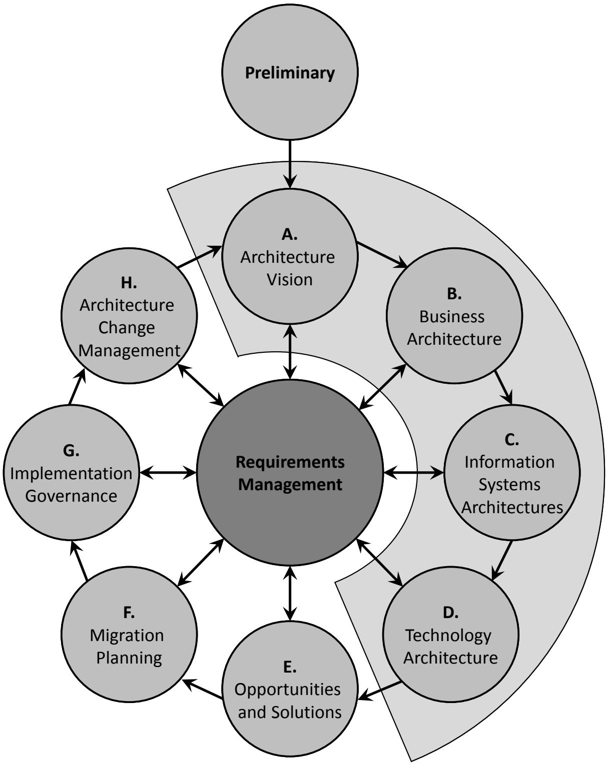

Fig. 4.4 The TOGAF Architecture Development Method (ADM) [13]

As architecture development is a quite generic task, the *Preliminary* phase is about the preparation of the architecture development within the enterprise, e.g., the definition of an enterprise-specific framework or setting up principles for development. The subsequent *Architecture Vision* is the first phase of an architecture development cycle. It is about the definition of the envisioned architecture scope, analysis of stakeholders and the definition of an initial outline of the target architecture addressing the architecture viewpoints (business, information systems and technology) which are in the scope of the development cycle.

Following the *A. Architecture Vision*, more detailed business, information systems and technology views are developed in the phases *B. Business Architecture*, *C. Information Systems Architecture* and *D. Technology Architecture* respectively. Again, the term architecture can here be understood ambiguously: on the one hand, it can be understood as a viewpoint framing concerns related to business, information systems and technology, which are viewpoints on the system "enterprise". On the other hand, it can refer to business, information systems or technology as systems which have an architecture. They identify elements (in a particular domain), their relations and principles and puts them into relation. When referring to one of these "architectures" in the following text, the architecture viewpoint or the development of the respective view is meant.

Primarily, the ADM follows a business-driven approach (top-down), i.e. business requirements are the driver for ICT in enterprises. This means, that information systems and technologies for the Smart Grid are solely required to accomplish business goals. Thus, the phase *B. Business Architecture* deals with identification business concerns and the development of the business architecture view. This comprises for instance capturing business processes and associated requirements, which have finally to be realized by information technology (hardware and software, phases C./D.).

However, it is also appropriate to begin with the identification of technology requirements and the definition of the technology or information architecture view (bottom-up), which is especially useful in case of emerging and technology-driven areas like the Smart Grid. Here, new, innovative technologies would be deployed whose additional value can affect several business areas. The deployment of Smart Meters could for instance influence consumer behavior and so affect elements in the business architecture in the form of changed business models (e.g., nearly real-time tariffs). In practice, a mix of both approaches—top-down and bottom-up—will be reasonable to exploit innovative potentials in the long run, and to optimally support the business with IT. For an economical operation, costs and benefits will have to be balanced against each other, especially in the context of the envisaged period of use and the generally short innovation cycles in the technology sector vs. the rather long innovation cycles in the context of business models.

The phases *Information System Architectures* and *Technology Architecture*, following *Business Architecture* phase, address the development of the actual elements in the scope of the architecture view. This comprises for instance the identification and development of business data entities and information system services in the *Information System Architectures* phase, and technology components or platform services in the *Technology Architecture* phase.

All of the phases B.–D. generally capture/document the current architecture (baseline architecture) and define an envisioned architecture (target architecture). This information provides the basis for a gap analysis to derive particular actions for its realization (transition architecture).

Following phase D., the ADM phase *E. Opportunities and Solutions* deals with the initial implementation planning of the previously defined architecture. This comprises the review of objectives and artifacts developed so far, their consolidation, consideration gap analysis results and the definition of how to deliver the architecture. Transition architectures are defined here to incrementally develop the architecture in several stages, still maintaining normal business operation.

Phase *F. Migration Planning* considers the formulation and coordination of a series of transition architectures, providing an implementation- and migration-plan. This includes among others, the prioritization (in terms of business value) of work packages, projects and building blocks, the finalization of architecture definition documents and the final confirmation of actions from relevant stakeholders.

The subsequent phase *G. Implementation Governance* addresses the governance of implementation projects, e.g. that the solutions meet the plan and architecture requirements. Within this phase, also the initiation of activities which are required for the operation of the implementation takes place.

In the last phase *H. Architecture Change Management* of the architecture development cycle, procedures for monitoring and reacting on changes to the new architecture are set up. These procedures shall ensure, that the new baseline architecture fulfills the requirements and when a new iteration of the ADM is to be triggered.

Finally, the central *Requirements Management* phase is related to all other phases, as illustrated in Figure 4.4. It is concerned with managing architecture requirements and making them accessible within the phases of the ADM. Requirements identified in the *Business Architecture* phase can for example have effects on the applications. Requirements identified in later phases can have effects on work done in previous phases and so the requirements management phase is to allow the consideration of this information.

TOGAF represents a framework and needs to be tailored for application by a particular enterprise. Regarding the ADM, iterations may for instance be carried out in other sequences if this fits better to the organizations goals. TOGAF itself also suggests more specific iteration cycles, e.g., an iteration cycle between *Preliminary* and *A. Architecture Vision* to define the architecture context, an *Architecture Definition Iteration* between *B. Business Architecture* and *F. Migration Planning* (including sub iterations for *C. Information System Architectures* and *E. Opportunities & Solutions* and *F. Migration Planning*), or an *Architecture Governance Iteration* between *G. Implementation Governance* and *H. Architecture Change Management*. Some of these cycles may for instance be executed once, others more often, which mainly depends on the scope and objectives of the development effort.

Additionally, the focus on baseline or target architectures can differ per iteration. Generally, the identification of baseline architectures will for instance be done in early iterations of the architecture definition iteration. In the context of Smart Grids, capturing and considering the current architecture is also an important step. Since it can be assumed that it will not be newly build from scratch, the use and integration of existing infrastructure is required and so its documentation is inevitable. Figure 4.5 shows the states between baseline and target architecture, outlining incremental architecture development. The target architecture represents an ideal to be reached. Oftentimes it is not possible to reach this envisioned state, e.g., resources required for realization are not available in terms of technology, restrictions in time, budget, or as changed requirements imply changes to the envisioned target. Transition

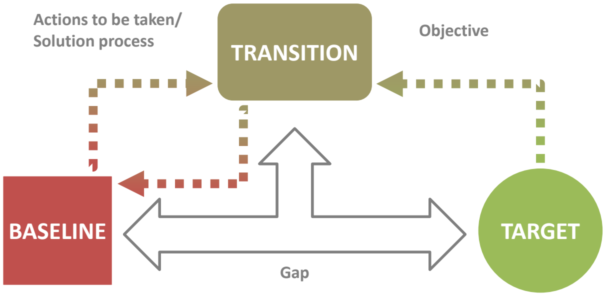

Fig. 4.5 Architecture development as a transition between baseline and target architecture

architectures are increments showing periods of transition and development for particular parts. They should be realized in specific projects and provide the basis for planning. They are defined in the last phases of an architecture definition iteration.

After the brief overview on the ADM, the phases most relevant for the architecture definition and requirements management shall be described in more detail.

4.4.2 Preliminary Phase

The preparations made within this phase are valid throughout the ADM-iteration. This includes to define why the development takes place, which stakeholders are involved, which scope of the enterprise architecture is considered and where and how the development process is conducted. As already mentioned, this phase can also be executed in parallel with or after phase *A. Architecture Vision* in terms of the *Architecture Content Iteration*.

Goals of this phase are to tailor the development process and to define in detail which methods are used to define the architecture. This can for instance mean to define the focus of the development effort within a cycle, as well as the individual activities to be done in particular phases. The last point also includes the definition of specific tasks, different work products, involved roles or individuals.

Another concern addressed in this phase is the definition of fundamental principles regarding the architecture (so called architecture principles). This can include the definition of enterprise principles or information technology principles. Additionally, tools to support the development process are identified, defined and introduced respectively.

4.4.3 Phase A: Architecture Vision

A first version of the envisioned architecture is developed in this phase. It determines the area and scope of the architecture development effort, defining the boundary of what is part of the target architecture and information which will not be considered.

The architecture vision encompasses a description of baseline and the target architectures for business, data, applications, and technology domains on a high-level. These architectures' outlines serve as input for subsequent phases which they are further developed. As it shall serve as guideline and foundation for the development, it should be widely-known and accepted within the identified stakeholder community.

In addition to the creation of an initial version of the architecture, this phase shall also outline the benefits for stakeholders. At first, this requires the identification and documentation of relevant stakeholders and their goals and concerns. This information is, among other things, the basis for the definition of the scope and focus of the architecture, which is also determined in this phase. Not least, this requires the identification and prioritization for further development of components of the baseline architecture, which can be used as input for the vision. This phase also targets to define essential business requirements which shall be addressed with the architecture development effort. In this context, existing business principles, goals and strategic drivers of the organization are to be identified. At the same time, this phase is also the beginning of a development cycle and therefore also includes motivational and organizational work. This comprises for instance the organization and definition of the development cycle within the boundaries defined in the *Preliminary* phase. Beyond that, planning of resources (time, finances, people), communication, risks, constraints, assumptions, and dependencies will be carried out in this phase.

4.4.4 Phase B: Business Architecture

Based on the *Architecture Vision*, phase B. elaborates the business architecture in more detail. The business architecture represents a viewpoint on the enterprise architecture. According to [13], it basically defines the business strategy, governance, organization and essential business processes. Business goals can be refined and decomposed to define business requirements and finally business services. These services inter-exchange data in the form of business objects, which are also identified in this phase. Additionally, business services can involve several roles which can also be identified. The business architecture provides input to the subsequent phases, defining its realization through IT.

However, defining the business architecture requires also to identify and examine appropriate architecture viewpoints, which include information relevant for the particular stakeholders. Furthermore, relevant tools and techniques supporting the development of respective views have to be selected. A gap analysis between baseline and target business architecture descriptions finally allows to derive further development actions.

4.4.5 Phase C: Information Systems Architectures

The *Information Systems Architectures* phase consists of two parts, considering different aspects of information systems: *Application Architecture* and *Data*

Architecture. Within this phase, baseline and target architectures for the data and application domain are being defined. Depending on the architecture project's objectives, the focus on only one of the domains, i.e. either data or application may be possible. Moreover, these two viewpoints and their respective views shall also illustrate relations to the business architecture in terms of a realization relationship. Precisely, this means, that information (represented by business objects) is expressed as data and business processes or their functionality respectively is realized by applications.

Furthermore, the order in which the relevant views are developed can vary and can be chosen depending on the context. There are data centered development approaches, starting with the data viewpoint, but also the functionality regarding the business processes to be realized can be used to argue for an application centered beginning.

On the one hand, the *Application Architecture* viewpoint identifies individual application systems including their relationships to the organization's core business processes (identified in the previous phase) they support. Thus, the viewpoint provides blueprints for these systems' development. The focus is not on the design of these systems, but rather on the identification of different system kinds and the requirements they address. It moreover depicts the interactions and relations to core business processes. Applications are understood as logical groups of functionality which process data objects of the data architecture and support business functions. The description of applications takes place on a logical level, i.e. technology-neutral. Identified applications are relatively persistent over time while technology changes more often. Typical applications in the energy sector are, e.g., Supervisory Control and Data Acquisition (SCADA) systems, although the description of their functionality is quite abstract. Further applications may for instance deal with billing, master data management or planning.

On the other hand, the *Data Architecture* includes the structure of logical and physical data required to exchange information and data management resources. It is concerned with the identification of high-level, enterprise-wide data, i.e. information relevant for business processes, but not with the design or development of data management systems like databases.

This is especially relevant for the understanding of data management, the migration of data, their maintenance and also their quality management. Possible considerations regarding data management can for instance begin with the identification of components relevant for creation, saving or use of data.

In the context of Smart Grids, the information collected in this phase is for instance required in order to exchange customer data, metering data or billing data across several involved Smart Grid actors. Within the energy sector, the *Common Information Model (CIM)*, defined in the IEC standard 61968/61970, is widely used. As a well-elaborated approach it is strongly recommended to incorporate this model in respect of strategic orientation.

4.4.6 Phase D: Technology Architecture

According to the previous phases, a baseline and target architectures are defined based on the identified business goals. The technology architecture is to define the physical aspects of the realization of the information systems architectures and hence the business architecture.

Considering a "complete" realization of the Smart Grid, it has to be determined to which extent the technology architecture shall be developed. Depending on the enterprise's market role, operational technology located in the field, like digital meters, home gateways or substation automation technology, can for instance be considered as "in scope" or be explicitly excluded. However, where the boundary of an architecture is drawn of course depends on the scope of the specific enterprise architecture effort. Through the increasing use of modern ICT, the consideration of operational technologies may yield synergy effects.

Classically, the technology architecture viewpoint describes logical hardware and software capabilities required to provide business, data and application services in the context of the enterprise architecture. As far as these components are involved in the delivery of these functions, they are part of the technology architecture. Again, depending on the scope, only abstractions of these technologies may be sufficient and, for instance, result in the identification of needed standards.

Elements of the technology architecture are, among others, IT-infrastructure, middleware, networks, and communication standards. In the context of standards, it is recommended to incorporate the standards framework given in IEC TR 62357. Further, aspects of legislation and regulation are to be taken into account, as they may prescribe specific technologies. By its character, the technology architecture provides links to implementation and also migration. These tasks is dealt with in the subsequent phases, which are not in the further scope of this chapter.

4.4.7 Requirements Management Phase

Another important task is requirements engineering, which is key to all phases in the TOGAF ADM. Especially in the context of Smart Grids, requirements are not clear or fix, but rather highly dynamic. Thus, requirements and changes to the requirements occur and must be tracked and their impacts be analyzed in all phases. That means, that all requirements must be captured centrally in terms of a defined requirements management and made available to other phases. Requirements are only collected but not prioritized, which is part of the respective phases. The process or documentation for the requirements management phase is not prescribed by TOGAF. For details on requirements engineering approaches in context of Smart Grids, therefore please refer to Chapter 2. Also use cases have proven useful in regarding the elicitation and documentation of requirements. A recommended, energy sector specific method is provided by the IEC specification IEC/PAS 62559 [6]. A use case development and management methodology based on the IEC/PAS 62559 is provided in Chapter 3.

4.5 Conclusion and Outlook

The term *architecture* is often used with different meanings and purposes in mind. Architectures represent abstractions of systems and generally encompass elements and relationships of a system. Each system has an architecture, which is not always documented or explicitly visible. Architecture descriptions try to express systems's architectures from several viewpoints, depending on the architecture stakeholders and their concerns.

A structured development effort can help to address these concerns in the complexity arising with system such as the Smart Grid. One important part of "architecture development" is the definition of architecture descriptions, which is the basis for communication about systems' elements, their planning, implementation or evolution. These descriptions can for instance capture the system's structure or its behavior. Architecture descriptions result in models of the architecture defined with a specific purpose reducing the complexity of the architecture as a whole. These models again can be used define systems or structures thereof in a model-based way. Moreover, architecture models covering different states (e.g., target and baseline) enable analyses and migration planning.

The definition of architectures, i.e. architecture descriptions, is a non-trivial task and is usually carried out in a well-structured process like the TOGAF ADM in the context of an enterprise as the system-of-interest. As architectures are often developed as an envisioned state, respective implementation and governance is required.

In the context of the Smart Grid, there exist various sub-systems having an architecture, ranging from software systems, to hardware, or socio-economic systems like enterprises. However, in order to align these systems in order to inter-operate, well-developed systems are a desirable goal. Architectures can provide helpful abstractions here to define the scope of systems, specifying their elements and relationships.

While foundations regarding architecture development and management are, among others, provided by ISO/IEC/IEEE 42010 [8] or TOGAF [13], their application and tailoring for actors within the power system domain is subject to ongoing research (for more details, see [14]). Figure 4.6 outlines the authors' approach of classification and integration of methodologies and tools for Smart Grid-oriented enterprise architecture development. It shall be briefly described in the following as it may also be used to identify topics of interest related to architecture development within other chapters of this book. In the figure, the need for meaningful orchestration of systems owned by different actors is expressed by the *External viewpoint*. *Artifacts* like reference architectures (e.g., the SGAM mentioned earlier in this chapter), roadmaps concerned with standardization (e.g., [4]) or technology (e.g,. [2], discussed in context of Requirements Engineering in Chapter 2), regulatory provisions and shared use cases (see Chapter 3) may among others be of interest as sources of requirements from the external viewpoint. Existing methodologies (e.g., SGAM or IEC/PAS 62559) regarding these artifacts may be used to gain access to this information. Regarding the application of shared use cases there additionally exists tool support in form of an Use Case Management Repository (UCMR).

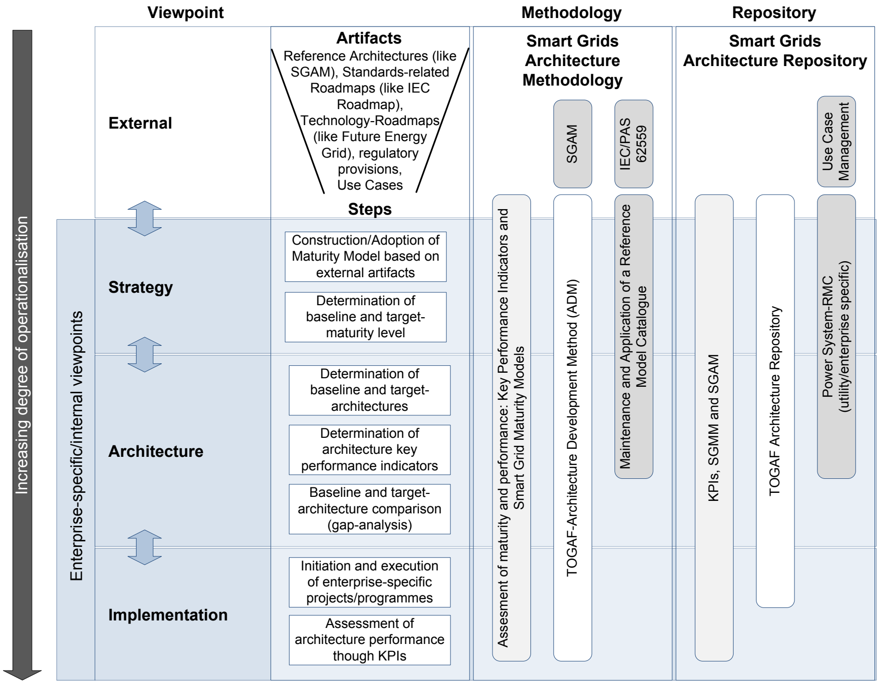

Fig. 4.6 Proposed integration of methodologies and tools regarding Smart Grid-oriented enterprise architecture development

Using a top-down approach, the enterprise's *Strategy* regarding Smart Grid programs represents the first *Enterprise-specific viewpoint*. We propose the construction of a maturity model in order to identify and assess maturity levels regarding technologies, products or business processes relevant to the enterprise in context of Smart Grid implementation. By determining the baseline and target maturity levels the enterprise is enabled to establish a strategic assessment tool. TOGAF as discussed in this chapter may for example integrate the maturity model in context of the architecture vision step of the ADM and use it in context of the migration planning phase to identify suitable transition architectures. The TOGAF Architecture Repository (see [13]) and the application of a Power-System-specific Reference Model Catalogue (as discussed in Chapter 5) provide the means to structure and preserve the information needed in this process.

Based on knowledge gained from the Strategy view, baseline and target architectures can be derived in the context of the *Architecture* viewpoint. The levels of maturity identified in context of the Strategy viewpoint are refined into architecture key performance indicators (KPI). These provide impartial criteria to analyze the gaps between baseline and target architecture and shall be used in context of the *Implementation* viewpoint to assess the current architectures performance.

Like in the ADM, this holistic perspective on enterprise architecture development should be elaborated iteratively with respect to the interdependencies between the viewpoints and their views' elements. While architecture descriptions represent an abstraction from both, business and implementation needs, valuable requirements originate from these perspectives.

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