A model for documenting architectural decisions

María Luciana Roldán, Silvio Gonnet, and Horacio Leone

INGAR (UTN-CONICET), Facultad Regional Santa Fe
Universidad Tecnológica Nacional
Santa Fe, Argentina
{lroldan, sgonnet, hleone}@santafe-conicet.gov.ar

Abstract. A software architecture is the result of architectural design decisions. Documenting a software architecture should not only describe the final model, but also why the architecture looks as it does. During the software architecture design process, several decisions are made, which need to be captured and documented in a systematic way to prevent knowledge vaporization and high architecture' costs of change. In this work, a model for capturing, documenting and recovering architectural design processes and their underlying design rationale is proposed. The design process is envisioned under an operational perspective, where design decisions are represented as sequences of operations. Besides, the model is extensible to manage several design products types from different domains and views, including aspects of architectural rationale. Complementary, the proposal provides a semi-automatic mechanism for generating architectural rationale documents based on the use of templates.

Keywords: architecture documentation, design rationale, design decisions

1 Introduction

Software architecture design process (SADP) comprises the early decisions to achieve the quality and functional requirements and constraints of a complex system [1]. Traditionally, software architectures have been described from structural and behavioral points of view as a set of interconnected software components. However, in the last years there has been a shift towards regarding software architecture as the composition of a set of architectural decisions and their rationale [2, 3, 4, 5]. Kruchten et al. [6] have joined these two dimensions of software architecture in the concept of Architectural Knowledge (AK), providing the formula: AK = Architectural Design + Architectural Decisions.

Designers, architects and other stakeholders have recognized the importance of documenting design decisions and rationale, and not only capturing the final architectural artifact but also the design decisions that generated it [7]. However, surveys have revealed difficulties in capturing and exploiting the design rationale: the practice of documenting AK has not been widely spread and adopted due to some inhibitors, such as the overhead imposed on the designer due to the required documentation effort. In practice, AK documentation is considered a resource-intensive process with-

adfa, p. 1, 2011.

out tangible (short-term) gains for the documenters themselves, reason why is often skipped or performed inadequately [8]. Documenting AK is traditionally considered an activity supplementary to architecting, thus typically, someone documents what the architect has decided after-the-fact [9].

Consequently, there is an imminent necessity of enhancing the architecting process with effective ways of AK documentation. We propose a model that captures each decision made in a SADP along with their resulting products and the rationale that supports them, and makes possible the tracing of the history of the design process. The model is extensible to permit working with several domains and representing software architecture models with elements from different architectural views, including reasoning aspects. To get higher benefits from the captured design decisions and their results, a mechanism for semi-automatically architectural rationale documentation is proposed.

The rest of the paper is structured as follows. In Section 2, the model for capturing and tracing SADP is described. Furthermore, we define a general software architectures domain, which includes design object types and operations relative to design rationale. Next, in Section 3, we propose a mechanism to automatically documenting design rationale. In section 4, a case study is developed to illustrate the proposed approach. Finally, in the last section, we compare this approach to related work and share some conclusions.

2 A model for capturing and tracing SADP

The proposed model is envisioned under an operational perspective, where design decisions are materialized as the execution of design operations, which are applicable to specific design object types. This scheme considers the SADP as a series of design decisions that transforms the products (or *design objects*) of the design process. Typical design objects are the structural elements of the artifact that is being designed (i.e. the components and connectors that comprise a software architecture), and the specifications to be met (i.e. quality requirements such as modifiability or performance). Naturally, these objects evolve as the SADP takes place, giving rise to several versions that participate in several model versions. A model version describes the state of the design process at a given point in the design process.

The capabilities of the proposed model for saving SADP design decisions are based upon a versioning scheme (Fig. 1) that capture all the executed operations and generated design objects. That versioning scheme has the necessary elements for representing the evolution of design objects during an architectural design project. Design objects are represented at two levels, the *repository* and the *versions' level*. The *repository* level keeps a unique entity for each *design object* that has been created and/or modified during a design project. This object is called *versionable object*. Associations among the different *versionable objects* are hold in the repository to represent the configuration of the architectural model (*Association*, Fig. 1). The *versions' level* keeps the different versions of each *design object*, which are called *object versions*. The relationship between a *versionable object* and its *object versions* is represented by the *version* association.

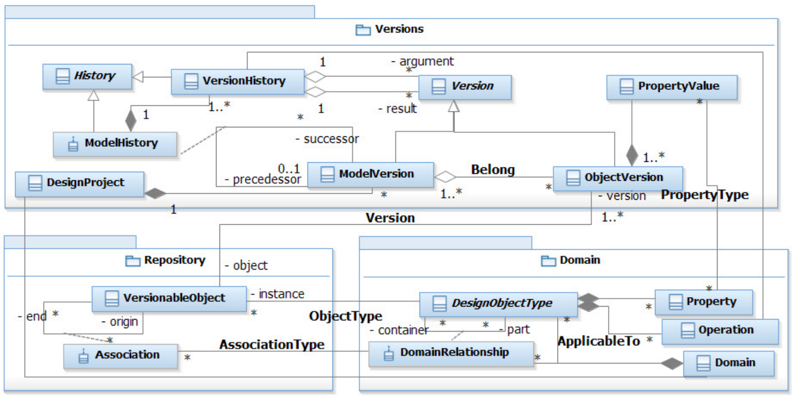


Fig. 1. Versioning scheme

Therefore, a *design object* keeps a unique instance in the *repository* and all the versions it assumes in different model versions belong to the *versions' layer*. Under this operational perspective, the evolution of an architectural model is posed as a history made up of discrete situations, where a new model version is generated by applying a *sequence of operations* (ϕ) on a *predecessor model version*, which generates a *successor model version*.

Domain Package (Fig. 1) enables defining the types of design objects, whose instances are going to be maintained in a given SADP. *Design object types* represent concepts of a domain and have properties specified by a set of instances of *Property* class. The possible relationships among the different *design object types* of a domain are instantiated from *DomainRelationship* class. Particularly, associations between design objects at repository level are instances of a given type of domain relationship.

In this approach, each sequence of operations is applied to a *model version* to transform it in a new model version. The sequence of operations is captured by means of a *model history* link, and each executed operation is represented by a *version history* link that keeps references among the *object versions* on which the *operation* was applied and the ones arising as a result of its execution. As it is shown in Fig. 1, a *ModelHistory* link aggregates various *VersionHistory* links, one for each operation in the sequence of operations.

Before starting a design process, an expert defines a domain or selects an existent one. Since there is no universal architectural design language, it is not possible to establish an "a priori" domain model covering all the possible information items, work processes, and relations that may be applicable in different design projects and situations. Therefore, the domain model is adapted to each particular design problem, including concepts suitable for the employed design method, the preferred approach for representing architectural views, the chosen design language, and the system domain. In a previous work [10], a conceptual software architecture domain model was proposed, regarding several concepts taken from the Attribute Driven Design method [1] for designing architectures. This method follows an iterative decomposition and proposes describing an architecture by means of several views [11]. Views are a representation of the system from a perspective of a related set of concerns, called *viewtype*. Therefore, a viewtype is a specification of the conventions for constructing and using a view, thus it determines the languages to be used to describe a view, and any associated modelling methods or analysis techniques to be applied to the representation of the view. The concept of *viewtypes* (but named *viewpoints*) is also regarded by the IEEE 1471 Standard the architectural description of software-intensive systems [12]. Examples are *Module*, *Component-and-Connector* and *Allocation*.

A possible SADP domain is presented in Fig. 2, which comprises elements from *Components-and-Connector* (*C&C*) and *Allocation* viewpoint. *C&C* viewpoint mainly focuses in the division of responsibilities and behaviour of the components of a software architecture and how they are interrelated. Design object types that are included are *Component*, *Connector*, *Port*, *Role* and *Attachment. Characteristic* and *Responsibility* design object types are included to represent some relevant properties and the behaviour of components and connectors. *RHasResponsibility* is a domain relationship that represents a link between a responsibility and the component.

RHasResponsibility has been reified as a design object type to enabling defining properties like *assignedBy* property, to represent who is the actor responsible of assigning or delegating a responsibility to a component. The domain under definition can be extended with concepts from *Deployment* viewpoint, a kind of *Allocation* view, which is useful for describing how software elements of a software architecture interact with non-software elements in the environment in which the software is deployed or executed, like *ProcessingNode* and *Network* [10].

The flexibility of the model allows us to define design object types for representing architectural design rationale (Fig. 3). These new elements are associated to other design object types relative to structure, behaviour and deployment of the software architecture model (*ArchitecturalElement* abstract design object type, in Fig. 3). A first set of design object types to support design rationale is also derived from some aspects of ADD method. ADD is based on a decomposition process, where architectural patterns are chosen to fulfill certain *requirements.* The inputs to ADD are *quality requirements* that are expressed as a set of system specific *quality scenarios*, *functional requirements* that are translated into a set of *responsibilities* that are assigned to components, and *constraints*.

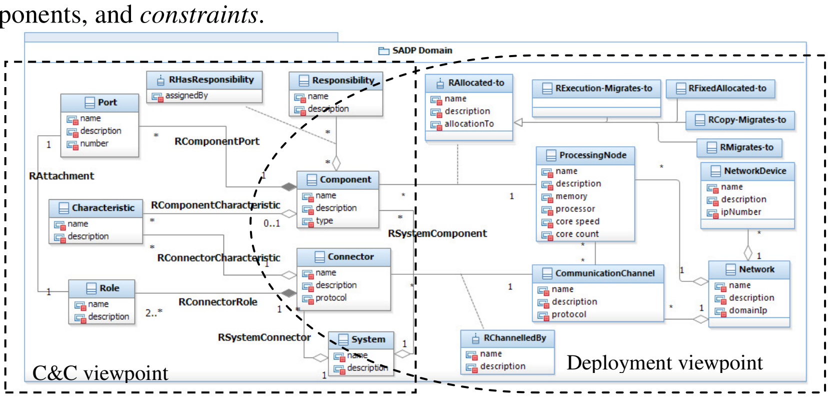


Fig. 2. Partial SADP domain with elements of C&C and Deployment viewpoints

ADD prescribes that at the end of an iteration, designers should assess the level of achievement of the architectural model to a given *quality scenario* (how close is the architecture model of achieving a requirement). For that reason *Assessment* design object is included as a domain concept. Also, *Constraint* type explicitly represents rules or conditions imposed on the architecture model, as well as *Assumption* design object type represents something that is taken for granted in the design process.

Other concepts included in the domain to represent design rationale are: *Alternative*, to represent possible directions in which the architecture of the intended system could be obtained, and *Argument*, useful for expressing the reasons that are advanced-for or against-to an alternative.

Design object types for rationale enables a designer to make explicit certain knowledge for explaining or rationalising an architectural model. In this way, explicit rationale object versions (such as requirements, assumptions, and arguments) can be added to the software architecture model and be associated to other architectural elements (like behavioural or structural versions). Therefore, SADP domain also includes suitable domain relationships to link architectural model elements and rationale elements. Examples of reified domain relationships are *RRegardsAssumption* and *RConstraintsTo*. *RTradeOff* is useful to express the existence of a trade-off between two quality requirements (when the achievement of one quality requirement is in detriment of the achievement of another, and vice versa). Moreover, *RSupportsArgument* and *RRejectsArgument* enable associating a set of *architectural elements* and the *argument* that justifies or rejects the presence of those elements in a given architectural model. Other relationships in the domain are *RSystemAlternative*, *ROppossiteTo*, and *RSimilarTo*, whose meaning is quite intuitive from Fig. 3.

To explicitly represent designer's intentions in a model version, suitable design object types can be included in the domain (Fig. 4). *RPossibleScenarioSolution* associates a *quality scenario* and *architectural elements* that are the results of an operation, indicating that the pursued goal of that operation is a given quality scenario. Similarly, *RConsidersConstraint* enables expressing that an architectural design (or a portion of it) fits to a particular *constraint* that is imposed on the system.

As it was introduced, domain operations are intended to transform the design products of a SADP, thus generating new versions, modifying or eliminating other ones. To transform *model versions*, the scheme provides a set of primitive operations: *add*, *delete*, and *modify* (specializations of *Operation* class, in *Domain* package of Fig. 1).

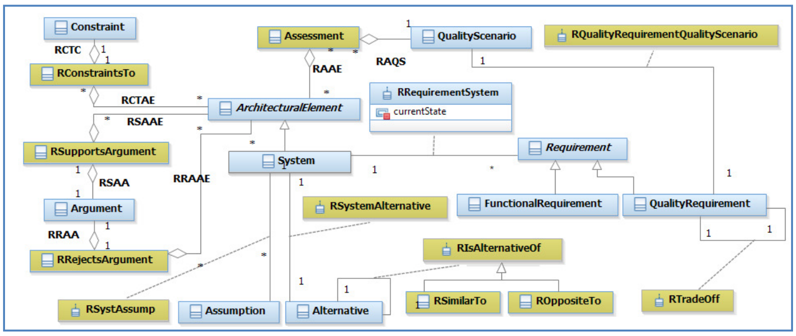


Fig. 3. Extending SADP domain with design rationale object types

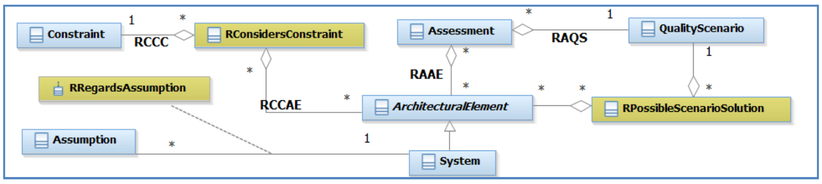


Fig. 4. Design object types to support designer intentions

By using the *add* operation, an *object version* that did not exist in a previous *model version* can be incorporated into a successor *model version*. Conversely, the *delete* operation eliminates an *object version* that existed in the previous *model version*. In addition, the *modify* operation creates a new *version* of a given version of a *design object*. When a sequence of operations is applied on a model version, a new model version is generated and an architectural design decision is materialized. Since primitives *add*, *delete* and *modify* are not enough to represent adequately high level design decisions, it is necessary to provide the model with capabilities for defining and executing complex operations for the SADP domain, which is provided by the elements of *Operations package* (Fig. 5). The central class in *Operations* package is the *command* abstract class. An *operation* is defined as a *macrocommand*, which is a command that executes a sequence of commands and can be applied to a specific design object type (*ApplicableTo* association). On the one hand, an operation requires defining its input *arguments*. *DataType* abstract class generalises the types of arguments supported by the model. On the other hand, an operation requires a list of subcommands that forms its *body*. The body can be primitives, auxiliary functions, and other operations from the same domain. Auxiliary functions are pre-built functions like *Iteration*, *VariableAssignment*, recovering and selection of elements (*Get* and *Select*), etc. *AddAssociation* is a function to set associations between versionable objects at repository level. To make possible the execution of operations, the *operations model* is integrated to the *versioning scheme* (Fig. 1) that provides the elements for capturing the execution of sequences of operations. Each particular operation executed in the sequence is captured by a history link (*VersionHistory*), which also keeps the *argument* values and the resulting versions (*result*). A *model history* link may also save information like date/time when the sequence was executed and the actor who made the decision.

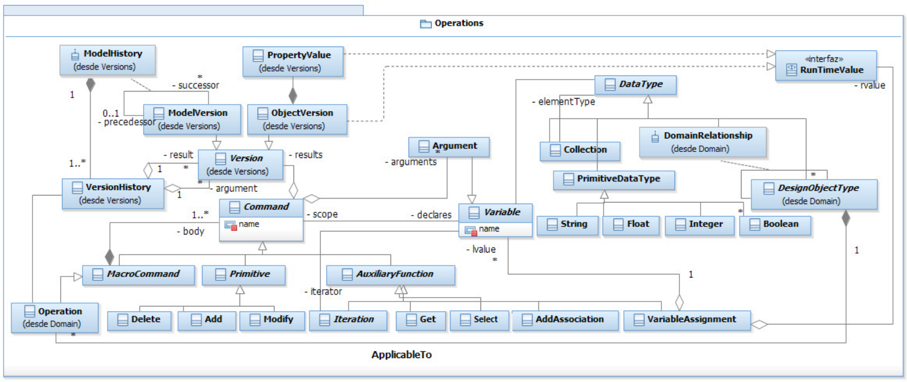


Fig. 5. Operations Package.

By instantiating the Operations model, a set of operations can be defined for manipulating design object types. The model is flexible for defining operations with different abstraction level, so they can be as basic as *addComponent*, or as complex as the operations that apply an architectural pattern or a tactic [1]. Fig. 6 shows some basic operations. The body of each operation is defined in terms of primitive operations like *add*(*np*, *Port*, l_{props}) in *addPort* operation, and non-primitive ones, like *addPort*(*c*, *np*, *[]*) in *addComponent*. The header of an operation indicates its name and its required arguments and types (enclosed in brackets). For example, the arguments of *addComponent* operation are: *s* (the system in which the component is going to be added), *nc* (the name of the component to add), l_{Resps} (a collection with the names of the responsibilities of the component), l_{Ports} (a collection with the names of the ports of the component), and l_{Props} (a collection with the values of the *properties* of the component). The operation incorporates a component *c* to a system. Then a set of responsibilities (l_{Resps}) and ports (l_{Ports}) are inserted using an *iteration*, which is syntactically expressed by means of "*for each … in …*" sentence. Finally, resulting design objects are associated at repository level in correspondence with the rules of domain relationships, by means of the auxiliary function *addAssociation*.

Architectural design patterns are more complex and higher level operations, as they represent well known and recurring design solutions. In Fig. 6, *applyMVC* operation encloses the knowledge of *MVC* pattern. The operation generates a topological configuration that fits to the MVC architectural pattern. The new architectural elements are: *View*, *Model*, and *Controller* components, their ports (*'V-P1'* and *'V-P2'* for View; *'M-P1'* and *'M-P2'* for Model; and *'C-P1'* and *'C-P2'* for Controller), and the connectors between them ('*ConnModView*', '*ConViewCtrlr*', and '*ConModCtrlr*') with their respective roles. Since the original component (*c* argument) is refined by the operation, its responsibilities must be delegated to the new components (*delegateResponsibility* operation). In addition, *Get* and *Select* auxiliary functions are used.

```
addComponent(s: System, nc: String, lResps: Collection[String],
lPorts: Collection[String], lprops: Collection[PrimitiveDataType])
c:= add(nc, Component, lprops)
for each nr in lResps
  addResponsibility(c, nr, [ ])
end for
for each np in lPorts
  addPort(c, np, [ ])
end for
  addAssociation(s, c, RSystemComponent)
end
```

```
addPort(c: Component, np: String,
 lprops: Collection[PrimitiveDataType])
        p := add(np, Port, lprops)
        addAssociation(c, p, RComponentPort)
end
```

```
addResponsibility(c: Component, nr: String,
                  lprops: Colección[TipoDeDatoPrimitivo])
        r := add(nr, Responsibility, lprops)
        rtr := add(null, RHasResponsibility, [ ])
        addAssociation (c, rtr, RCompRTR)
        addAssociation (rtr, r, RRTRResp)
end
```

```
applyMVC(c: Component)
  s := get(System, c)
  view := addComponent(s, 'View', ['V-P1', 'V-P2'], [])
  controller := addComponent (s, 'Controller', ['C-P1', 'C-P2'], [])
  model := addComponent (s, 'Model', ['M-P1', 'M-P2'], [])
  modVista := addConnector(s, 'ConnModView',
['MV-R1', 'MV-R2'], get(Port, model(0)) • get(Port, view(0)), [])
  viewCtrlr := addConnector(s, 'ConViewCtrlr', ['VC-R1', 'VC-R2'],
              get(Port, view(0)) • get(Port, controller(0)), [])
  modCtrlr := addConnector(s, 'ConModCtrlr', ['MC-R1', 'MC-R2'],
              get(Port, model(0)) • get(Port, controller(0)), [])
  delegateResponsibility(c, model(0))
  delegateResponsibility (c, view(0))
  delegateResponsibility (c, controller(0))
(cont.)
// Connections are reattached with new components
  lpc := get(Port, c) // ports of the refined component
  lps := get(Port, null) // all ports in the system
  for each p in lpc
    np := select(lps)          // ask the user for the new port
    r := get(Rol, p)           // get the role of the former port
    addAssociation(np, r, RConnection)
  end for
  deleteComponent(c) // the original component is deleted
end
```

Fig. 6. Specification of some basic operations and an architectural pattern

Since we count with design rationale related types, the SADP domain can be extended with operations to make explicit certain designer's intentions and supporting rationale information (Fig. 7). A straightforward way of capturing intentions is defining operations with an additional argument for indicating the goal the architect is trying to achieve at the moment of executing them. The effective value of a goal argument can be a *quality requirement* to be satisfied, a *scenario* to be approached, a *constraint* to be considered, an *assumption* to be regarded, etc. In this way, the previously defined design operations (Fig. 6) can be specified regarding the goal to be reached. For example, *applyMVC-go* operation (Fig. 7) aims to achieve a given quality requirement. In the operation specification that is expressed by associating the resulting versions of *applyMVC* execution with a selected scenario of the intended requirement (*goal*), by means of *assignPossibleScenarioSolution* operation. Additionally, *deleteConnector-go* operation (Fig. 7) enables capturing the knowledge for expressing that the argument connector (*c*) is eliminated because the constraint (*g*) has been considered.

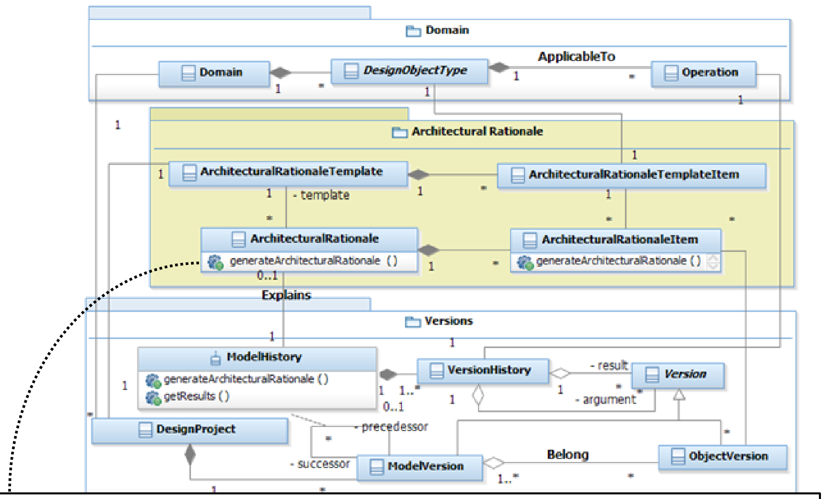
3 Mechanism for Documenting Architectural Rationale

In this section, a complementary documentation mechanism is proposed, which organizes the captured knowledge in a structured document. This mechanism considers an applied "sequence of operations" as an "architectural design decision", which is captured by a *model history* link. The mechanism consists on: i) generating an *architectural rationale* (AR) object from the captures of the model evolution each time a design decision is made, and ii) attaching that AR object to the *model history link* that captured the applied sequence of operations.

AR objects are instances of *ArchitecturalRationale* class, which is related to *ModelHistory* class with a one-to-one association (*Explains* association, in Fig. 8). An AR object can be considered as a structure formed by several fields, in which each field keeps some information about a particular item. The format of such object is inspired on various templates for documenting decisions and rationale about software architectures [2, 4]. These templates have a fixed number of mandatory fields that should be filled, but our proposal enables tailoring the items of the template to the documenting needs of the specific project. Examples of items of an AR object are: "elicited requirements for a system", "pursued scenarios", "imposed constraints", "arguments in favour of the decision", and "arguments against the decision".

applyMVC-go(c: Component, g: QualityRequirement) lres := applyMVC(c) ls := select(get(Scenario, g)) for each s in ls assignPossibleScenarioSolution (s, null, lres) end for end	**deleteConnector-go(c: Connector, g: Constraint)** s := get(System, c) deleteConnector(c) considersConstraint(null, g, [s], []) end
assignPossibleScenarioSolution(npss: String, sce: QualityScenario, versionsList: [ArchitecturalElement]) pss := add(npss, RPossibleScenarioSolution) addAssociation(sce, pss, RPSSQS)	**(cont.)** for each v in versionsList addAssociation(pss, v, RPSSAE) end for end

Fig. 7. Specifications of goal-oriented operations




```
ModelHistory::generateArchitecturalRationale(){
  ar := new ArchitecturalRationale(this.predecessor.project.architecturalRationaleTemplate, self);
  ar.generateArchitecturalRationale();}
ArchitecturalRationale::generateArchitecturalRationale(){
  for each i in architecturalRationaleItem
    i.generateArchitecturalRationale();}
ArchitecturalRationaleItem::generateArchitecturalRationale(){
  resultsList := architecturalRationale.getModelHistory.getResults();
  for each r in resultsList {
    if (r.type() is architecturalRationaleTemplateItem.designObjectType) {
      architecturalElements := r.getAssociatedArchitecturalElements(getCurrentModelVersion());
      architecturalRationaleElements :=
                   r.getAssociatedArchitecturalRationalElementos(getCurrentModelVersion()); }}}
ModelHistory::getResults(){
  results := new List;
  for each vh in this.getVersionHistoryList {
    results.add(vh.results);  }
  return results;}
```

AR documentation mechanism

Fig. 8. Architecture rationale documentation model

An *AR template* is constituted by different *AR template items* (represented in Fig. 8 by the aggregation between *ArchitecturalRationaleTemplate* and *ArchitecturalRationaleTemplateItem* classes). Each *AR template item* is associated to a given *design object type* to indicate the type of object versions that will provide the necessary information to fill that item. When starting a new SADP project, the documenting preferences for each model evolution should be defined by instantiating *ArchitecturalRationaleTemplate*.

Fig. 8 also presents the mechanism for generating architectural rationale objects, which is implemented as the method *generateArchitecturalRationale* of *ModelHistory* class. The first step of *ModelHistory::generateArchitecturalRationale* method is constructing an empty instance of *ArchitecturalRationale* (*ar*) based on the template that has been defined for the current project (*new* operation). Then, the *ar* object is linked to the *model history* that represents the model evolution (*self* in *generateArchitecturalRationale* method). The following action is obtaining the information to fill in each *item* of the *AR* object (*ArchitecturalRationale*::*generateArchitecturalRationale* method), which delegates to the items the responsibility of obtaining the pertaining information for filling in itself. Thus, each item performs *ArchitecturalRationaleItem*:: *generateArchitecturalRationale* method. *ArchitecturalRationale-Item*::*generateArchitecturalRationale* method, shown in the pseudocode of Fig. 8 is repeatedly executed by each item of the architectural rationale object. The first action of that method consists on recovering all the resulting object versions generated by the execution of the sequence of operations that caused the model evolution that is being documented (see *ModelHistory::getResults()* method). By means of *getResults()* method, the resulting object versions of the sequence of operation are obtained and assigned to the variable named *resultsList*. Then, a loop takes place on *resultsList*, which for each element checks whether its type matchs to the type of the wanted *designObjectType* indicated by the AR *template item*. In this case, two actions are carried out regarding the current element in the iteration (*r*). First, all the object versions whose type is a subtype of *ArchitecturalElement* abstract type that are related to *r* (by means of inferred repository associations) and belong to the *current model version* are saved as the architectural elements that are influenced by *r* (*getAssociatedArchitecturalElements* operation, whose results are assigned to the *architecturalElements* variable). Second, all the object versions whose type is a subtype of *ArchitecturalRationaleElement* abstract type that are related to *r* and belong to the *current model version* are saved as the rationale elements that explain the reason of the existence of the previous ones (thus, the *architecturalElements*). This is observed in *getAssociatedArchitecturalRationaleElements* operation, whose results are assigned to *architecturalRationaleElements* variable. These results together with the *r* version constitute the captured information about this particular item in that model evolution. The information can be saved as references to the involved object versions or may be converted to text to create a printable document.

Table 1 offers some examples about how a template should be configured to obtain interesting design rationale information for documenting a software architecture design process. It should be noted that the information is gathered from the object versions that belong to the current model version, since an architectural rationale object documents a model evolution that is generated when that evolution occurs. It should be also noted, that the configuration of the template depends on the design object types included in the domain and relationships defined among them, and finally the preferences of the designers.

4 Case Study

The proposed model has been implemented in a software prototype named TracED [10], which allowed us to carry out several case studies. In this section, we introduce a case study that resembles the design process of architecture of Apache Struts, a free open-source framework for creating Java web applications. Struts is mainly based on the Model-View-Controller architectural pattern and its design process was conducted by following the ADD method [1]. The first decision of the designer is materialised in the first sequence of operations (ϕ_1 = { addSystem('*Struts*') }), which is applied on the *Root Model Version* (an empty model version) and comprises an *addSystem* operation. The effect of that execution operation is creating the first object version of the architectural model that represents the system whose architecture is going to be designed (*V1Struts* object version).

Then, for this system the designer defines the quality requirements that should be considered for the intended architecture: *Modifiability* and *Testability*. He or she identifies also a set of functional requirements and a constraint to impose on the system (*WebEnvironment*). *WebEnvironment* constraint is about the context where the future application is going to run, which means that the connections between servers and clients are "stateless", thus the server does not maintain the state of connections.

Table 1. Examples of possible items of an architectural rationale template

Item Name	AR Element Type	Source Design Object Type	Description
Elicited requirements	Requirement	RRequirement-System	The content of this item is obtained from all the *requirement* versions added to the model during the applied sequence of operations in the last model evolution.
Elicited scenarios	QualityScenario	RQualityRequirementQualityScenario	The content of this item is obtained from all the *scenario* versions added to the model during the applied sequence of operations in the last model evolution.
Regarded assumptions	Assumption	RRegardsAssumption	The content of this item is obtained from the resulting object versions whose type is *RRegardsAssumption*, which have been generated in the last applied sequence of operations. Navigating through their associations, it is possible recovering the object versions belonging to the current model version that represent *assumptions* and *system.*
Imposed constraints	Constraint	RConstraintsTo	The content of this item is obtained from the resulting object versions whose type is *RConstraintsTo*, and finding their associated object versions that belong to the current model version. The associated architectural elements could be a system or a portion of a system (a set of object versions).
Regarded constraints	Constraint	RConsidersConstraint	The content of this item is obtained from the resulting object versions whose type is *RConsidersConstraint*. Beginning from that version, the *constraint* and the associated versions are recovered. These associated versions have been included in the model having into account the constraint. In case of having deleted versions for accomplishing the constraint, the container version is the associated version.
Quality requirement approaching	QualityRequirement	RPossibleScenarioSolution	The content of this item is obtained from all the *RPossibleScenarioSolution* versions added to the model during the applied sequence of operations in the last model evolution, which are related to the scenarios for a given *quality requirement.*
Arguments in favour of a decision	Argument	RSupportsArgument	The content of this item is obtained from the resulting object versions whose type is *RSupportsArgument*. Beginning from that version, the associated *argument* version is obtained and also the object versions that represent the architectural elements that are consequence of the decision.
Arguments against a decision	Argument	RRejectsArgument	The content of this item is obtained from the resulting object versions whose type is *RRejectsArgument*. Beginning from that version, the associated *argument* version is obtained and also the object versions that represent the resulting architectural elements.

The designer incorporates these requirements and constraints by applying a ϕ_2 sequence of operations on *Model Version 1* (ϕ_2 = { addQualityRequirement(V1Struts, '*Modifiability*', ['*It should be easy to perform changes to the system. The structure and the flow of the application should be clearly defined in order to make its understanding and modification easier. System's modules should be low coupled.*']), addQualityRequirement(V1Struts, '*Testability*', ['*The features of the system should be extended, enhanced, or corrected easily, by avoiding bugs caused by unexpected impacts of changes introduced in code. Also refers to the easy way in which the software can demonstrate its faults through (typically execution-based) testing*']), addFunctionalRequirement(V1Struts, '*BusinessLogic*', ['*The entire features related to the business logic that the systems should support.*']), …, …, …, addConstraint(V1Struts, '*StatelessConection*', ['*In a Web environment there is no record of previous interactions between servers and clients. Each interaction request has to be handled based entirely on information that comes with it.*']) }). The resulting model version is *Model Version 2*.

The next designer's decision is focused on translating the proposed quality requirements into measurable elements, to evaluate how close the architecture is of achieving the requirements. Therefore, for each *quality requirement* some *quality scenarios* are proposed, by means of applying ϕ_3 sequence of operations on *Model Version 2* (ϕ_3 = { addScenario(V1Testability, '*ScTestability1*', ['*Writing and running a unit test for a specific business logic component takes at most 1 person-hour. The test methods exercise the class to be tested, and verify that such a class behaves as it is expected.*'], addScenario(V1Modifiability, '*ScModifiability1*', ['*A functional requirement changes, which means that certain functions of the business logic has to be modified. The implementation of the required changes and the tests are completed in 1 day.*']) }). The resulting model version is *Model Version 3*. The designer continues the design process by incorporating to the model elements related to the structure and the behaviour of the architecture (ϕ_4 = { addComponent(V1Struts, '*WebApplication*', ['*RSubmitRequest*' , '*RRequestHandling*', '*RValidate*', '*RControlActions*', '*RDataPreparation*', '*RSendResponse*', '*RDBAccess*', '*RBusinessLogic*', '*RViews*'], [ ]) }). Therefore, a first component named *WebApplication* and its responsibilities are added by means of an *addComponent* operation, thus obtaining *Model Version 4*.

At this point of the design process, the designer gives a higher priority to *Modifiability* quality requirement. Therefore, the architect considers it is convenient applying Model-View-Controller (MVC) architectural pattern as it is a recurring solution for achieving such quality requirement. Therefore, the next sequence of operation (ϕ_5 = { applyMVC-go(V1WebApplication, *Modifiability*) }) comprises *applyMVC-go* operation, which refines *WebApplication* component in a set of components and connectors, with follow an MVC configuration and have the properties and responsibilities that the style prescribes. It should be noted, that *Modifiability* is the effective argument for the goal-oriented operation. As a result, *Model Version 5* is obtained, where *Model*, *View*, and *Controller* have been included as components of the *Struts* system. These components are communicated by means of *ConnViewCtrlr*, *ConnModCtrlr* and *ConnModView* connectors that represent the interactions among them (*V1ConnViewCtrlr*, *V1ConnModCtrlr* and *V1ConnModView* object versions). Given that *applyMVC-go* is a goal-oriented operation, as a consequence of its execution a series of links are set among the resulting object versions and the intended quality scenario that is related to *Modifiability* quality requirement. In this way, the intention of the designer for satisfying *Modifiability* requirement is captured, as well the portion of the architectural design to (possibly) achieving that.

Proceeding in the Struts' design process, the designer focuses now in the *WebEnvironment* constraint (*V1 WebEnvironmentConst*). This constraint precludes the *Model* of notifying to the view of changes, which in a Web environment means that the client (a browser) has to re-query the server to discover modification to the state of the application. To make the architecture complaint with this constraint, the designer decides to relax the MVC architecture by deleting the *ConnModView* connector (*V1ConnModView* object version). That decision is materialised in a sequence of operations ϕ_6 that includes *deleteConnector-go* operation (ϕ_6 = { deleteConnector-go(V1ConnModView, *V1WebEnvironmentConst*) }). The last argument of such an operation (*V1WebEnvironmentConst*) indicates the considered constraint. As it was presented in Fig. 7, such an operation adds an *RConsidersConstraint* object version that links the container of the deleted connector (*V1Struts*) and the considered constraint (*V1WebEnvironmentConst*), with the aim of explicitly expressing that the constraint has been considered and the architecture fits to it.

The architect continues the design process by refining the current components, and deploying them in specific network nodes. When the designer evaluates the architecture model and finds out that the scenarios have been satisfied, the design process ends.

Several queries can be placed to recover the architectural knowledge kept by all the captures. Some examples of queries are: *By means of which design operations model version 5 was obtained*? *Which are the alternative model versions of Model Version 5? How did the WebApplication component change along the design process? Which design operations have the designers applied with the intention of addressing Modifiability requirement? Or conversely, why did the architect execute an applyMVC-go operation? Which were the new products generated because of the execution of addComponent in the sequence of operations ϕ_4?*

Additionally, the knowledge obtained by the previous queries can be complemented with the *AR* objects that were generated for each sequence of operations applied during the design process. For example, AR object in Fig. 9 documents the decisions made in the evolution from *model version 4* to *model version 5.* We suppose that in this project an *AR template* was defined with the *items* in Table 1, and for presentation purposes only items with relevant information are shown. The description item has been manually completed by the designer, but the rest of the items have been automatically filled by the documenting mechanism. Moreover, consecutive model evolutions can be grouped, thus merging *AR objects* in a single documenting object. For instance, AR object in Fig. 10 documents the fragment of design process from the *Initial Model Version* to *Model Version 4*.

5 Conclusions

In this article, we have introduced a model for capturing and tracing the software architecture design process. The proposed approach considers the SADP as a composition of design operations that operate on design products. An architectural design process is documented from the captures of the executed design operations and their results, which fits within the natural course of architecting, without introducing an additional burden for the software architects and developers. The model has two main aspects regarding AK documentation.

ARO – 0001 (from *model version 4* to *model version 5*)

Item Name	Quality requirement approaching
AR Element	*V1Modifiability*
Source Design Object	*RPossibleScenarioSolution* versions
Resulting Object Versions	*V1Model, V1View, V1Controller, V-P1, V-P2, C-P1, C-P2, M-P1, M-P2, ConnModView, ConViewCtrlr, ConModCtrlr, MV-R1, MV-R2, VC-R1, VC-R2, MC-R1, MC-R2*
Description	*applyMVC-go was executed to satisfy a scenario related to Modifiability quality requirement. The level of satisfaction should be assessed.*

Fig. 9. AR object for documenting a evolution

ARO – 0002 (from the *initial model version* to *model version 4*)

Item Name	Elicited requirements
AR Element	*V1Modifiability*
Source Design Object	*RRequirementSystem* version
Resulting Object Versions	*V1Struts*
Description	*The software architecture of the system must satisfy quality requirements of Testability and Modifiability*

Item Name	Elicited scenarios
AR Element	*V1Modifiability*
Source Design Object	*RQualityRequirementQualityScenario* version
Resulting Object Versions	*V1ScModifiability, V1ScTestability*
Description	*For each quality requirement proposed for the system, quality scenarios are proposed, which allow the designer an easy evaluation of the architecture model.*

Item Name	Imposed constraints
AR Element	*V1WebEnvironmentConst*
Source Design Object	*RConstraintsTo* version
Resulting Object Versions	*V1Struts*
Description	*A constraint is imposed on the system, which is derived from the context where the system is going to run*

Fig. 10. AR object for documenting evolution from the *initial model version* to *model version 4*

On the one side, it enables the definition of several domains (design object types + design operations to manipulate them), which encloses a portion of AK like basic synthesis activities, well known architectural patterns and tactics, and goal-oriented operations. On the other hand, the execution of sequences of operation materialises the design decisions of the architect at each point in the design process, and, in some cases, which are the intentions of the designer. Captures of made design decisions maintain the performed operations, the effective arguments and resulting products, thus representing another great portion of AK documentation. To enrich and extend the AK generated in each model evolution, a mechanism for semi-automatic documentation is proposed. It aims to reducing the effort of AK producers, thus, helping them to fill templates to document architectural decisions. Several approaches have been proposed for documenting architectural design decisions [1, 3, 5, 6, 8, 9]. Some of them are based in the use of templates with attributes to represent architectural design decisions, like the one of [2, 4].

Despite of the benefits of the proposal on capturing and documenting SADP as the process takes place, the approach has some limitations. The main restriction is inherent to the size of the repository that keeps all the design operations performed and versions generated during an architectural design process. A way of diminishing the problem is the definition of high-level operations, which encapsulate complex decisions (that could comprise dozens basic operations in just one operation). It must be also stated, that in order to obtain advantages of the model, it should be integrated to other architectural design tools.

Acknowledgments

The authors wish to acknowledge the financial support received from CONICET, Universidad Tecnológica Nacional and Agencia Nacional de Promoción Científica y Tecnológica (PAE PICT 02315).

References

1. Bass, L., Clements, P., Kazman, R.: Software Architecture in Practice, Second Edition. Addison-Wesley, Boston, MA (2003)
2. Tyree, J., Akerman, A.: Architecture Decisions: Demystifying Architecture, IEEE Software 22(2), 19-27 (2005)
3. Jansen, A., Bosch, J.: Software Architecture as a Set of Architectural Design Decisions. In: Proceedings of the 5th IEEE/IFIP Working Conference on Software Architecture, pp. 109-120 (2005)
4. Babar, M. A., Gorton, I.: A Tool for Managing Software Architecture Knowledge. In: Proceedings of the Second Workshop on Sharing and Reusing Architectural Knowledge Architecture, Rationale, and Design intent. International Conference on Software Engineering. IEEE Computer Society, Washington, DC, 11(2007)
5. van Heesch, U., Avgeriou, P., Hilliard, R.: A documentation framework for architecture decisions. Journal of Systems and Software, 85 (4), 795-820 (2012)
6. Kruchten, P., Lago, P., van Vliet, H.: Building up and reasoning about architectural knowledge. In: Proceedings of the Second international conference on Quality of Software Architectures (QoSA'06), Springer-Verlag, Berlin, Heidelberg, 43-58 (2006).
7. Tang, A., Ali Babar, M., Gorton, I., Han, J.: A survey of architecture design rationale. Journal of Systems and Software, 79 (12), 1792-1804 (2006)
8. Falessi, D., Cantone, G., Kruchten, P.: Value-Based Design Decision Rationale Documentation: Principles and Empirical Feasibility Study. In: Proceedings of the Seventh Working IEEE/IFIP Conference on Software Architecture, 189-198 (2008)
9. Avgeriou, P., Kruchten, P., Lago, P., Grisham, P., Perry, D.: Architectural knowledge and rationale: issues, trends, challenges. SIGSOFT Soft. Eng. Notes, 32 (4), 41-46 (2007)
10. Roldán, M. L., Gonnet, S., Leone, H.: TracED: a tool for capturing and tracing engineering design processes. Advances in Engineering Software, 41 (9), 1087-1109 (2010)
11. Clements, P., Bachmann, F., Bass, L., Garlan, D., Ivers, J., Little, R., Merson, Paulo, Nord, R., Stafford, J.: Documenting Software Architectures: Views and Beyond, Second Edition. Addison-Wesley (2010)
12. IEEE: IEEE 1417, Recommended Practice for Architectural Description of Software-Intensive Systems. IEEE Press (2000)