

APEP – An Architectural Pattern Evaluation Process

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An architectural pattern describes a solution to a recurring problem in a given context. When writing such a pattern the author is faced with several challenges. The first writing attempts are often vague and not clearly formulated and do not describe the pattern sufficiently. Other software engineers do not understand the pattern well enough and cannot use it to solve their problems. In this paper, we introduce APEP, an **Architectural Pattern Evaluation Process**. It allows conducting a review of an architectural pattern drafts based on adaptations of sophisticated methods for architectural evaluation. One such method is a Review of Intermediate Architectural Patterns (RIAP), which we design and introduce in this paper. To prove feasibility, we conducted two case studies based on an exemplary architectural pattern.

CCS Concepts: •**Software and its engineering** → **Patterns**; *Designing software*;

1. INTRODUCTION

A pattern is a solution to a recurring problem in a given context [Alexander 1977]. A reference model decomposes a problem into parts that in conjunction can solve the problem at hand. It always arises by experience and thus only appears in mature domains [Len et al. 2003]. In conjunction, both comprise a reference architecture.

A software architecture is an instantiation of a reference architecture. It describes the structure of the system, the relationship between its components and their externally visible properties [Len et al. 1998]. A software architecture is very expensive to change once it is being implemented. Architectural evaluation is a method to identify issues before implementing an architecture to avert these costs [Clements et al. 2002].

In contrast, no methods exist to evaluate an architectural pattern. We introduce an Architectural Pattern Evaluation Process (APEP) to guide an author when continuously evaluating an architectural pattern. It comprises multiple different evaluation methods. Those methods are based on existing evaluation methods for architectures and are specifically tailored to serve the purpose of pattern evaluation. In the course of this paper, we introduce these existing evaluation methods and introduce APEP. Additionally, we contribute one tailored evaluation method for architectural patterns, a Review of Intermediate Architectural Patterns (RIAP). Finally, we present two case studies that show the feasibility of the presented evaluation tools.

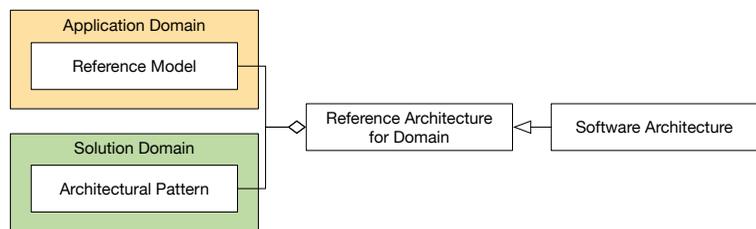


Fig. 1. Relationship between reference model, architectural pattern, reference architecture and software architecture as UML class diagram (based on [Len et al. 1998])

2. FOUNDATIONS

When targeting a specific architecture, several alternatives exist on how to evaluate it. Abowd et al. divide them into two main categories: qualitative questions and quantitative measurements [Abowd et al. 1997]. Qualitative questions use scenarios or checklists, while quantitative measurements use metrics or simulations and experiments to assess the suitability of the architecture for a system in terms of requirements fulfillment. Scenario-based evaluation methods are for example the “Software Architecture Analysis Method” (SAAM) by [Kazman et al. 1994] and the “Architecture Trade-Off Analysis Method” (ATAM) by [Kazman et al. 2000]. SAAM and ATAM have been used for several years, and other authors have brought up several adaptations. A comparison of these methods can be found in [Babar et al. 2004] or [Dobrica and Niemela 2002].

While SAAM and ATAM target fully specified architectures, which develop over the course of a project, *Active Reviews for Intermediate Designs* (ARID) were introduced by Clements to be much more lightweight and concentrate on the viability of the software architecture [Clements 2000]. ARID is best suited to be used at the beginning of a design process to discover errors or inconsistencies and to thereby reduce the costs of such problems. Additionally, by involving different stakeholders upfront they are more likely to accept the design.

ARID is a combination of two approaches: *Active Design Reviews* (ADR) and ATAM. ADRs were first introduced by Parnas & Weiss in [Parnas and Weiss 1985]. It is a method that actively challenges reviewers to solve review tasks using the design in relevant scenarios instead of asking simple yes / no questions (cf. Table I).

Table I. Conventional design review question vs. active design review instruction [Clements et al. 2002]

Conventional Design Review	Active Design Review
Are exceptions defined for every program?	Write down the exceptions that can occur for every program.
Are the right exceptions defined for every program?	Write down the range or set of legal values of each parameter. Write down the states under which it is illegal to invoke the program.
Are the programs sufficient?	Write a short pseudo-code program that uses the design to accomplish [some defined task].

The general outline of ARID is based on the structure of ATAM. It is divided into two main phases: the rehearsal and the review. In the rehearsal, the lead designer and a facilitator meet up to create the exercises for the review. This phase is comprised of the following four steps:

- (1) **Identify the reviewers:** As ARID evaluates an intermediate architecture, the reviewers best suited for the job are the software engineers that are expected to apply the architecture. In this step, a group of around a dozen software engineers is selected.
- (2) **Prepare the design briefing:** The lead designer is supposed to introduce the design to the reviewers. This step is used to prepare the corresponding presentation and to do a dry run. The dry run is presented to the facilitator, which brings benefits: first, the facilitator might come up with questions for which the designer can prepare. Second, the presentation itself is evaluated both content-wise as well as from a presentation perspective. And finally, the designer can practice the presentation to give it in the given time frame. The presentation should not exceed two hours.
- (3) **Prepare the seed scenarios:** The lead designer and facilitator then continue to craft several scenarios, in which the design could be used. These do not need to be used for later evaluation but can serve as a valuable starting point and generally make the design more understandable.
- (4) **Prepare the materials:** Finally, the rehearsal concludes by preparing all necessary materials for the review, like copies of the presentation, seed scenarios and agenda.

In the review phase, the stakeholders conduct the actual review by following the next five steps:

- (5) **Present ARID:** The facilitator starts the review by presenting ARID and the steps involved.
- (6) **Present the design:** The lead designer presents the design briefing and introduces the seed scenarios. While doing so, the audience is only allowed to ask comprehension questions; questions regarding rationale or suggestions are not allowed. All comprehension questions are noted down by a scribe; those questions indicate a lack of clarity in the design or its documentation.
- (7) **Brainstorm and prioritize scenarios:** In the next step, the group brainstorms scenarios in which the design could be used. The seed scenarios are included in the pool. Each participant gets a vote total of 30 percent of the number of scenarios. They are free to allocate all their votes to one specific scenario that they deem important or distribute them between the different scenarios as they wish. The scenarios that receive the most votes are used in the review.
- (8) **Apply the scenarios:** In this step, the facilitator asks the group to craft real or pseudo code using the design to tackle the problem presented in the scenarios. Usually, the group starts with the scenario that received the most votes. In some cases, it might be more useful to start with an easier one, if the top-rated scenario seems to be too daunting of a task. During this step, the lead designer is not allowed to help the group or give hints. Only when the group becomes stuck the facilitator is asked to intervene, and the lead designer may steer the group in the right direction. Every time this happens, an issue is recorded, which indicates a flaw in the design. The reviewers are also asked to bring up any discrepancies they uncover as issues. This step continues until either time has run out, the top-rated scenarios are solved or the group concludes that the design is suitable or unsuitable.
- (9) **Summarize:** Finally, the facilitator recalls all identified issues, thanks the reviewers for participating and asks for feedback regarding the review.

The result of the ARID, SAAM and ATAM is list of issues. This list contains issues that the reviewers have uncovered in the architecture, such as that certain quality attributes cannot be fulfilled or that the design is not feasible. Those issues help the lead designer to improve the architecture.

3. APEP

Writing an architectural pattern is an iterative process [Wellhausen and Fießer 2012]. The goal of APEP is to support a pattern designer in evaluating and iteratively improving an architectural pattern. The process starts and ends with the architectural pattern. An evaluation method is chosen and conducted. Based on the resulting issues, the pattern is improved and another iteration of APEP can be started (cf. Figure 2).

3.1 Design

APEP requires two main roles: designer and reviewer. Because both roles deal with the intricacies of software architectures, APEP demands both roles to be staffed with software engineers.

As a prerequisite to APEP, the designer has to create an architectural pattern. For APEP, we do not require a particular state that the pattern is in. APEP can be used both for the early evaluation of non-mature patterns - which we call Intermediate Architectural Patterns - and for the evaluation of mature patterns. Figure 3 presents an overview of the different steps and artifacts of APEP. The designer

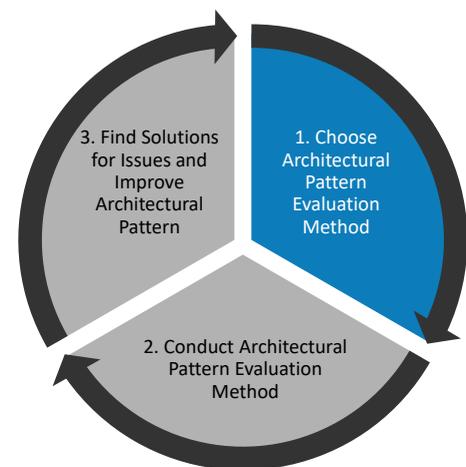


Fig. 2. Overview of the iterative APEP process

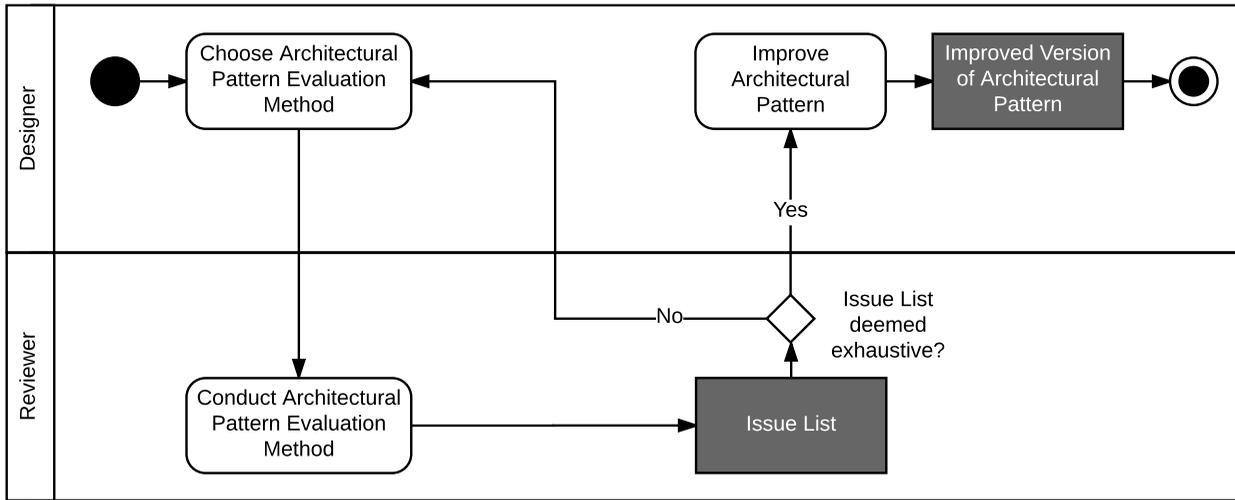


Fig. 3. Overview of one iteration of APEP as UML activity diagram

initiates the process by choosing an architectural pattern evaluation method. These methods will be delineated in Section 3.2. The reviewers then conduct the architectural pattern evaluation method and bring up issues. Those issues are gathered in an issue list and described further in Section 3.3. If the issue list is deemed exhaustive, the designer crafts an improved architectural pattern. Otherwise, another architectural pattern evaluation method is chosen and conducted.

3.2 Architectural Pattern Evaluation Methods

We differentiate evaluation methods for architectures and architectural patterns:

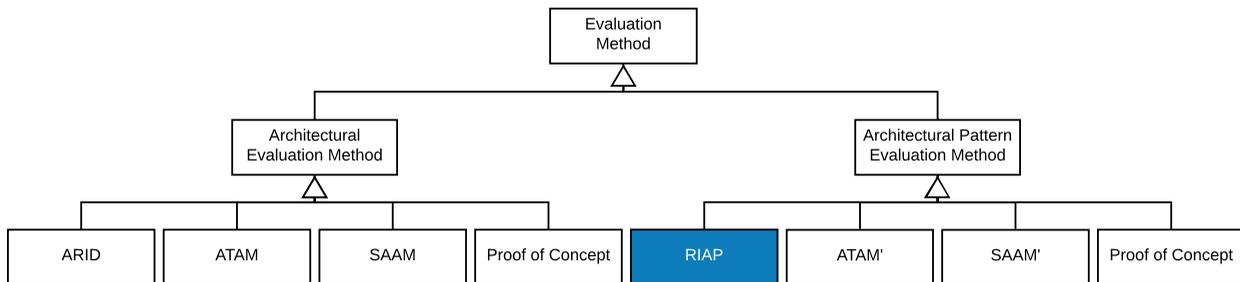


Fig. 4. Taxonomy of methods for architectural evaluation and architectural pattern evaluation as UML class diagram

Based on the methods for architectural evaluation depicted in Section 2, we propose to adapt them for architectural pattern evaluation. In the scope of this paper, we design an adaption of ARID — namely **RIAP**, a **R**eview for **I**ntermediate **A**rchitectural **P**atterns. ATAM' and SAAM' are adapted versions of ATAM and SAAM. A proof of concept implementation shows both the feasibility of an architecture as well as of an architectural pattern, by implementing a specific scenario.

The architectural pattern evaluation methods enable the reviewers to instantiate the pattern, elicit quality requirements and evaluate the resulting architecture based on these requirements. The sequence of activities while conducting the architectural pattern evaluation method are depicted in Figure 5.

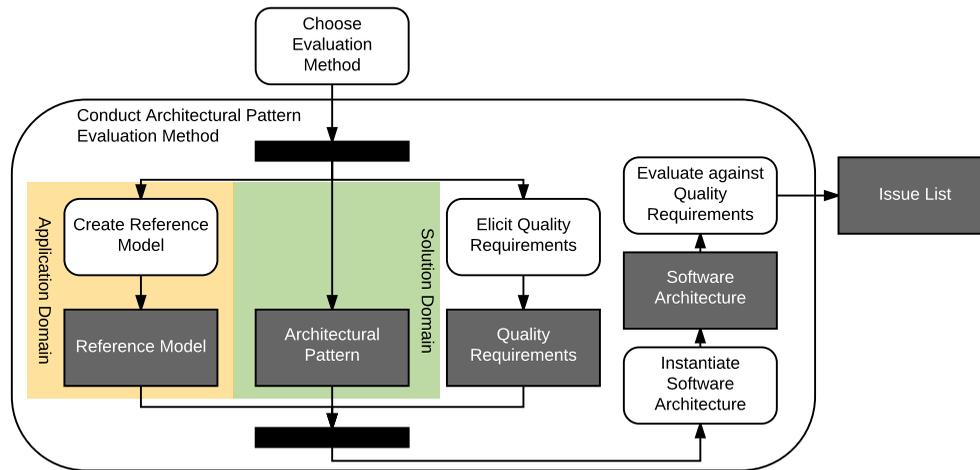


Fig. 5. Conduct architectural pattern evaluation method in detail as UML activity diagram

With respect to Figure 1, a software architecture is the result of a reference model and architectural patterns. Therefore, the evaluation method requires the reviewers to create a reference model. The architectural pattern is provided by the designer. In addition, quality requirements must be defined to assess the suitability of the architecture. With those three artifacts, the reference model, the architectural pattern and the quality requirements, the reviewers can instantiate a software architecture. This is evaluated against the elicited quality requirements and results in an issue list that describes all issues that were uncovered during the process and the evaluation against the quality requirements.

3.3 Issue List

All described architectural pattern evaluation methods bring up *Issues*. These issues arise in a *Context*, for example during the implementation of the communication between two components of the architectural pattern. They feature a *Problematic Solution* and give rise to an *Improved Solution*. The improved solution is used to enhance the architectural pattern.

This tripartite is used in the style of an anti pattern as described in [Brown et al. 1998]. The context is adopted directly. We merge “Problem” and *Problematic Solution* into the problem of the issue and the “Refactored Solution” transitions to our solution.

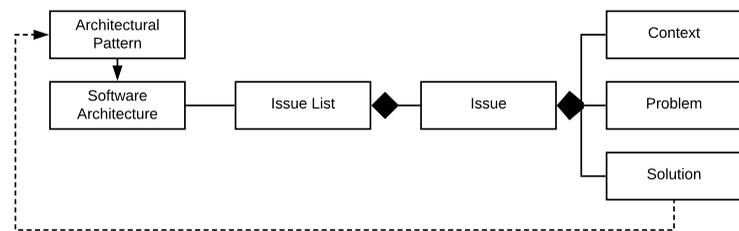


Fig. 6. Structure of the issue list in context of APEP as UML class diagram

4. RIAP

As an architectural pattern evaluation method for APEP, we introduce RIAP - a **R**eview for **I**ntermediate **A**rchitectural **P**atterns. RIAP is an adaption of ARID (cf. Section 2) for architectural patterns. Like ARID, RIAP is capable of early evaluations of intermediate architectural patterns.

4.1 Design Goals

The goal of RIAP is to strengthen the evaluated pattern. RIAP is part of the APEP process and is used for the early evaluation of intermediate architectural patterns.

4.2 Characteristics

When designing RIAP, we thought about what characteristics RIAP must have in order to be applicable in practice. In the sense of requirements, we distinguish between functional and non-functional characteristics: features that RIAP must fulfill (functional characteristics) or a restriction it must obey (non-functional characteristics) to be able to carry out the specified objective of strengthening the pattern [Brügge and Dutoit 2004].

In consultation with other pattern authors and inspired by other methods of architecture evaluation methods, we identified these functional and non-functional characteristics for RIAP that we describe in this section.

CR1 - Identify Issues: RIAP must identify issues of the architectural pattern.

CR2 - Improve Pattern: The identified issues must be usable to improve the pattern.

CR3 - Instantiate Architecture: According to APEP, an evaluation method must instantiate a concrete architecture. RIAP must instantiate an architecture that includes the architectural pattern that is evaluated.

CR4 - Provide Guidance: In contrast to the underlying ARID method, RIAP targets an intermediate architectural patterns instead of an intermediate designs. This increases the scope of the review. RIAP must provide guidance during the review, e.g. by a person guiding the reviewers through the process.

NCR1 - Time: RIAP must be able to be carried out in a reasonable time frame - we define reasonable in this context as less than four hours. In contrast to architecture evaluation methods described in Section 2, reviewers do not associate themselves with the pattern as much as with an architecture they would be using in a project.

NCR2 - Simplicity: Since RIAP targets intermediate architectural patterns, it must be feasible for undocumented patterns as well.

NCR3 - Heterogeneity of Participants: RIAP must be executable with a heterogeneous group of software engineers. Heterogeneous in this context means that they may not have experience in the domain the pattern is applicable, and additionally the group may have different levels of experience with software engineering in general.

4.3 Implementation

ARID serves as the basis for RIAP as it is lightweight, can be completed in a reasonable time frame and can also be used for intermediate architectural patterns. RIAP needs a facilitator, a designer and reviewers. The designer provides the architectural pattern and is responsible for introducing it and answering questions that arise during the review. The role of the facilitator is to guide the process and capture issues. The reviewers' task is to test and review the architectural pattern. They do not

need experience in the domain where the pattern is applicable. RIAP is therefore applicable with a heterogeneous group of software engineers, although we expect knowledge of software architecture and software engineering in general. The duration of RIAP is set at three hours to stay within a reasonable time frame.

The process is divided into two phases: the rehearsal and the review. In the rehearsal phase, the designer and facilitator prepare the actual review, which takes place in the review phase.

4.3.1 Rehearsal. The rehearsal consists of four different steps. We depict those steps in an activity diagram in Figure 7. The facilitator and the designer meet and pick the reviewers first. Afterwards, the designer prepares a pattern briefing, in which he explains the architectural pattern. He chooses a problem domain in which the pattern is to be evaluated. Since an architectural pattern is used in a broader context than a design, we assume that the scenarios that the evaluators would develop were too different to evaluate. We therefore restrict all scenarios to a specified problem domain. The facilitator prepares the RIAP presentation that includes the design briefing and the description of the problem domain. We recommend printing both the design briefing and the problem domain on a handout that the reviewers can use throughout the review.

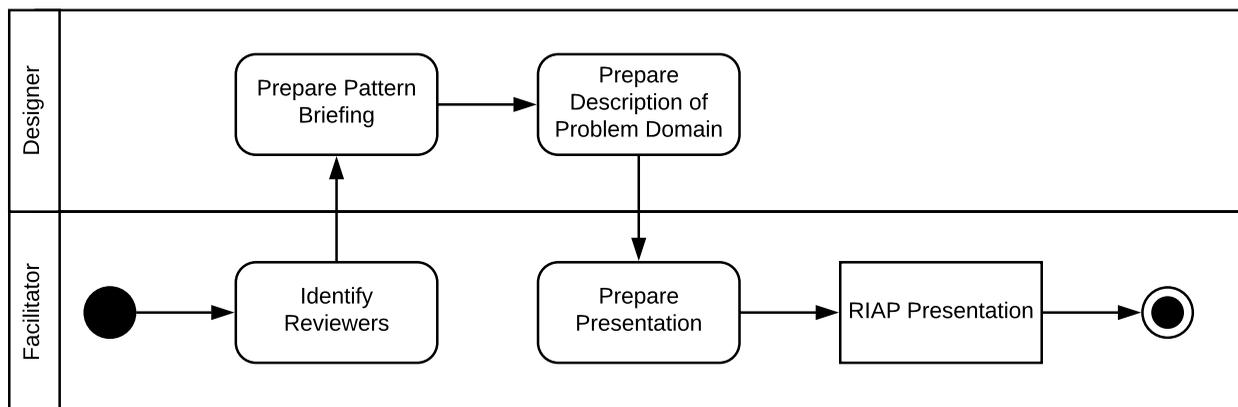


Fig. 7. RIAP rehearsal phase as UML activity diagram

4.3.2 Review. While ARID targets a design, RIAP targets an architectural pattern: evaluating this seems to be too daunting of a task for the reviewers to tackle on their own. RIAP therefore provides for strict guidance through the process. The review phase is depicted in Figure 8.

In the review phase, the facilitator introduces RIAP to the reviewers by describing all steps. Then the designer introduces the architectural pattern. During that time, the reviewers may ask questions regarding the understanding of the architectural pattern. Those questions are recorded as issues by the facilitator. Afterwards, the designer presents the problem domain to the reviewers.

To guide the reviewers in the following more active part, we pose a total of seven tasks. Each task is introduced by the facilitator. The reviewers complete the task, while the designer may answer questions. Those questions may only target the understanding of the architectural pattern. The designer may not give his opinion on how to implement certain aspects of the system, as this would influence the reviewers design decisions. The questions as well as any problems that arise during the completion of the tasks, such as how to map some components of the pattern onto the scenario, are recorded by the facilitator.

The seven tasks are described in the following:

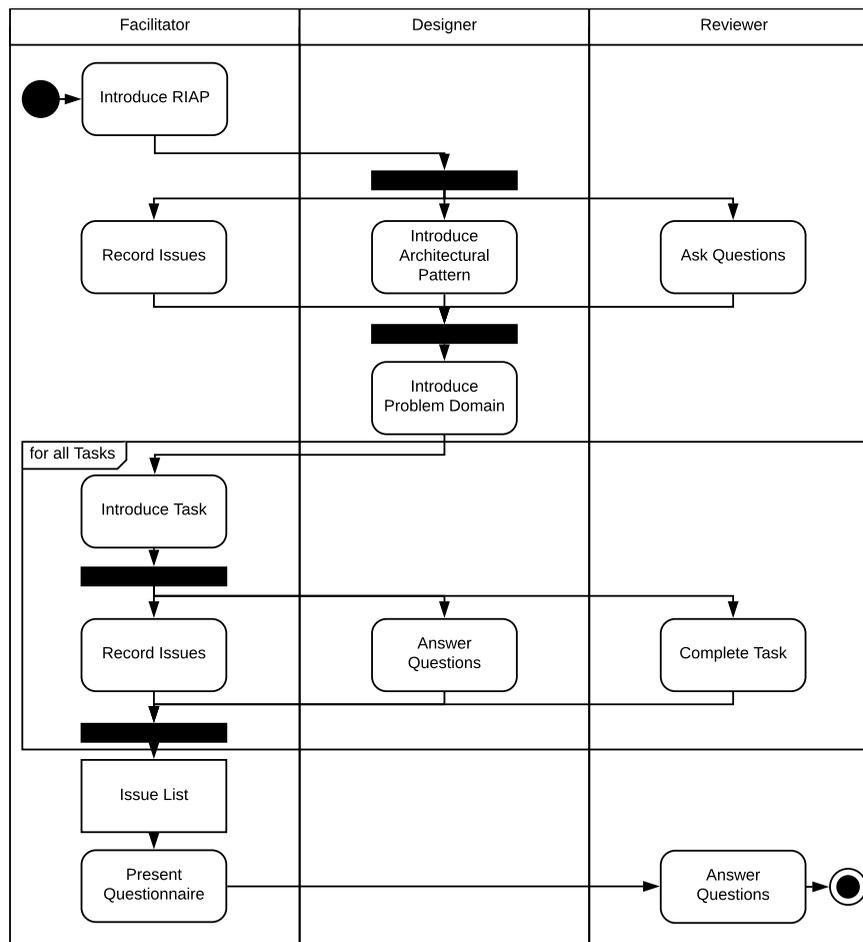


Fig. 8. RIAP review phase as UML activity diagram

T1: Brainstorming Scenarios. The goal of this task is to generate scenarios, in which the architectural pattern is applicable and that fit the suggested problem domain. We propose using brainstorming techniques such as the gallery method¹ or brain sketching². There, the reviewers are asked to think about concrete scenarios that fit the problem domain. They write the scenario title onto a card and give a brief description. The cards are collected on a white-board and displayed for all reviewers to see, and the reviewers may ask questions, if a scenario is unclear. The process of writing cards and looking at the results may repeat until the reviewers have run out of ideas.

T2: Prioritize Scenarios. For time reasons, it is not possible to implement each scenario that the reviewers come up with. Therefore, the scenarios must be prioritized. For that, every reviewer has a total of three votes, which he can allocate freely to the scenarios. We suggest handing out stickers to the participants and letting them stick them to the cards on the white-board as described in the sticking dots method³. After this, the top-rated scenario is used for all subsequent tasks.

¹see https://www.mycoted.com/Gallery_method (accessed: 08/13/2017)

²see <https://www.mycoted.com/BrainSketching> (accessed: 08/19/2017)

³see https://www.mycoted.com/Sticking_Dots (accessed: 08/19/2017)

- T3: Formulate Demo Scenario.* The scenario has a title and a brief description. To implement it, the reviewers formulate a detailed description of the flow of events (cf. [Brügge and Dutoit 2004]). The implementation must be able to carry out all these steps.
- T4: Elicit Non-Functional Requirements.* The group elicits non-functional requirements that are important for the scenario and must be considered during design.
- T5: Subsystem Decomposition.* For designing the system, the reviewers create a subsystem decomposition (cf. [Brügge and Dutoit 2004]). All parts of the pattern must be included.
- T6: Hardware/Software Mapping.* To show that the provided subsystems can be mapped to hardware, the group creates a hardware/software mapping, showing the hardware used and the protocols used for communication between the different subsystems (cf. [Brügge and Dutoit 2004]).
- T7: Apply the Demo Scenario.* The group is supposed to show how the designed system carries out all individual steps of the demo scenario. To do so, they may for example show the dynamic behavior of all participating subsystems. During this task, designer and facilitator may ask critical questions regarding the feasibility of the proposed solution. They may for example investigate how the system fulfills the elicited non-functional requirements.

After all tasks have been carried out, the facilitator has crafted a list that includes all issues from the tasks and the initial presentation of the architectural pattern. To further encourage the reviewers to offer feedback, we conclude the RIAP with a questionnaire. All these questions are written in the style of active design review questions and aim to make the reviewers question the architectural pattern in this scenario. The facilitator presents the questions about the architectural pattern — e.g. whether the pattern could fulfill all quality requirements, or more generally what the purpose of the pattern is — and the reviewers answer them. This concludes the review.

5. CASE STUDY

To evaluate RIAP, we conducted two case studies in July 2017 based on an architectural pattern. A total of eight reviewers participated in the first case study and six participated in the second one. The first case study took three and a half hours while the second was reduced to three hours. The pattern to be evaluated is Fogxy, an architectural pattern for Fog Computing [Seitz et al. 2018]. The pattern was not yet published at that time and was still in a raw version. The results of RIAP were used to improve Fogxy.

5.1 Materials

To prepare for the case study, the designer and the facilitator met to craft a presentation and a handout. The presentation contained the following slides:

- introduction to RIAP and the steps involved in the process
- design briefing for the architectural pattern
- problem domain
- task description
- questionnaire

5.2 Reviewers and Environment

We distinguish two groups of reviewers: software engineers familiar with the concepts of fog computing and people with less knowledge about fog computing. The first group consisted out of students researching in the area of fog computing. The second group were doctoral students in the area of software engineering.

The review took place in a meeting room at university. The room offered magnetic boards for mounting or sticking cards and was large enough to work comfortably. An impression of the working environment is shown in Figure 9.



Fig. 9. Working environment and participants during the first RIAP meeting

5.3 Problem Domain & Questionnaire

In the first case study, we used an example from the domain of renewable energy. The second tested the architectural pattern in the field of autonomous driving. For the questionnaire, we chose to present the following active design review questions:

- What is the idea and purpose of the architectural pattern?
- What are the shortcomings in this scenario?
- Where did you have problems implementing it?
- Which non-functional requirements could not be fulfilled?

The goal of these questions was to let the participants revise the architectural pattern and the scenarios and to give them a chance to address further issues.

5.4 Changes to the RIAP method

During the first case study, it became clear that our decision to select a problem domain and not provide seed scenarios was suboptimal. The tasks of brainstorming and prioritizing scenarios and determining non-functional requirements were not well received by the participants. These tasks were simply a means to an end — and thus took too long. Additionally, it was unclear to the reviewers how they were supposed to formulate scenarios independently of the architectural pattern evaluated. Therefore, we decided to predetermine the concrete scenario and its non-functional requirements. We ensure that the architectural pattern is generally plausible to be used in the scenario, and there is not much discussion about the different scenarios.

5.5 Findings & Limitations

Table II gives an overview and compares the two conducted case studies. Based on the introduced changes to RIAP, we were able to reduce the time of the evaluation to three hours. In both case studies, we implemented one scenario. In each case study, two groups formed, which presented different designs. The first case study discovered seven issues. The second case study verified these issues but did not bring up any new issues. This might be due to the chosen scenario. The questionnaire did not bring up any new insights in both sessions.

Table II. Metrics of the two RIAP case studies

	CS 1	CS 2
Time	3h 30min	3h
# reviewers	8	6
# created scenarios	8	1
# implemented scenarios	1	1
# different designs	2	2
# issues	7	6 (all duplicates)

6. CONCLUSION

With this paper, we introduce RIAP, a method to evaluate intermediate architectural patterns that is integrated in the APEP process — a process for architectural pattern evaluation. Two successful case studies showed that RIAP and APEP are valuable for improving an architectural pattern. The goal of APEP is to provide an iterative process for conducting an architectural pattern evaluation. During our research, we conducted two iterations: the first iteration using the RIAP method to identify issues that lead to an improved version of the architectural pattern; the second iteration showing that this proposed improvement was indeed feasible by implementing a proof of concept. The RIAP method itself was formatively evaluated during the case studies. We identified that the scenario creation took far too long in comparison to its results. We therefore predetermined the scenario to be used in the RIAP method. The predetermination of the scenarios in the RIAP method improved the process, as time was saved and the process was much clearer to the participants.

Additionally, we found that the questionnaire did not yield the expected additional results in contrast to the tasks that were executed beforehand. Some participants in the two groups were already familiar with the general concepts of the pattern and were, therefore, able to express all the obscurities in advance. With other participants, the questionnaire might retain its justification by bringing the evaluation process to an orderly conclusion. APEP and RIAP should be applied to other architectural patterns to continue refining both process and method formatively.

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REFERENCES

- Gregory Abowd, Len Bass, Paul Clements, Rick Kazman, Linda Northrop, and Amy Zaremski. 1997. *Recommended Best Industrial Practice for Software Architecture Evaluation*. Technical Report. Software Engineering Institute, Carnegie Mellon University.
- Christopher Alexander. 1977. *A pattern language: towns, buildings, construction*. Oxford University Press.
- Muhammad Ali Babar, Liming Zhu, and Ross Jeffery. 2004. A framework for classifying and comparing software architecture evaluation methods. In *Australian Software Engineering Conference Proceedings*. IEEE, 309–318.
- William J. Brown, Raphael C. Malveau, Hays W. McCormick III, and Thomas J. Mowbray. 1998. *Anti Patterns*. John Wiley and Sons, Inc.
- Bernd Brügge and Allen H. Dutoit. 2004. *Object-oriented software engineering - using UML, patterns and Java*. Prentice Hall.

- Paul Clements. 2000. *Active reviews for intermediate designs*. Technical Report. Software Engineering Institute, Carnegie Mellon University.
- Paul Clements, Rick Kazman, and Mark Klein. 2002. *Evaluating Software Architectures*. Addison-Wesley.
- Liliana Dobrica and Eila Niemela. 2002. A survey on software architecture analysis methods. *IEEE Transactions on Software Engineering* 28, 7 (2002).
- Rick Kazman, Len Bass, Gregory Abowd, and Mike Webb. 1994. SAAM: A method for analyzing the properties of software architectures. In *Software Engineering, 1994. Proceedings. ICSE-16., 16th International Conference on*. IEEE, 81–90.
- Rick Kazman, Mark Klein, and Paul Clements. 2000. *ATAM: Method for architecture evaluation*. Technical Report. Software Engineering Institute, Carnegie Mellon University.
- Bass Len, Clements Paul, and Kazman Rick. 1998. *Software architecture in practice*. Addison-Wesley.
- Bass Len, Clements Paul, and Kazman Rick. 2003. *Software architecture in practice*. Vol. 2. Addison-Wesley.
- David L. Parnas and David M. Weiss. 1985. Active Design Reviews: Principles and Practices. In *Proceedings of the 8th International Conference on Software Engineering*. IEEE Computer Society Press, 132–136.
- Andreas Seitz, Felix Thiele, and Bernd Bruegge. 2018. Fogxy - An Architectural Pattern for Fog Computing. In *Proceedings of the 23rd European Conference on Pattern Languages of Programs (EuroPLoP '18)*. ACM, New York, NY, USA.
- Tim Wellhausen and Andreas Fießer. 2012. How to write a pattern?: A rough guide for first-time pattern authors. In *Proceedings of the 16th European Conference on Pattern Languages of Programs*. ACM, 5.