



FAKULTÄT FÜR INFORMATIK

TECHNISCHE UNIVERSITÄT MÜNCHEN

Master Thesis in Informatics

**Improving the Software Architecture
Documentation Process for Mediawiki
Software**

Ankitaa Bhowmick





FAKULTÄT FÜR INFORMATIK

TECHNISCHE UNIVERSITÄT MÜNCHEN

Master Thesis in Informatics

Improving the Software Architecture Documentation Process for Mediawiki Software

Author:	Ankitaa Bhowmick
Supervisor:	Matthes, Florian; Prof. Dr. rer. nat.
Advisor:	Klym Shumaiev
Submission Date:	15th August, 2015



I assure the single handed composition of this master thesis in informatics only supported by declared resources.

Munich, 15th August, 2015

Ankitaa Bhowmick

Acknowledgments

Abstract

The thesis involves the initial research on the available state-of-the-art Software Architecture documentation processes, tools, etc. that help in maintaining a software architecture documentation that is consistent with the evolving architecture.

Understanding the current software architecture documentation process at Wikimedia, keeping the evaluation goals in mind, is an essential part of this thesis. It also focuses on critical evaluation of the documentation process to derive requirements for its improvement.

Based on analysis, an improved Software Architecture documentation process will be proposed and evaluated.

Contents

Acknowledgments	iii
Abstract	iv
I. Introduction	1
1. Introduction	2
1.1. Motivation	2
1.2. About the Topic	2
1.3. Research scope	3
1.4. Reader's guide	3
2. Research Questions	4
2.1. Initial Hypothesis	4
2.2. Research Questions	5
2.3. Current state-of-art	5
2.3.1. Software Architecture Documents	6
2.3.2. Software Process	7
2.3.3. Documentation Process	9
2.4. Problems	10
2.4.1. Maintainability	10
2.4.2. Roles and Responsibilities	11
2.4.3. Availability and Management	11
2.5. Requirement Analysis	11
2.5.1. Stakeholders	11
2.5.2. Meetings / Interactive Sessions	12
3. Literature Survey	14
3.1. Some Important Concepts	14
3.2. Points from Literature	15
3.2.1. Improved Documentation Process	15
3.2.2. Current Industrial State-of-the-Art	17

3.2.3. Evaluation and quality assurance of Documentation Process . .	18
3.2.4. Stakeholder Requirement Satisfaction	20
3.3. Idea Generation	22
II. Thesis Contribution	24
4. Conceptualization	25
4.1. Idea Generation and Evolution	25
4.1.1. Preparatory Tasks	25
4.1.2. Initial Ideas - Use case scenarios	30
4.1.3. Pros and Cons of the initial ideas	32
4.1.4. Define feasibility and scope	32
4.2. Improved Process	32
4.2.1. Roles and Responsibility definition and co-ordination	32
4.2.2. Document Maintenance Bot	34
4.2.3. Guidelines for the future process orientation	34
4.2.4. A proof of concept	34
5. Implementation	36
5.1. Assumptions	36
5.2. Architecture and Technical outline	36
5.3. Details of the implementation	36
5.4. Future implementation	36
III. Evaluation and Conclusion	37
6. Evaluation	38
6.1. Meetings and Discussions	38
6.2. Survey	38
6.3. Evaluation	38
7. Conclusion	39
7.1. Challenges	39
7.2. Benefits of implemented solution	39
7.3. arguments to support the idea	39
7.4. Concluding Remarks	39
List of Figures	40

Contents

List of Tables	41
Bibliography	42

Part I.

Introduction

1. Introduction

1.1. Motivation

A good software architecture is the focal point of an evolving software [10]. To make this software maintainable, extendable and sustainable, a robust software architecture and a defined documentation process for this architecture are required [5].

Documentation is a factor that determines the quality of a software. A good software architecture documentation helps to understand, evaluate and communicate the various architectural decisions from different stakeholder viewpoints [2]. Also, as the software evolves and its complexity and dependencies increase, the corresponding architecture documentation needs to be updated as well [28].

Standardized software processes and tools for Application Lifecycle Management provide structural support to a software engineering project's life-cycle. The quality of a software process directly affects the quality of the software [9].

Summing up, a standard process for documentation improves the quality of the documents and ultimately, the quality of the software itself.

1.2. About the Topic

Open source softwares have distinguished themselves as the trendsetters in the field of software engineering in this era and have demonstrated advantages which are beyond comparison. But there are a few downsides to this approach of software development [19]. When a software depends on its online community which is only virtually connected, it suffers due to issues like "persistent identity, newcomer confusion, etiquette standards, leadership roles, and group dynamics" [12]. In the pretext of software process, open source software communities can be categorized as loosely co-ordinated and less process-oriented [29]. They believe in "Do-ocracy" where there is more focus of doing (building) the software from small to big, rather than following a process-oriented strict software life-cycle management process. This leads to the basic scope of this thesis : Improving the process in an open source environment

In the recent past, Mediawiki software (WMF Foundation) has grown to become one of the largest open source communities in the world. This prompted the choice for the candidate software for the thesis: Improving the process for Mediawiki software

As discussed above, software architecture documentation is as important in the software project as the software architecture itself. With some background study, it was found that lack of documentation is one of the major downsides of open source development model [6] [29]. Hence this thesis topic aims to find a proof of concept and a theoretical reasoning that may prove helpful for Open Source community in general and in particular : Improving the software architecture documentation process of Mediawiki software.

1.3. Research scope

The scope of the thesis has been reduced to maintenance of mid-level software architecture documentation of Mediawiki that is available as a part of the source code on mediawiki.org.

Moreover, a process has been defined and demonstrated that can be used as a basis for a process that can aide in maintenance of documents over a period of time. Coupling the existing review process and task management system, this documentation process is well-bound to the practices in the Mediawiki community and aims to win greater acceptance of the defined process. [6]

1.4. Reader's guide

The next chapter will enumerate the questions to which this thesis aims to provide an answer. This will help us understand our initial assumptions, the existing problems and the expected solution.

The following chapter will present literature analysis giving theoretical proofs to explain the important concepts for this research and the reasoning to support the thesis work (chapter 3).

Then, chapter 4 will show the approach followed to find a proper solution by conducting discussions and meetings with the stakeholders. The system design is also covered in this chapter.

The consecutive chapter will present a detailed description of the system implementation, defining all of its features (chapter 5).

With regards to chapter 6, the thesis focuses on evaluating the proposed solution by comparing it with the standard processes in the industry and also by evaluating stakeholder satisfaction

Lastly, chapter 7 will conclude the concepts of this work, its future scope and the answers to the initially proposed research questions.

2. Research Questions

2.1. Initial Hypothesis

A software architecture document is not just a necessary afterthought of architecture design ([2]), but an important contributor to the entire software design and development lifecycle. At an initial phase, for a new project, the software architecture document is produced as an artifact for software architecture views for different stakeholders. During the course of project lifecycle, the software architecture document grows and serves as an artifact to record important architectural decision made by the architects. At the design phase the software architecture document provides developers with a high level view of the software architecture and helps to understand the system interfaces, component interaction and basic functionality of each architectural component.

A software architecture document is not a static artifact. Rather, it is as dynamic as the software requirements itself [2]. Maintenance of software architecture requires deep understanding of the skeleton system and depends heavily on its documentation. This escalates documentation to the highest position in the software evolution cycle. But usefulness of this document is measured by its relevance and consistency. This requires maintenance of the document itself to keep it as up-to-date as the current system. Thus, software architecture documentation is an integral activity that revolves not only at a software inception phase, during software architecture design, but also during the course of software's development maintenance and evolution. Since documentation is an activity, it needs to be regulated as a software process.

Software process is affected by organizational behavior of a community [9]. Different organizations work on a culture specific to the standards and processes followed by the within their scope of control. In this context, Open Source software communities are noteworthy due to their relaxed process control and organizational structure. With regards to any form of artifact, especially documentation, this community is loosely coordinated where developers or contributors tend to code solutions without producing adequate documentation [6].

This brings us to an initial hypothesis that forms the basis for this research work on Software architecture documentation process: Open source software community lacks a process for maintenance of software architecture documentation. For a concrete example, Mediawiki was chosen as the ideal candidate. In the last few years the wiki

community (WMF - Wikimedia Foundaion) become one of the largest open source communities in the world. The software that runs the these wikis is the Mediawiki engine. The robust architecture of the mediawiki software is a complex system that has evolved over the years and its architecture complexity has grown manifolds. To explain its architecture, some documentation is available on “mediawiki.org”. But to cater to new developers and first time users of mediawiki, architecture details and technicalities of architectural components is scarcely available on “mediawiki.org”. Although some architectural component documentation is available as a part of the source code, this documentation is not well structured or available in wiki format. This deficit was realized as a part of the initial study and discussions with the stakeholders at mediawiki which will be elaborated in section 2.3. Hence, all the research and conceptualization of improved documentation process is based on these initial ideas. The following section lists the research questions that are intended to be answered by this thesis work.

2.2. Research Questions

1. RQ1 : How software architecture documentation process can be improved for Wikimedia Software?
2. RQ2 : What state-of-the-art architecture documentation process (methodology, tools) are available in the industry that meet domain-specific requirements – e.g. Open Source Software ?
3. RQ3 : What are the metrics for evaluation of the software architecture documentation process and how can the quality of documentation process be assured ?
4. RQ 4 : Which specific requirements of Mediawiki stakeholders should be met by documentation process for Software Architecture Documentation ?

The following sections will explain the reasons and requirements that lead to the formulation of the above-mentioned research questions :

2.3. Current state-of-art

The following sub-sections explain the current state of Mediawiki software architecture documents and the current software and documentation process in the organization.

2.3.1. Software Architecture Documents

Mediawiki currently has all its software architecture documentation available on “mediawiki.org”. The wiki pages belong to different “namespaces” such as “Manual:”, “Help:” etc. to segregate them according to the intended information. Yet, these documents are scattered as a forest of links like any typical wiki, which makes it hard to follow for new users and harder to maintain for the existing users.

The available documents are useful for understanding some architecture components and help new Mediawiki users to understand their installation, usage and operational details. But, these documents are not detailed enough for new developers to acquire a thorough understanding of the architectural component. Documentation of the Mediawiki core source code is auto-generated via “Doxygen” and is available at <https://doc.wikimedia.org/mediawiki-core/master/php>. This auto-generated code level documentation is always updated as a part of cron-jobs during deployment cycles and hence they are auto-maintained. The overview of Mediawiki’s architecture was captured and written as a part of the book “The Architecture of Open Source Applications” by *Sumana Harihareshwara* and *Guillaume Paumier*. This documentation, available on “Mediawiki.org”, is an excellent explanation of the various architectural decisions and corresponding rationale that were adopted over the years leading to the current architectural state of Mediawiki software. It is available under the “Manual:” namespace on “Mediawiki.org” and can be viewed for an abstract high level understanding of the system.

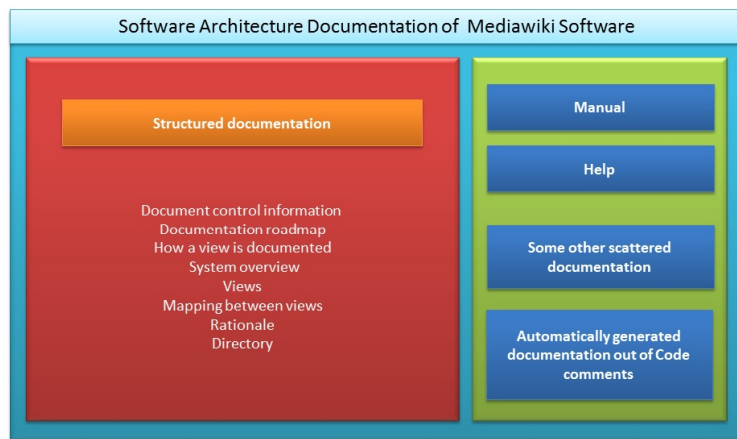


Figure 2.1.: Current state of documentation for different software architecture levels.

In Figure 2.1 we can see the current documentation structure that is available for different levels of detail of the software architecture. The green area indicates the exist-

ing documentation and the red area indicates the lack of availability and maintenance of complete architecture documentation in accordance with the standard software architecture documentation structure [2] which covers the different views, rationale, etc.

2.3.2. Software Process

Mediawiki software community follows a process for maintaining its software (code base) that involves the interaction of the multiple systems for its review, versioning, tracking and task management. In this regard, before a piece of code is deployed into production environment, it is important to understand the role of the following entities as a part of the software process.

1. **Developers** : The software developers are the the most important functional entity of the software process in any software project or organization. Similarly in the mediawiki community, the process is driven, managed and used by the developers of the software. Although other roles like software architect may exist as a subset of the stakeholders within the community, they all belong to the larger set of “Developers”. Developers have the ultimate responsibility to implement and maintain the software process.
2. **Maintainers** : As the name suggests, Maintainers are developers with the acquired competence and experience to take up the responsibility and become maintainers of different modules in the mediawiki code base. They are instrumental in reviewing and following the software process and help to track and complete required functionality <https://www.mediawiki.org/wiki/Developers/Maintainers>.
3. **Mediawiki BOTs** : Besides human maintainers, Bots assume the role of semi-automated process to carry out maintenance activities that may be time-consuming or impossible to perform manually <https://www.mediawiki.org/wiki/Project:Bots>.

The above-mentioned entities need supporting systems to perform their daily activities as a part of the software process. In mediawiki, the software process activities are supported by following systems that simplify the process management activities.

1. **Gerrit** : Gerrit (<https://code.google.com/p/gerrit>) is a web-based code collaboration tool that has been adopted by the mediawiki community for managing the code base. This tool allows the review and maintenance of the master and forked branches of the mediawiki code repository and allows the developers to manage their contributions. The tools allows code management as a part of the software process of mediawiki which helps in easy maintenance of the software.

2. Phabricator : Phabricator (<http://phabricator.org/>) is an open-source task management and project communication platform that helps to manage different projects and their stakeholders within the organization. The mediawiki community has adopted the Phabricator to manage their daily tasks related to software development. The tasks can be managed according to projects, build versions, tags, etc by human maintainers. It provides features to discuss on issues related to the task and to also fork new related tasks.
3. Mailing Lists and IRC : Most open source communities adopt basic modes of communication channels to interact with their stakeholder and users. Mailing lists provide the best channel to discuss issues related to the software, request new features, highlight documentation inadequacy, exchange ideas, etc. Similarly, Internet Relay Chat (<http://www.irchelp.org/>) provides an informal channel or process to communicate in real-time with groups within Mediawiki or with individuals within the community in order to request, discuss, understand, inform and talk about the software.
These systems may seem as casual modes or components of a software process, but they fit well into the open source milieu.

Figure 2.2 shows the sequence diagram that explains a simple use case scenario : A software development task and the process followed for task management.

A developer may create a task on Phabricator to add/update a software functionality. He assigns the task either to himself or to another developer. The developed piece of code is pushed to an intermediate repository in Gerrit and awaits review. Once the code is reviewed and approves by senior developers, it is pushed to the authoritative repository which is ready for deployment. Once this is completed the task is finally closed.

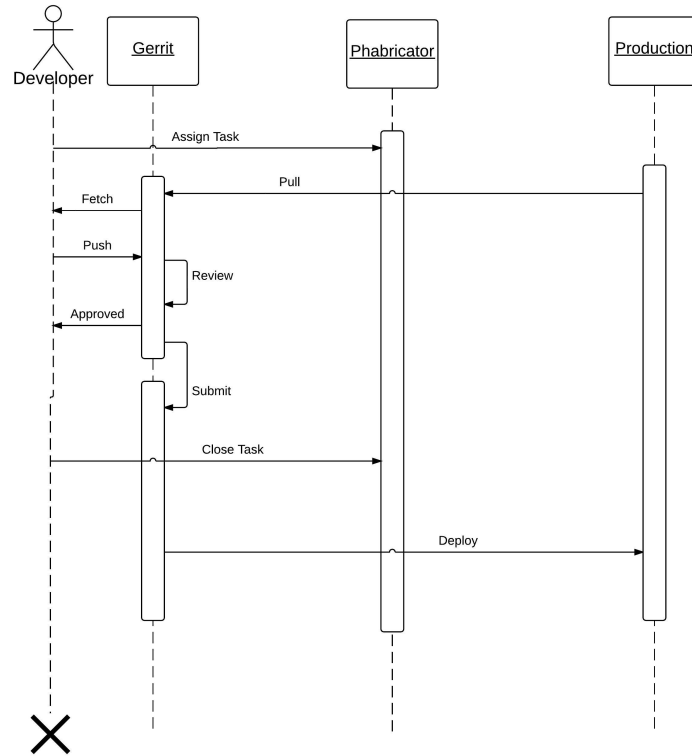


Figure 2.2.: Mediawiki Software Process Sequence diagram.

2.3.3. Documentation Process

Similar to their software process, the mediawiki community has a standard software architecture documentation process which involves the interaction of human maintainers and use of Phabricator for task management. Tasks for documentation activity are created manually, based on the need realized by developers. The management of the task is manual and its tracking, organization and management is supported by Phabricator

Figure 3.2 sequence diagram explains the use-case scenario : Manage a documentation task to update a document on “mediawiki.org”

In this case a developer himself may create/ assign a task on Phabricator for document update on “mediawiki.org”. Once the update has been completed, a the task maintainer comments and closes the task on Phabricator.

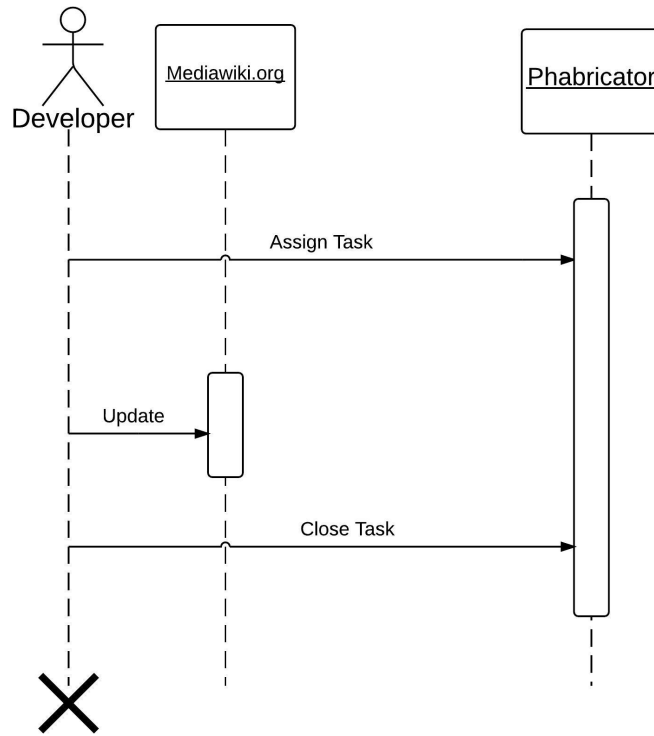


Figure 2.3.: Mediawiki Documentation Process Sequence diagram.

Understanding the current software documentation process leads to the following inherent problems and required improvements that need to be catered by answering the research questions

2.4. Problems

This section elaborates on the problems that have been identified in the software architecture documentation process of Mediawiki that call for an improvement in the documentation process (RQ1).

2.4.1. Maintainability

As seen in the scenario covered in the previous section, it is evident that the documentation has shortcomings in terms of its maintainability with the rapid evolution of the software architecture itself. The process followed by the community is not strictly

structured to ensure that the documents are maintained up-to-date. Phabricator may help to organize the task of documentation but does not guarantee the availability of precise documentation itself. Also only a manual check on document maintenance, without a strict process, is highly dependent on the motivation of the task owner to create, assign and complete the task. With the existing documentation process, a key requirement of document maintainability is not completely satisfied. Hence there is a need for an improvement to incorporate the requirement of up-to-date documents as a part of the documentation process.

2.4.2. Roles and Responsibilities

Mediawiki is an open source software community and hence it is not structured in its organization of well-defined roles and responsibilities. This poses a problem in defining, maintaining and following a strict process-based approach for software development and documentation. As compared to code maintainers mentioned in the previous section, there is no defined responsibility in the mediawiki community specially focused on documentation. The role of a developer for a certain architectural component implicitly assigns him the responsibility of corresponding documentation maintenance. But the lack of explicitly defined responsibility for the same creates a relaxed documentation process.

2.4.3. Availability and Management

An issue with the current documentation process is that software architecture documentation is not available under a single “namespace” or “category” and rather scattered in the wiki-forest. This makes it harder to manage the documentation and guarantee its availability on “mediawiki.org”.

2.5. Requirement Analysis

The above listed problems were identified to understand the requirements to be met by the improved process (RQ1).

2.5.1. Stakeholders

To understand a system and its architecture, it is important to understand the stakeholder perspective (RQ4). Mediawiki’s software architecture documentation is available for developers, architects and system administrators on “mediawiki.org”. Out of this the developers are the largest stakeholder group that access and use the architecture documents to the maximum. To cater to new developers various channels and features

offer help in the form of mailing lists, IRC (Internet Relay Channel), Feedback dashboard, etc.

But a more concrete documentation needs to be prepared and maintained by the architecture component developers themselves. These detailed documents will help future developers to understand the software architecture in a more comprehensive way and on a more readable medium (mediawiki.org). This requirement was also realized during the “Mediawiki Developer meetup – 2009” which suggested the need for improved documentation and hinted on the usage of Bots for maintenance purpose. Also, as a part of the “Mediawiki coding conventions” it was suggested to include a textual documentation of the code details in a separate file as a part of any coding activity.

Stakeholders play an important role in the implementation and maintenance of a process. Likewise in the case of documentation process, the developers are the key stakeholders who as both provider and user of the documents. As the developers understand their respective development in the best possible way, they themselves should prepare the documentation for the corresponding component/ feature/ module. This will help to capture the architecture decisions and rationale that can be utilized for future reference.

2.5.2. Meetings / Interactive Sessions

To understand the requirements from the perspective of stakeholders, sessions were held remotely and on-site with the members of the mediawiki organization at Berlin. These meetings and conversations gave a chance to understand the existing process and requirements for process improvement in a more detailed and focused manner (RQ2). The mediawiki representatives explained that although a compressed user guide could be copied along with a fresh wiki installation that includes basic information/ details in a concise yet understandable form, there is dire lack of a structured, detailed and complete architecture documentation within the community (RQ4).

Some documentation is available as a part of the source code for some architectural components. But the community prefers to have all documentation available on “mediawiki.org”(RQ4).

The problem that documentation is often not updated / maintained due to lack of a strict process was realized within the community who wanted quality documents that were mostly up-to-date (RQ3). A process that streamlines this maintenance activity was put up as an important requirement during these meetings (RQ4). The availability of guidelines to support the preparation of software architecture documents and assigning responsibility of its maintenance to developers or bots will assure the quality of the resulting documents (RQ4). The documentation is best understood and evaluated by

2. Research Questions

the developers using them and thus, quality of documentation process was indicated as an important requirement.

3. Literature Survey

This chapter aims to answer the previously formulated research questions by surveying already available literature and the related work in this direction. This literature survey forms a basis in this thesis to derive ideas from existing examples and to come up with ideas to conceptualize the implementation work ahead. Also the related work helps to start with the initial idea and build upon it to derive a novel solution to solve the existing problems.

3.1. Some Important Concepts

Software Architecture : Software architecture documentation provides a blueprint of a software-intensive system for the communication between stakeholders about the high-level design of the system [6]

Complete : A software or documentation or requirement is complete when it is “good enough to meet our expectations for this system within the context in which we are developing it” [2]

Documentation : Software architecture should be documented from a knowledge management perspective because “If it is not written, it does not exist” [14]

System : A collection of components organized to accomplish a specific function or set of functions [26].

Environment : Environment determines the setting and circumstances of developmental, operational, political, and other influences upon that system [26].

Stakeholder : An individual, team, organization who has an interest in a system [26].

Architectural View : A representation of a whole system from the perspective of a related set of concerns [26].

3.2. Points from Literature

This section elaborates on some facts and answers to research questions derived from existing literature. These points of reference help to build on ideas for finding solutions to the research questions formulated in this thesis.

3.2.1. Improved Documentation Process

How software architecture documentation process can be improved for Wikimedia Software and why is it required?

Software Architecture Documentation : A very extensive research and usage of software architecture documents, documentation process and evaluation has been covered in the book “Documenting Software Architecture- Views and beyond” [2]. The book suggests implementation of a “Package Module” for documentation that aims at collecting all relevant architecture documentation as a package i.e. all in one place. The architecture documentation is regarded complete when it captures the following aspects :

- Document control information
- Documentation roadmap
- How a view is documented
- System overview
- Views
- Mapping between views
- Rationale
- Directory

This makes the documents more available and improves ease of access. The book elaborates on capturing various views of the software architecture from the stakeholder’s perspective and explains the structuring of documentation based on these “stakeholder views” (e.g) in this thesis the target stakeholders are the developers- hence a software architecture documentation that explains the architectural component overview and inter-component interaction specification is required for the better training of new developers and serve as reference for experienced developers.

The book also answers the question : “Why choose wiki ?”. It suggests that documenting software architecture on a wiki platform has several advantages :

- wiki-links are easy to navigate
- they provide easy formatting options
- wiki is easy to learn and more or less, intuitive
- it delivers nice readable web pages which provide editing and revision feature for version tracking and maintenance
- the wiki-pages are available/ accessible by all

Process and Community : “Software processes are processes too !” [9] Literature supports the idea the understanding the social environment of software communities has helped to understand their functional model and process-orientation. This understanding has lead way for guidelines and best practices to improve their current processes, as explained in [14]. The Open source culture of Mediawiki community poses limitations brought about by the relaxed process management and control [6]. Hence an improvement requires a process to be built upon the existing, available resources that can be easily be adopted or integrated into the environment. The “Eclipse Development Process” suggest that guidelines can be provided for new members such that they follow processes in a more self-regulated manner [8]. The eclipse development process sets an example for open source communities by providing such guidelines for user groups like “committers” and “contributors” .

Software architecture documentation is an inherent part of the software architecture itself and is an integrated part of the architecture design process [24]. It is very important to document the software architecture as it helps to identify and record important decisions taken during the course of architecture design and also forms the basis for future architectural re-factoring.

Open Source Software Architecture documentation : The article “Empirical study of the effects of open source adoption on software development economics” [1] quotes that “When adopting an Open Source Software, software architecture documentation has a positive impact on the degree and cost of the software adoption”. Thus, it is important for open source communities to offer concrete documentation to expand and enrich their contributing community. Some research has indicated that a lack of software architecture documentation maintenance in open source projects may hinder the use and further development of the software [17].

Research and empirical studies [6] have revealed that there is no dedicated role in open source communities to take responsibility of collecting, archiving , aligning and maintaining the software architecture documentation. This mandated the need for an

advanced documentation process to handle the responsibility gap.

Documentation Level and Extent : The scope of detail in software architecture documentation “how much is enough and appropriate” and its need within open source developer community is largely dependent on “the contextual factors of software development, such as development method, rate of change, size of project, and architecture stability” ([13] [4]).

3.2.2. Current Industrial State-of-the-Art

What standard architecture documentation processes are available in the industry and practice of open source software?

Many industry standards have been defined in literature and practiced in the field of software engineering that support software process management and evaluation. Also, there is a possibility of adopting these standards in the open source community. Some research on the current practices in open source software development helps to understand the community processes and methodologies

Application Lifecycle Management tools : There are a host of ALM software suits available in the industry that support a software product’s governance, development and maintenance in order to streamline the development process and achieve better standards. The figure shoes a typical Application lifecycle management process, highlighting the important roles defined by the process.

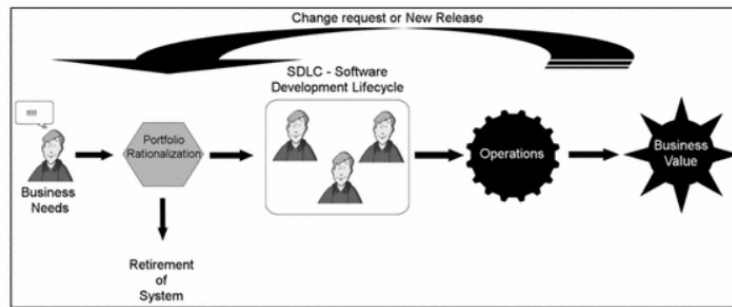


Figure 3.1.: ALM process and some roles.

Capability Maturity Model : For process oriented software engineering, CMM standards [22] have been set for process maturity evaluation. But open source communities are more focused on development maturity rather than process maturity. The Open Source Maturity Model (OSMM) [7] defines the standards and maturity levels to help

organisation to assess the open source software before adopting it.

IEEE1471-2000 standard : Documentation in standard software engineering projects follow the IEEE1471-2000 standard [2] from the project inception phase to document their software architecture. The standard outlines and also details the need for documentation of software architecture views and viewpoints.

Software process in Open Source community : The journal for “Systems and Software” [29] surveyed that over 61% of the open source projects employ bug tracking tools, and a majority of projects use bug tracking tools provided by the host web sites to maintain their software and process. No explicit standard or process has been defined for documentation alone but some maturity levels and standards have been defined by the comprehensive QualOSS assessment model [25] for open source software that can help to understand and improve the process maturity. Some earlier assessment models that concentrated mostly on OSS code, documentation and community structure are :

- Open Business Readiness Rating (OBRR)[11]
- Qualification and Selection of Open Source Software(QSOS) <http://www.qsos.org/>

Natural Language and visualizations : It was surveyed and studied that 70.4 % of the OSS projects use natural language with HTML as the main format for documenting software architecture [6].

XWiki : <http://www.xwiki.org/xwiki/bin/view/Main/WebHome> is a professional wiki the can not only provide a WYSIWIG (what you see is what you get) editing feature for content collaboration but can also be used for collaborative web applications. The popularity of this wiki tool suggests the demand for wiki as a platform for documentation and collaboration.

3.2.3. Evaluation and quality assurance of Documentation Process

What are the metrics for evaluation of the software architecture documentation process and how can the quality of process be assured?

As seen from the graph extracted from the survey of open source communities [29], we can evaluate and understand the documentation process followed by them. Similar results that were found in all responses to conclude that informal “TODO-lists” were the most common channel used for documentation.

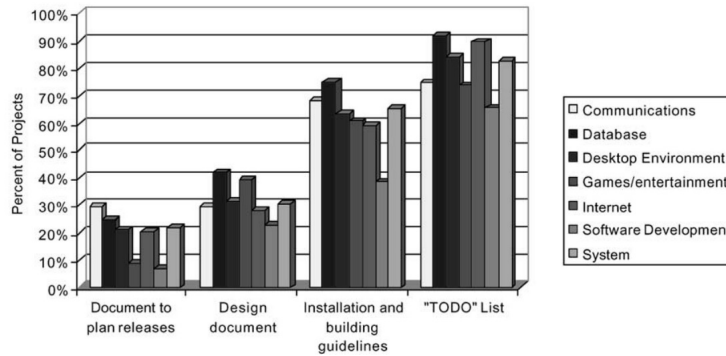


Figure 3.2.: Statistical evaluation of Documentation process/ modes in Open source communities.

The following can be considered as factors that define metrics for evaluating the documentation process:

Socio-Technical factors : Software quality is influenced by the way the community interacts [16]. The socio-technical environment within a community of developers who are geographically separated and not bound by strict process control tends to introduce risk factors in terms of software quality. QualOSS assessment model [25] suggest that the organization of open source communities is loosely-bound and statistical research [29] proves that only about 20% of the open source projects have planned release dates . Some process oriented co-ordination approaches have been developed and adopted by open source software communities to manage their software processes .The “STIN” (Socio-Technical Interaction Networks)in Free/Open Source Software Development Processes [20] describes the well-established STIN (“Socio-Technical Interaction Networks”)relationship for process enforcement by combining the socio-technical aspects that effect open source organizations.

Process Quality metrics : Maintainability, evolvability and sustainability of the system should be supported by the software process [2] [25]. There is a direct correlation between the quality of the process and the quality of the developed software [9]. The article on “Software Process Roadmap” [9] suggests that the degree of maturity of the process is a main dimension of process assessment. Open source communities have can be evaluated on the basis of a few exceptional metrics in this regard [29] :

- Responsibility : level of user participation in open source projects is extremely high
- Organizational process : simpler feature-request process and easier transition from detection to debugging

- Efficiency : larger motivation of developer to propagate personal need to community need
- Collaboration : open source processes and tools for change management include cutting edge, large-scale collaborative software development

The quality assurance activities in open source communities, that heavily rely on large scale distributed software development, is still an evolving discipline. Although the open development model may pose challenges with regard to quality assurance, sometimes it may prove successful as compared to traditional software development practices [29]. For example, more people or users of the code and documents will result in more errors / shortfalls / requirements to be detected, ultimately resulting in an accelerated software development and better quality. An extensive study of the open source Apache Server [18] resulted in findings that grounded the hypothesis that open source software development processes prove to reach the quality standards of traditional software processes and sometimes even reach better standards.

To assure quality the open source software community emphasize majorly on certain key process areas (KPA) which include high maturity levels of configuration management and project tracking, as compared to traditional software projects [29]. “User participation and feedback” serve as an important metric for assuring quality of open source software, its architecture and documents.

3.2.4. Stakeholder Requirement Satisfaction

Which specific requirements of Wikimedia stakeholders should be met by documentation process for Mediawiki SAD ? At mediawiki, the most active and important stakeholders are the coders or developers of the software.

Documentation within source code : The open source developers need to collaborate at a larger extent than traditional software systems. The daily work of developers within the community involves version control systems to manage and maintain the software repository. Thus, a requirement arises for collaboration in terms of code commit and source code consistency. Also, the documentation should be consistent with software version. It is always preferable and desirable that documentation confirms to the master branch source code.

Also, a centralized control structure like version control ensures and mandates restrictions into the community, thus, ensuring a structured process within organisation [27].

Community acceptance : Any existing or newly incorporated software process should fit into the socio-technical environment of the open source community [16].

munity interaction helps to understand the roles and responsibilities of community members as a part of the software process.

It is also observed that the free/ open source communities believe in the “opprtunity to learn and share what they know about the software” such that as the software evolves, the community grows as well [21].

Architectural views : [2] stresses the a good software architecture document should provide the different architectural views for all the different stakeholders of the software. In Figure 3.3 the standard views in accordance with the software architecture has been mapped to stakeholder concern. With the specific case of mediawiki software where the Developers(Programmers) are the prime stakeholders, all documentation needs to be created and maintained for the developers and by the developers.

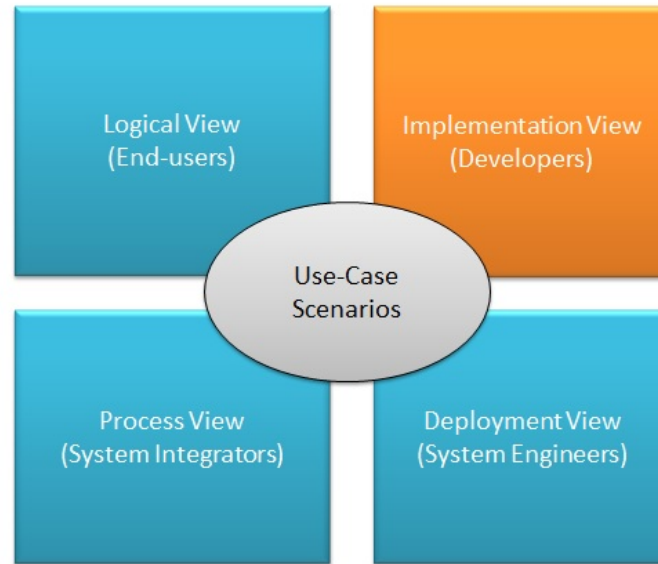


Figure 3.3.: "4+1" Unified View of the Software Architecture.

The document itself and the process to create/ update and maintain this documentation should assist the stakeholders and not add to cost of the software project ([23]).

Roles and Responsibility : The user management system is usually well-established in any software development organization which follow group management where user rights are group specific. Also, guidelines for user management with regard to the responsibility within the documentation process can be issued and followed [25]. This would include change submission and review of documents in the same process as the documentation.

Documentation Availability and Readability : Literature suggests that the following are the advantages of using wiki as a tool to document software architecture [3] :

- Higher Granularity of text with better readability and navigation options.
- No special deployment needs, only a web browser is required at any place that has network connectivity.
- Search option is not limited to current page, rather to the entire wiki.
- Feedback page (in the form of discussions) improve user participation and feedback to assure quality of the documents [29].

3.3. Idea Generation

This section covers the ideas that were derived from the literature to improve the documentation process for Mediawiki.

The book “Documenting Software Architecture – Views and Beyond” [2] suggests to define a page for architecture document in the existing wiki.

Idea : Use category feature of wiki to segregate “Mid-level Software Architecture Documentation” pages. Also, add templates on wiki page such that source-code consistent documentation belongs to non-editable parts and cannot be modified by sources other than Mediawiki developers.

Wiki is not able to track and edit past changes and only provides a discussion page.

Idea : Add the software architecture documentation to version control system (along with the source code). Also, migrate document related discussion from wiki page to task management system where documentation process can be tracked as a task.

Many options are available to capture documentation in wiki format. The book “Documenting Software Architecture – Views and Beyond” [2] suggests to use word2wiki to migrate word documents into wiki. Also XWiki (<http://www.xwiki.org/xwiki/bin/view/Main/WebHome>), a free wiki software platform includes WYSIWYG editing, OpenDocument based document import/export options, semantic annotations and tagging, and advanced permissions management.

“Software Process” [9] suggests to pay attention to the complex interrelation of a number of organizational, cultural, technological and economical factors.

Idea - It is wise to interact personally with members of the community to understand

their specific requirements, already existing practices/ processes and try to improve it, rather than bringing in something completely new. This increases the acceptance of the process within the community

“Documenting Software Architecture from Knowledge Management perspective” [14] suggests to provide rationale for final architectural solution. Within a software organisation, the extent of design that constitutes its software architecture is based on its “context, domain, culture, assets, staff expertise, etc.”. And this “thin line in the sand” must be made visible to all stakeholders. Also, it is important to “revisit, redefine and adjust” the architecture design decisions as the software and organization evolves. It is the software architect’s responsibility to “make design choices, validate them, and capture them in various architecture related artifacts” [15]. The Mediawiki coding convention suggests having a text (.txt) file for the corresponding component in the source code *mediawiki.org/wiki /Coding conventions Documentation*

Idea : The documentation should be written by the architect/ developer as they understand the architectural components in the best possible way. While an architectural component is added/ updated, the corresponding text file documenting the component should also be update. There can be inter-references between the code and document to find relevant parts easily.

The architectural viewpoint needs to capture details that are more abstract than source code functional details and less abstract than high-level architectural component interaction [14].

Idea : Capture the architectural component details and their functional details from a developer’s view of the system to add relevant details as understood by current developer and as would be required for the future developer.

“Mediawiki.org” follows a standard user based rights system to grant permissions (*Manual:User Rights*) to user groups with the special case of BOTs that have the rights to access and modify “mediawiki.org” pages for huge volume of maintenance activities.

Idea : Apart from manual creation of documents by the Mediawiki developers, the responsibility for their maintenance can be partially automated by the usage of BOTs.

Part II.

Thesis Contribution

4. Conceptualization

After framing of research question and sorting ideas from related work and literature, the thesis contribution aims to answer the questions posed initially and conceptualize an optimal solution. The solution should not only meet the stakeholder and community requirements but also confirm to some already established / deployed standards or tools. The ultimate aim is to find a solution that is evaluated and accepted by Mediawiki stakeholders as a deployable/ usable solution.

4.1. Idea Generation and Evolution

This section outlines the approach that was taken to understand the existing system and derive solutions for improved documentation process.

4.1.1. Preparatory Tasks

During the initial weeks of conceptualization phase discussion were held and emails were exchanged with the developers / architects at Mediawiki to come to an understanding of their current community setup and to get a beginner's guide to the system. Their suggestions and the advise of experienced developers to kick-start included the following :

1. **Understand and use the Software :** It was important to download and locally install Mediawiki open source software to understand the basic components of the software architecture. The installation guide (https://www.mediawiki.org/wiki/Manual:Installation_guide#) helped in understanding the system requirements and successfully configuring and setting up the executable code on the "localhost" under the the name "en" to denote the english language version of the setup.

4. Conceptualization

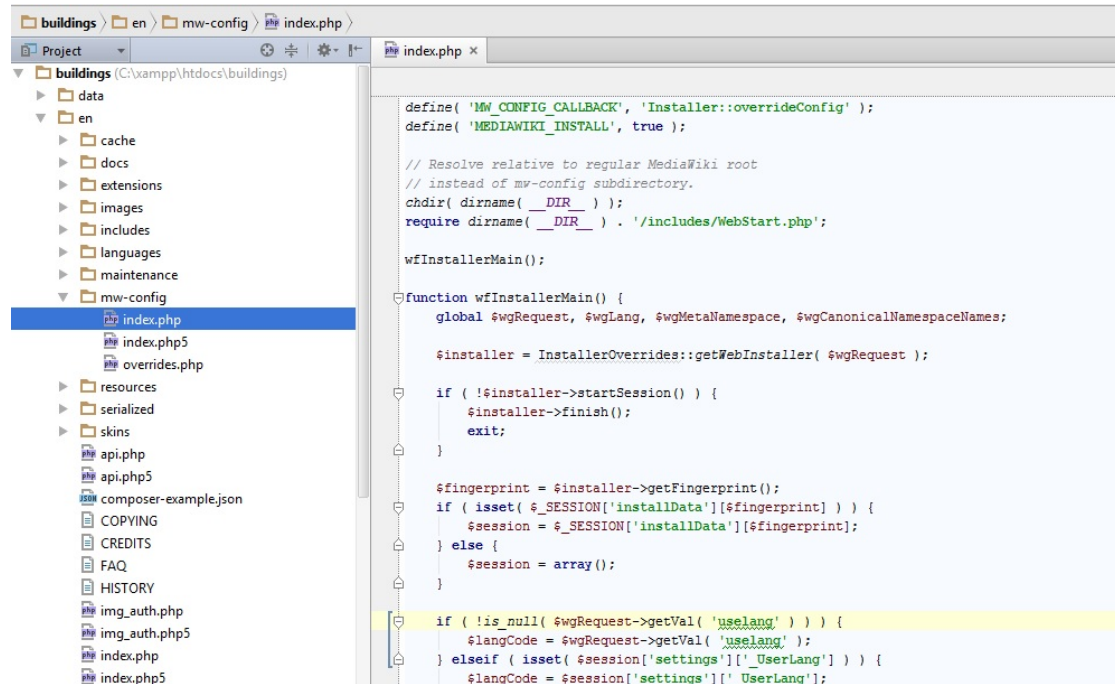


Figure 4.1.: Mediawiki source code and configuration file.

In Figure 4.1 we can see the The Mediawiki code is completely written in PHP. The first approach to understand the architecture was to dive into the “\includes” folder which comprises the code for the basic architectural components of the Mediawiki software like “api”, “cache”, “db” and many more. The successful setup of Mediawiki software and configuring the necessary database and server setup, the main page of the local installation powered by the Mediawiki engine could be launched as seen in the Figure 4.2.

4. Conceptualization

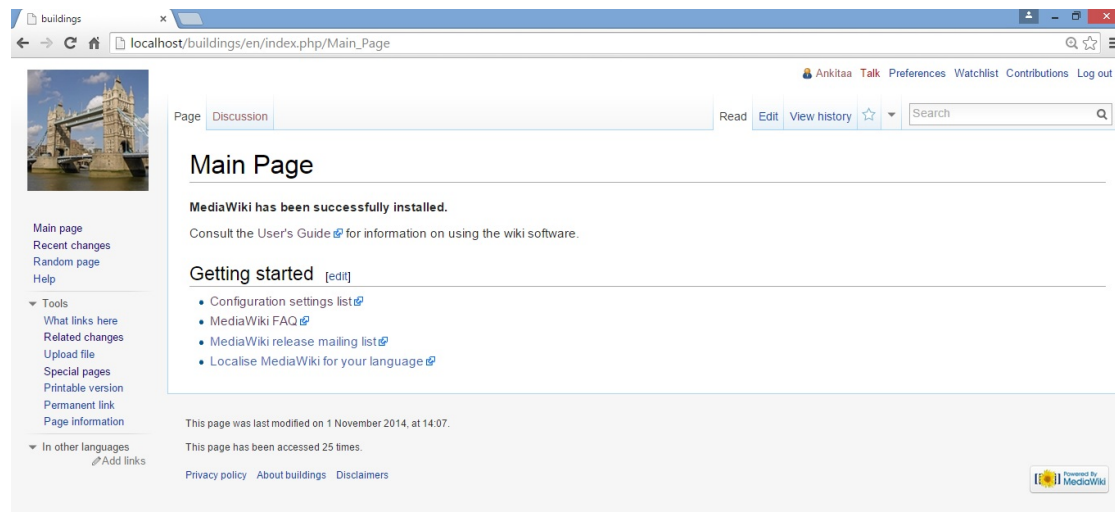


Figure 4.2.: Main page of the local Mediawiki installation.

This complete setup now helped to play around the software and the wiki to understand, use and modify its features.

2. **Analyze the documentation that already exists :** It was important to understand the documentation that is already available on “Mediawiki.org” in order to analyze the pros and cons of the existing structure and process of the software architecture documentation. The existing documentation helped to get a high level understanding of the system and some low-level implementation details of certain components which are well-documented (e.g) Mediawiki APIs (<https://www.mediawiki.org/wiki/API:Tutorial>), Extensions (<https://www.mediawiki.org/wiki/Manual:Extensions>) etc. Documentation is also available for developers and system administrators at <https://www.mediawiki.org/wiki/Documentation>. During code analysis the important architectural components and modules were identified as candidates that were in need of an improved, organized, detailed and structured architecture documentation :

- Installation, Update and Deployment
- Page processing, rendering and caching
- Extensions
- Architecture and Software Performance
- Internationalization / Localization
- Static and Dynamic Structure

- User and Access Control
- Database Design
- Security

It was advised to look into “Doxygen” tool’s auto-generated documentation of the software that captures the code and function level details of the Mediawiki software architecture. As seen in Figure 4.3, it is clear that the the architecture details are captured at “Module”, “Class” and “File” level.

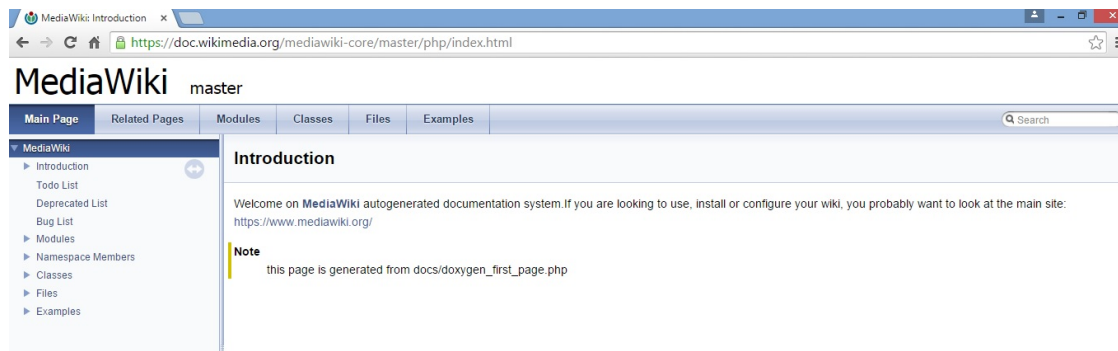


Figure 4.3.: Auto-generated doxygen documentation.

Having realized the need for improved documentation of Mediawiki software architecture, the conscious demand arose for an improved process that could ensure the creation and maintenance of improved documents. Hence the scope of this thesis work was limited and set to the defined scope of “Improving the Software Architecture Documentation process of Mediawiki Software”.

3. **Organizational structure :** When understanding a software system as an organization and the processes that drive its daily activities, it is important to understand the “Who, What and How ?” of the system. This helps to grasp the organizational behavior as a complex socio-technical system. Thus the initial phase of the thesis involved the identification and understanding of current roles, responsibilities and processes that are practiced in the Mediawiki community. The outline of the current state-of-the-art organizational components have been captured in chapter 2 Section 2.3.
4. **Documentation process as a part of the software process :** Every software development organization follows a process in order to manage, co-ordinate and

streamline its daily SDLC (Software Development Life-Cycle) activities. Documentation itself is a part of this development process. Thus, it was important to analyze the process for generating and maintaining documentation by mediawiki community in order to assess its shortfalls and required improvements. The software and documentation process components and an outline of their basic interaction can be seen in the figure Figure 4.4 The important roles within the community that are a part of the software process have been captured in the blue ellipses. The interaction of these roles with the system components and the activities involved as a part of individual responsibility has been captured in the diagram.

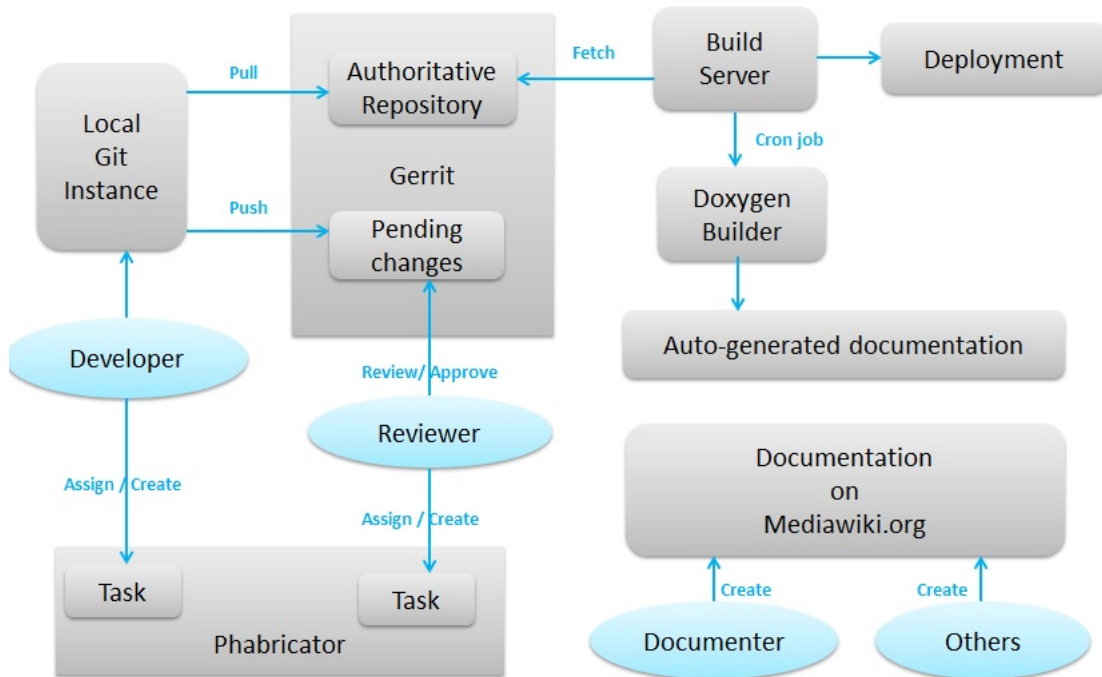


Figure 4.4.: Mediawiki Software Process including Documentation process.

5. **Understanding wiki (Mediawiki.org) :** It was suggested that in order to understand the wiki platform provided by “mediawiki.org”, it was important to use various features like templates, extensions, visualizations, etc. that are used for rendering and structuring the content with better readability and navigability. Also, it is useful to understand the “namespaces” like “categories” that can help to

organize the wiki pages into more understandable linearly-hierarchical structure. “Discussion pages” helps to improve the documentation where suggestions are given.

Other possibilities of documentation are also available on Mediawiki that prove the fact that conscious efforts have been made towards creation and maintenance of documentation in general and software architecture documentation in particular.

- Suggestions from 3rd party Mediawiki discussion pages can be used to create new requests that can be linked to “phabricator tasks” (https://www.mediawiki.org/wiki/Third-party_MediaWiki_users_discussion)
- “Project:PD” intends to create documentation as help pages that reach out to the public domain (https://www.mediawiki.org/wiki/Project:PD_help). The idea of this project is to provide a set of pages which can be copied into a fresh wiki installation, or included in the Mediawiki distribution. This will include basic user information and other “Meta information”, in a reasonably concise form. The basic concept is to create a compressed user guide which should focus on what users want and not explain other functions.
- Mediawiki manual on coding conventions mandates having a “.txt” file in “\docs” folder (https://www.mediawiki.org/wiki/Manual:Coding_conventions#Documentation)

During these preparatory activities, different versions of the solutions were conceptualized and reasoned for their applicability and usability within the existing socio-technical environment of Mediawiki. Arguments made for and against the concepts, judging the user scenarios and assessing the scope and feasibility of the concept helped in the decision-making process.

4.1.2. Initial Ideas - Use case scenarios

In order to understand the documentation process and intended improvements, the use cases for document creation and maintenance activities were developed.

Use Case 1 : When task for documentation is created by developer

User : Developer / Reviewer

Activity : task to write code and add document

System : Phabricator

Task Details : Documentation task is added by code developer / reviewer. The task is tagged with the related code patch git commit id.

Use Case 2 : When developer writes and commits a piece of code

User : Developer

Activity : Software Development - write code

System : Mediawiki

Task Details : A usual development activity to add code which is then review and pushed into production. Documentation may or may not be created or updated

Use Case 3 : When only document is added

User : Documenter

Activity : Creating / updating / reviewing software architecture documentation of mediawiki.

System : Mediawiki

Task Details : A usual documentation activity to add software architecture documents for which may or may not be a part of maintenance activities

Use Case 4 : Documentation task on phabricator

User : Developer / Reviewer

Activity : task to Creating / updating / reviewing software architecture documentation of mediawiki.

System : Phabricator

Task Details : Task to add software architecture documents is created under the project "MediaWiki-Documentation" <https://phabricator.wikimedia.org/tag/mediawiki-documentation/> and tagged as "documentation" to link all the tasks under this project. This task may or may not be assigned . Open comments section serves as a discussion forum to find related tasks or find people to complete the task.

In the figure Figure 4.5 all the above use case have been considered in a single use-case diagram.

Table 4.1.: Table to compare the wiki and other version control system

	Documentation on Wiki (Disadvantages)
Maintenance	Review is not possible. Anyone who has access to the wiki pages can edit and save pages.
	Tracking major changes is not possible.
Usability	Offline work not possible.
	A page save creates a new history entry. An insignificant change may lead to unnecessary

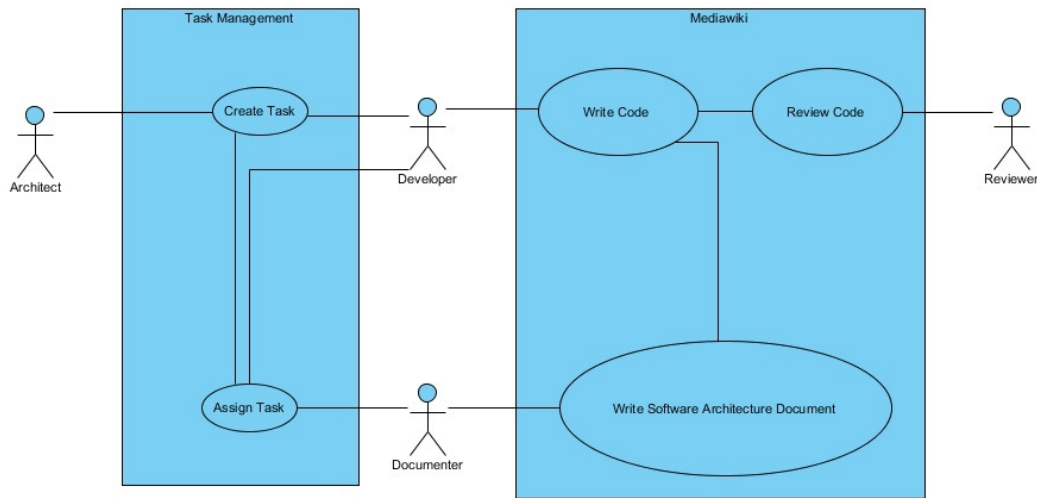


Figure 4.5.: Use-case scenarios explaining user roles and tasks.

4.1.3. Pros and Cons of the initial ideas

As a part of the literature survey Section 3.2.1, it was observed that documentation of wiki had several advantages over traditional documentation. But the concept of improved documentation process using only wiki as the platform may pose certain downsides. The following table compares the wiki with a version controlled platform on certain important criteria.

The table ?? projects the cons of wiki and the pros of version control, hence, suggesting the need for version controlled documentation.

4.1.4. Define feasibility and scope

4.2. Improved Process

Documentation health monitor Review of documents in a process-oriented structure - Gerrit review

4.2.1. Roles and Responsibility definition and co-ordination

Key principles to address challenges of the task-centered collaboration approach are [Felix Master thesis]

1. the self-organization of the community through task decomposition
2. an on-line community support based on social design principles and best practices
3. an open science process to enable unanticipated contributions

Solves issues identified previously streamline more people into a process

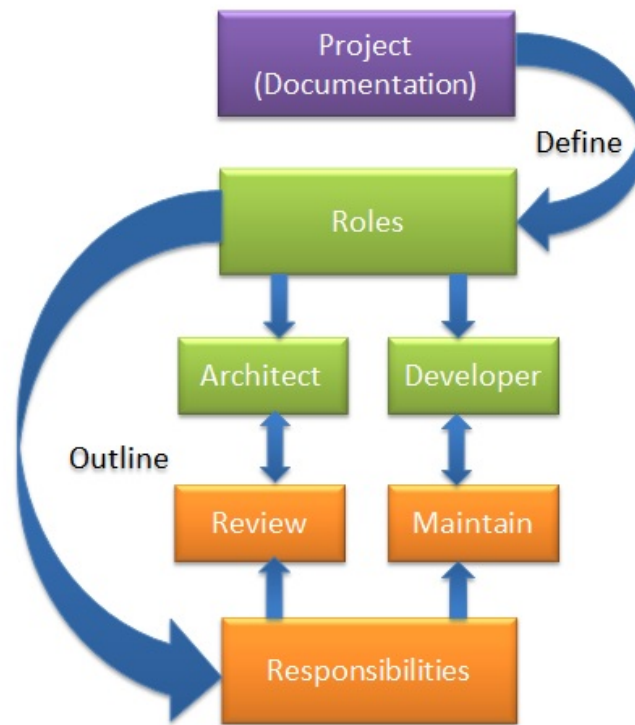


Figure 4.6.: Defining distinct roles and responsibilities in a process.

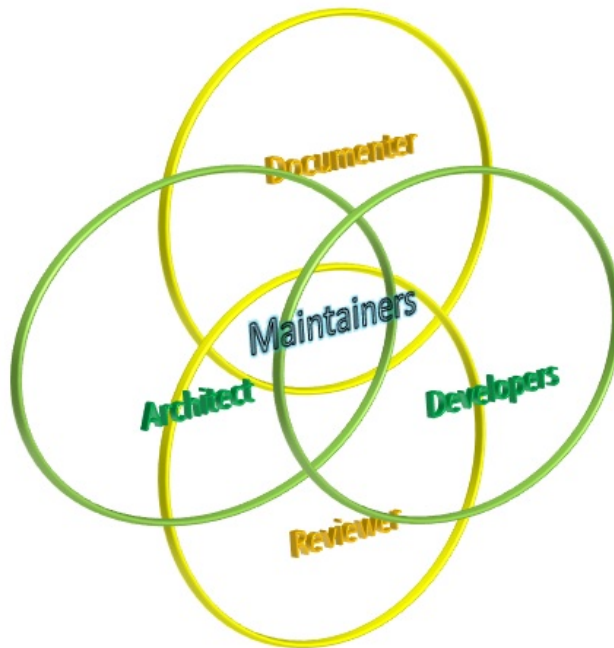


Figure 4.7.: The sphere of Maintainer's roles and responsibilities.

4.2.2. Document Maintenance Bot

Using bot to take on the responsibility of maintainable/ visible

4.2.3. Guidelines for the future process orientation

4.2.4. A proof of concept

figure : Bot in the system

In Figure 4.8 we can see the

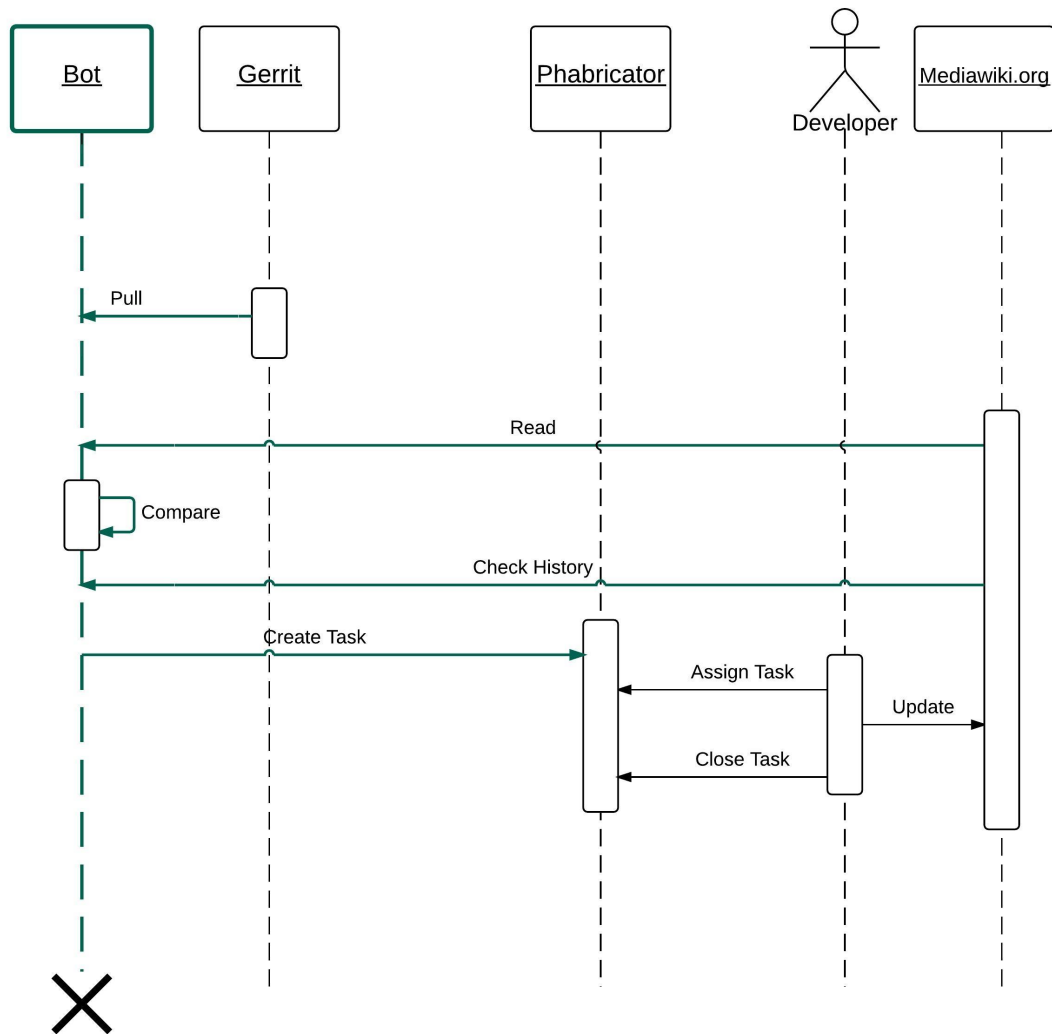


Figure 4.8.: Maintenance Bot Sequence diagram.

5. Implementation

5.1. Assumptions

the architectural components have been identified and a “.txt” file exists for each component

all corresponding docs are already available as of date on “Mediawiki.org”

annotations in the source code “@see” help to navigate to the corresponding text file in the docs folder.

The corresponding pages on Mediawiki.org have restricted access and are a part of the non-editable section such that they cannot be modified by other Mediawiki BOTs or users.

5.2. Architecture and Technical outline

5.3. Details of the implementation

5.4. Future implementation

Part III.

Evaluation and Conclusion

6. Evaluation

The QualOSS standard suggests that the quality of a process can be assessed on grounds of the following metrics :

- Evolvability or Maintenance capacity for continuous support and improvement
- Sustainability and survive the loss of important contributors over time
- Process Maturity

6.1. Meetings and Discussions

6.2. Survey

Is the process adequate for its intended purpose ?

6.3. Evaluation

7. Conclusion

7.1. Challenges

Acceptance within community Socio-behaviorial aspects of OSS community technical challenges

7.2. Benefits of implemented solution

7.3. arguments to support the idea

7.4. Concluding Remanks

List of Figures

2.1. Documentation available for software architecture levels	6
2.2. Current software maintenace process Sequence diagram	9
2.3. Current documentation process Sequence diagram	10
3.1. ALM process and roles [ALM2009]	17
3.2. Statistical evaluation of Documentation process/ modes in Open source communities	19
3.3. "4+1" Unified View of the Software Architecture [14]	21
4.1. Mediawiki source code and configuration file	26
4.2. Main page of the local Mediawiki installation	27
4.3. Auto-generated doxygen documentation	28
4.4. Mediawiki Software Process including Documentation process	29
4.5. Use-case scenarios explaining user roles and tasks	32
4.6. Defining distinct roles and responsibilities in a process	33
4.7. The sphere of Maintainer's roles and responsibilities	34
4.8. Maintenace Bot Sequence diagram	35

List of Tables

Bibliography

- [1] S. A. Ajila and D. Wu. "Empirical study of the effects of open source adoption on software development economics." In: *Journal of Systems and Software* 80.9 (Sept. 2007), pp. 1517–1529. ISSN: 01641212. DOI: 10.1016/j.jss.2007.01.011.
- [2] F. Bachmann, L. Bass, P. Clements, D. Garlan, J. Ivers, M. Little, P. Merson, R. Nord, and J. Stafford. *Documenting Software Architectures: Views and Beyond*. Second. Addison-Wesley Professional, 2010.
- [3] F. Bachmann, P. Merson, S. Architecture, T. Initiative, and T. N. Cmu. "Experience Using the Web-Based Tool Wiki for Architecture Documentation." In: *Technology* September (2005). ISSN: 1548-8837, 1548-8837.
- [4] L. Briand. "Software documentation: how much is enough?" In: *Seventh European Conference on Software Maintenance and Reengineering, 2003. Proceedings.* (2003). ISSN: 1534-5351. DOI: 10.1109/CSMR.2003.1192406.
- [5] e. a. Crouch Stephen. *The Software Sustainability Institute*. Computing in Science & Engineering , vol.15, no.6, pp.74,80, . Dec. 2013. URL: <http://www.software.ac.uk/>.
- [6] W. Ding, P. Liang, A. Tang, H. V. Vliet, and M. Shahin. "How Do Open Source Communities Document Software Architecture: An Exploratory Survey." In: *2014 19th International Conference on Engineering of Complex Computer Systems*. Aug. 2014, pp. 136–145. ISBN: 978-1-4799-5482-7. DOI: 10.1109/ICECCS.2014.26.
- [7] F-W. Duijnhouwer and C. Widdows. "Open Surce Maturity Model." In: *Capgemini Expert Letter* August (2003), p. 18.
- [8] Eclipse. 2013.
- [9] A. Fuggeffa, A. Fuggetta, and P. Milano. "Software Process : A Roadmap Software Process : A Roadmap." In: 97 (1988).
- [10] D. Garlan and M. Shaw. "Software Architecture: Reflections on an Evolving Discipline." In: *Proceedings of the 19th ACM SIGSOFT Symposium and the 13th European Conference on Foundations of Software Engineering* (2011), p. 2. DOI: 10.1145/2025113.2025116.

- [11] B. Golden. "Open Source in the Enterprise : From Invisible to Transparent The Litany of Enterprise Open Source Complaints." In: (2006).
- [12] A. J. Kim. *Community Building on the Web: Secret Strategies for Successful Online Communities*. 1st. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2000. ISBN: 0201874849.
- [13] P. Kruchten. "Contextualizing agile software development." In: *Journal of Software: Evolution and Process* 25.4 (2013), pp. 351–361. ISSN: 2047-7481. DOI: 10.1002/smr.572.
- [14] P. Kruchten. "Documentation of Software Architecture from a Knowledge Management Perspective – Design Representation." In: *Software Architecture Knowledge Management*. Ed. by M. Ali Babar, T. Dingsøyr, P. Lago, and H. van Vliet. Springer Berlin Heidelberg, 2009. Chap. 3, pp. 39–57. ISBN: 978-3-642-02373-6. DOI: 10.1007/978-3-642-02374-3_3.
- [15] P. Kruchten. "What do software architects really do?" In: *Journal of Systems and Software* 81.12 (Dec. 2008), pp. 2413–2416. ISSN: 01641212.
- [16] T. Mens and M. Goeminne. "Analysing the evolution of social aspects of open source software ecosystems." In: *Proc. 3rd Int. Workshop on Software Ecosystems* (2011), pp. 1–14.
- [17] M. Michlmayr, F. Hunt, and D. Probert. "Quality Practices and Problems in Free Software Projects." In: *Proceedings of the First International Conference on Open Source Systems*. Ed. by M. Scotto and G. Succi. Genova, Italy, 2005, pp. 24–28.
- [18] a. Mockus, R. T. Fielding, and J. Herbsleb. "A case study of open source software development: the Apache server." In: *Proceedings of the 2000 International Conference on Software Engineering ICSE 2000 the New Millennium* (2000), pp. 263–272. ISSN: 02705257. DOI: 10.1109/ICSE.2000.870417.
- [19] W. Scacchi. *Architectural Issues*. Vol. 69. Advances in Computers. Elsevier, 2007, pp. 243–295. ISBN: 9780123737458. DOI: 10.1016/S0065-2458(06)69005-0.
- [20] W. Scacchi. "Socio-Technical Interaction Networks in Free/Open Source Software Development Processes." English. In: *Software Process Modeling*. Ed. by S. Acuña and N. Juristo. Vol. 10. International Series in Software Engineering. Springer US, 2005, pp. 1–27. ISBN: 978-0-387-24261-3. DOI: 10.1007/0-387-24262-7_1.
- [21] W. Scacchi, J. Feller, B. Fitzgerald, S. Hissam, and K. Lakhani. "Understanding free/open source software development processes." In: *Software Process Improvement and Practice* 11 (2006), pp. 95–105. ISSN: 10774866. DOI: 10.1002/spip.255.

- [22] SCAMPI Team. "Standard CMMI Appraisal Method for Process Improvement (SCAMPI) Version 1.3a: Method Definition Document for SCAMPI A, B, and C." In: March (2013).
- [23] M. Shahin, P. Liang, and M. A. Babar. "A systematic review of software architecture visualization techniques." In: *Journal of Systems and Software* 94 (2014), pp. 161–185. ISSN: 01641212. DOI: 10.1016/j.jss.2014.03.071.
- [24] M. Shahin, P. Liang, and M. R. Khayyambashi. "Architectural design decision: Existing models and tools." In: *2009 Joint Working IEEE/IFIP Conference on Software Architecture & European Conference on Software Architecture* (2009), pp. 293–296. DOI: 10.1109/WICSA.2009.5290823.
- [25] M. Soto and M. Ciolkowski. "The QualOSS open source assessment model measuring the performance of open source communities." In: *Empirical Software Engineering and Measurement, 2009. ESEM 2009. 3rd International Symposium on*. Oct. 2009, pp. 498–501. DOI: 10.1109/ESEM.2009.5314237.
- [26] I. Standard. *INTERNATIONAL STANDARD ISO / IEC*. Vol. 2007. 2007. ISBN: 0738125180.
- [27] M.-w. Wu and Y.-d. Lin. "Open Source Software Development : An Overview." In: June (2001), pp. 33–38.
- [28] S. Yeates. *OSSWatch*. June 2008. URL: <http://oss-watch.ac.uk/resources/archived/documentation>.
- [29] L. Zhao and S. Elbaum. "Quality assurance under the open source development model." In: *Journal of Systems and Software* 66.1 (Apr. 2003), pp. 65–75. ISSN: 01641212. DOI: 10.1016/S0164-1212(02)00064-X.