A Comparative Review of Processes for Research Development on Applied Computing

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Abstract

The increasing volume of research projects on applied computing is a motivation for analyzing processes which are used to develop such projects. There are significant differences between research projects on applied computing and industrial software projects, for example, in research domain there is the interest in prototype development instead of product development. As a consequence, definition of specific processes to attend this context is required. Additionally, these processes are relevant because, with the widespread of the Internet, many researchers are working on collaborative projects from geographically distant areas and an adjusted process can help management overtime of artifacts like models, prototypes, and scientific documents. In this paper, the goal is to provide a comparative review of processes for research development on applied computing, based on requirements described in the literature. He hope that results of this review be useful to help researchers to select one approach or defining their own process.

1. Introduction

It is remarkable that, in the last years, results gathered from development of research projects on applied computing have contributed in a significative way for scientific and technological development. Regarding the increasing complexity of research projects and the diversity of areas involved, the definition, deployment, and improvement of processes in this context can be noted as very important [11, 28]. By research development we mean the process of knowledge acquisition, aiming at confirming or refuting previous knowledge. Also, research development is related to demonstrate new ideas, by means of proofs of concept.

Crucial elements differentiate development of research and industrial projects in computing area. For example, in research environment, there is the interest in software prototype development. In industrial environment, there is the interest in software product development, commercialization, and profit. Additionally, as stated by Bellotti et al [6], in industrial setting, the strategic value in a software project is related to the business model that is the inspiration for the software development effort. On the other hand, in research environment, the strategic value is related to acquire knowledge. Certainly, such differences have an impact on the process and, as a consequence, there is a demand of special approaches for research development domain. Moreover, artifacts are different in both settings and processes should provide mechanisms to produce them.

As pointed out by Ambati and Kishore [2] and Boldryeff et al [9], researchers have encountered problems with management and evolution of their collaborative projects in applied computing. It is common multiple re-writes of existing functionality, rather than prototype evolution. In spite of difficulties, there is interest of industry in partnership with successful laboratories [15]. According to Kornecki et al [20], companies focusing on software-intensive safety-critical products understand the importance of having a permanent academic partner familiar with the company domain and culture. In fact, early experiences [31] demonstrate that process improvement in a small Software
Engineering laboratory was fundamental to partnership formation with industry.

In this context, researchers with different goals, interested in improving their processes can ask themselves “Are there processes that can be used for development of research projects on applied computing?”; “What are the main characteristics of such processes?”; and “What process activities should be carried out in research setting?”. In this paper, the objective is to explore these questions, i.e., we present a comparative review of four Processes for Research Development (Pro-RD) on applied computing published in the last years. The comparison criteria was a set of requirements for Pro-RDs identified from literature. The main contribution is to indicate state of art in this context and help researchers to select one Pro-RD or establishing their processes, based on experimented proposals.

The methodology was identifying a list of requirements for Pro-RDs (Section 2), presenting characteristics and activities of four Pro-RD proposals (Section 3) and discussing if requirements were covered in the context of Pro-RD proposals (Section 4). The paper concludes with an overview about characteristics of each Pro-RD and discussion of research open issues.


Initially, we present requirements for Pro-RDs. They were identified from an extensive bibliographical review. We included only requirements mentioned for at least three researchers in literature. A brief description for requirements and bibliographical references indicating them are presented.

[Requirement 1] A Pro-RD must support pre-development activities: it is important to provide mechanisms helping definition of research subject, planning of research activities, and training for novice members [2, 11, 17, 25, 31].

[Requirement 2] A Pro-RD must support life cycle activities: it is important to provide mechanisms helping requirements analysis, design, codification, and tests. Additionally, should be regarded (1) combination between elements of agile and traditional methods, (2) iterative development, and (3) prototyping paradigm [2, 17, 25, 28].

[Requirement 3] A Pro-RD must support management activities: it is important to provide mechanisms helping management of tasks, schedules, risks, costs, resources, configuration, infra-structure, and knowledge [2, 11, 12, 13, 16, 17, 21, 25, 30, 31].

[Requirement 4] A Pro-RD must support quality assurance activities: it is important to provide mechanisms helping verification, validation, documentation, peer review, and measurement involving artifacts resultant not only from the software prototype development, but also from the research development (for example, to provide mechanisms helping validation of research results against the initial plan) [2, 9, 11, 12, 17, 21, 25, 30, 31].

[Requirement 5] A Pro-RD must support collaborative development: it is important to provide mechanisms helping communication among members of groups, coordination of groups, roles definition, knowledge sharing, and artifacts integration. Also, it should be possible that members have perception about activities carried out by other members [1, 2, 9, 11, 28, 29, 30].

[Requirement 6] A Pro-RD must support distributed development: it is important to provide mechanisms helping distributed coordination, distributed management, artifacts control (monitoring progress of artifacts), and problem resolution [1, 2, 7, 11, 28, 29].

[Requirement 7] A Pro-RD must support activities promoting research development: it is important to provide mechanisms helping systematic review, experimentation, writing technical documents (technical report, paper, etc), and preparing didactic material [1, 3, 9, 11, 12, 28, 31].

[Requirement 8] A Pro-RD must support transference of knowledge from academy to industry (and vice versa): it is important to provide mechanisms helping definition of an academy-industry cooperation plan (regarding a win-win approach), preparation of material for training in industry, preparation for receiving and monitoring trainee researchers in industry, and transferring of ideas, solutions, prototypes, and infrastructure [5, 19, 20, 27].

[Requirement 9] A Pro-RD must support partnership formation between academy and industry: it is important to provide mechanisms helping definition of a partnership plan, communication among researchers and professionals, elaboration of contracts including information about copyright, patents, confidentiality, publication permission, intellectual property, financial support, and profit division [10, 14, 17, 20].

In summary, it is possible to observe that activities composing requirements are similar those mentioned in conventional standards, for example, ISO/IEC 12207 [18]. Additionally, as mentioned in requirements 5 and 6, there is the inclusion of new activities covering characteristics of a contemporary era (internet advent led us to cooperation, distribution, and collaboration). It is important to highlight, also, the inclusion of activities for research development domain (requirement 7) aiming at covering specificities of this particular context. Finally, requirements 8 and 9 indicated the increasing interest in cooperation between academy and industry.
3. Description of Processes for Research Development on Applied Computing

An overview about characteristics of four Pro-RDs selected in the literature is presented following. Two criteria were considered for selection: availability of complete description for proposal and publication of proposal over the last five years.

3.1. eXtreme Researching – XR

Chirouze et al [11] revisited eXtreme Programming (XP) practices [4] for the context of research development. According to the authors, properties of an agile methodology were chosen because it is people oriented, adaptable, and incremental. Also, the proposal extends the main practices of XP for distributed research development.

An important element emphasized in XR is the communication among members of the research project, using tools such as email, teleconference, and video conference. As XP, XR is composed by twelve practices: (1) frequent integration; (2) remote pair programming; (3) on-site customer; (4) collective knowledge; (5) planning game; (6) metaphor; (7) 40 h week on average; (8) coding standards; (9) controlled software spikes; (10) testing; (11) refactoring; and (12) object-oriented component-based modeling.

An adaptation for these practices was purposed. For example, for the practice “on-site customer”, the authors stated that “The principle investigator fulfils the role of the on-site-customer, who has final deciding powers. The customer’s requirements are supported by the entire research team” and, for the practice “40 hours week on average”, the authors stated that “Researching suffers unduly from outside influences such as writing publications and grant funding. The number of hours per week can vary quite considerably”.

An application supporting XR, named XPWeb (http://xpweb.sourceforge.net/), is available. By using it, researchers are able to share knowledge. Facilities such as version control, prototyping modeling, and unit tests are also provided. A screenshot of XPWeb is presented in Figure 1.

As positive aspect of XR, it is possible to mention that it was based on a known method (XP). Additionally, the availability of XPWeb is an important facilitator for carrying out the practices. As negative aspect of XR, it is possible to mention the high level description, i.e., activities and artifacts were not discussed. Another negative point is that a limited discussion concerning application of XR in real projects was presented.

![Figure 1. Screenshot of XPWeb [11]](http://xpweb.sourceforge.net/)

3.2. R&D Standard Process

Hwang and Park [17] defined the R&D Standard Process based on international standards for systems and software engineering and on their previous experience.

The process was developed in the Electronics and Telecommunications Research Institute in Korea. The goal was to provide a common framework so that R&D projects can be performed effectively. Another goal is to improve efficiency of organizations in relation to quality management systems.

As main characteristics, it is possible to mention that the proposal (1) included traditional work methods; (2) covered many areas, for example, systems, software, and hardware; (3) included a process tailoring guideline; (4) focused on an efficient configuration management process and a quality assurance process; and (5) provided several templates.

The R&D Standard Process is comprised of subprocesses divided into four categories: R&D Life Cycle, Supporting, Project Management, and Organizational Processes. The category of R&D Life Cycle is divided into System/Software, Devices, Basic Technology, Standardization, Policy, and Strategy. Sub-processes from R&D Life Cycle category are presented in Figure 2 and sub-processes from Supporting, Project Management, and Organizational categories are presented in Figure 3.

The objective of R&D Life Cycle Processes is to guarantee that products will satisfy the requirements. Supporting Processes are used to ensure the integrity of products. Project Management Processes establish project plans and evaluate the progress of the project. Organizational Processes establish the business goals and help organization to achieve them. Hwang and Park [17] regarded the approach as an initial baseline from which improvements to the R&D standard processes can be made, allowing to achieve com-
petitiveness and customer satisfaction.

As positive aspect of R&D Standard Process, it is possible to mention its extension. Consequently, it may attend different situations. A negative aspect is the lack of discussion about the possibility of using the process in an environment different of those for which it was elaborated. Additionally, in spite of the existence of documentation describing the proposal in details, it is not available for users.

3.3. Higher Degree Process – HDG

HDG [31] was defined by researchers of Software Engineering Application Laboratory (SEAL), in South Africa. It is a reference model for evaluating processes carried out in software research laboratories. The main purpose of HDG is to develop human resource with competence to carry out independent research. Proponent of HDG stated that many benefits may be achieved as a result of implementation of the process. Some examples are: the purpose of the investigation is understood; knowledge about relevant technical literature is acquired; the significance of the findings are assessed; and research results are disseminated.

HDG was presented as a set of ten base practices, presented in Figure 4. For each base practice, the author described the Process Name, Process Purpose, and Work Products. In HDG, main work products are: project proposal, technical paper, dissertation/thesis, project plan, work breakdown structure, meeting agenda/minutes, work product list, and technical paper review criteria.

As positive aspect of HDG, it is possible to mention its simplicity. Few base practices were suggested and artifacts that are specific for research environment were highlighted. As negative aspect of HDG, it is possible to note that most of base practices is presented in a generic way. For example, certainly, base practice 5 encompasses many activities and this is not discussed. HDG may be a good option for research groups beginning the improvement of their processes. It can be used initially, when researchers are learning how to change the process. Afterwards, it can be replaced by another approach.

The author mentioned a number of lessons learned with process improvement in the SEAL. We highlighted some of them:

- Measurement should be emphasized if researchers are interested in improving processes in laboratories: it is critical to the success of the programme;
- Supporting processes do not need to be highly automated to be effective;
- Sustained process improvement requires a sound process perspective.
3.4. The Yao’s Proposal

Yao [32] presented a framework of web-based research support systems by focusing on research activities, phases, and technology support needed.

In general, the framework is composed by seven main phases:

- **Idea-generating phase**: the objective is to identify a topic of interest to study (preparation or exploration phase).
- **Problem-definition phase**: the objective is to precisely define vague ideas generated in the previous phase.
- **Procedure-design/planning phase**: the objective is to make a research plan.
- **Observation/experimentation phase**: the objective is to observe real world phenomenon, collect data, and carry out experiments.
- **Data-analysis phase**: the objective is to make sense out of the data collected.
- **Results-interpretation phase**: the objective is to build models and theories that explain the results from the data-analysis phase.
- **Communication phase**: the objective is to publish the research results.

Additionally, according to Yao, in research environment it is important to consider the activities: profile management, that is responsible for collecting, organizing, and storing all relevant information about a research project and the scientists involved; resource management, that is the organization of many types of resources supporting research; and data/knowledge management, that is the record of useful data, information, and knowledge during the entire research process.

Other specific supporting functionalities are related to exploring, retrieval, reading, analyzing, and writing support. The first one is important because scientists may have only a vague idea about the project and it can help to gather useful data by means of browsing databases, libraries, and web. The second one assists retrieval related activities, such as browsing, searching, and organization of information. The third one is related to supporting extensively reading, i.e., assisting a reader in actively finding relevant material, as well as constructing cognitive maps from material. The fourth one aims at helping a scientist find the right tool for a particular problem. The fifth one is important because it may help researchers writing technical reports, a common and important activity in research environment.

As positive aspect of the Yao’s Proposal, it is possible to mention the close relationship of the process with a web-based system. Certainly, this is an important motivation for experimenting the proposal. As negative aspect, it is possible to note that the author did not regard the specificities of the context, for example, prototype development. Also, the author did not explain how activities and supporting functionalities are related to phases composing the framework.


After identifying requirements for Pro-RDs and describing main characteristics of four proposals defined in the last years, we are interested in discussing which requirements were covered in each proposal. Results of our comparative analysis are presented following.

**Requirement 1: A Pro-RD must support pre-development activities**

This requirement was not extensively emphasized in the Pro-RD proposals. Authors of Pro-RDs did not regard the importance of preparing the members and environment for a new scientific investigation. For example, they did not mention how to choose the research subject or define the scientific methodology.

Authors of XR regarded the Planning Game activity, focusing on how much the research project will cost and what the priorities are. In R&D Standard Process, an activity called Project Planning was included. Planning resources, schedule, and responsibilities was emphasized. The author of HDG included the Definition of Research Project Goals and Planning the Investigation base practices. The first is related to definition of research project objectives, key requirements, resource needs, and schedule implications. The second is about the definition of how the investigation will be carried out, in terms of activities to be performed and responsibilities of members. In Yao’s Proposal, the author included the idea-generating phase and the problem definition phase. Both are related to preparation for new research, however, the author provided few guidelines helping researchers to carry out such phases.

**Requirement 2: A Pro-RD must support life cycle activities**

The main requirement regarded during elaboration of Pro-RDs was the support to life cycle activities. As presented by Segal [28], development in laboratories is iterative and requirements are in a continual state of change. In fact, the majority of Pro-RD proponents assumed this when presenting the life cycle activities.

In XR, rapid prototyping and researching are closely related. Because it is based on an agile method, the adaptive characteristic was valued and, as a result, the prototype is
developed incrementally. Main life cycle activities in XR are Remote Pair Programming and Testing.

In R&D Standard Process, authors did not mention if life cycle activities should be carried out using an iterative or sequential approach. Traditional life cycle activities for system/software development are suggested in this Pro-RD: Requirements Definition, Architectural Design, Detailed Design, Implementation, Integration Test, and System Test. The same set is suggested for devices (hardware) development.

In HDG, the author did not discuss life cycle activities. In a base practice he suggested the execution of the research project but activities were not mentioned. The same is valid for the Yao’s Proposal.

**Requirement 3: A Pro-RD must support management activities**

An activity of XR related to management is the Collective Knowledge. In this activity, it is suggested that the entire research team maintains a collective knowledge through constant reference to the online repository.

Conversely, management activities were strongly taken into account in R&D Standard Process. The set of activities covers partially the requirement 3 in Section 2, however, it is notable that this Pro-RD is the most complete in terms of management activities.

A base practice of HDG is Planning the Research Project, however, management is not emphasized.

In the Yao’s Proposal, management activities were also included. The author regarded (1) the Profile Management activity, divided into research project profile management and scientist profile management and (2) the Resource Management activity, related to human resources, tool resources, and information/knowledge resource management. Such activities were extensively covered in the proposal.

**Requirement 4: A Pro-RD must support quality assurance activities**

In XR, the On-site Customer activity collaborates to validation during all prototype development. Also, Verification is strongly recommended in XR. The Refactoring activity was suggested and it is about improving quality of artifacts and reuse them in other iterations.

The Quality Assurance activity was included in R&D Standard Process but authors did not mentioned which tasks researchers need to execute. Therefore, there is not a complete specification for this activity.

HDG is based on review. The author suggested the Detailed Technical Review of Project Technical Goals and Review and Approve Technical Outputs base practices. The supervisor approves work products when goals for technical content and quality criteria have been met. Another base practice related to quality assurance in HDG is Validate the Research Outputs Against Proposal. In the Yao’s Proposal, quality assurance activities were not included.

**Requirement 5: A Pro-RD must support collaborative development**

Proponents of XR highlighted the importance of a coordinated research approach because, in general, research brings together diverse skills and talents. The Remote Pair Programming activity emphasizes the importance of communication by means of videophone, web cam, and desktop sharing. The Collective Knowledge activity also supports the collaborative requirement.

This requirement was not regarded in the context of R&D Standard Process, HDG, and Yao’s Proposal.

**Requirement 6: A Pro-RD must support distributed development**

In XR, authors suggested the Frequent Integration activity, that is the use of an online, always on, code repository available for distributed teams. The online repository is used for executing other activities. For example, when describing the Metaphor activity, author mentioned that metaphors are stored and updated through the use of the online repository. In general, the distributed requirement is scattered in many activities.

This requirement was not regarded in the context of R&D Standard Process, HDG, and Yao’s Proposal.

**Requirement 7: A Pro-RD must support activities promoting research development**

This requirement was not regarded in the context of XR and R&D Standard Process. In HDG, there is a base practice named Disseminate research results, that is related to assemble the findings of the research project onto technical documents and presentation at formal meetings. In the Yao’s Proposal, the Writing support activity was included. The author suggested usage of writing support software tools, such as word-processor, and additional functions such as grammar-checking. This activity is closely related to the communication phase.

**Requirement 8: A Pro-RD must support transference of knowledge from academy to industry (and vice versa)**

This requirement was not regarded in the context of XR, R&D Standard Process, HDG, and Yao’s Proposal. In spite of publication of specific approaches for changing experiences between academy and industry [8, 26], analyzed Pro-RDs did not encompass them.

**Requirement 9: A Pro-RD must support partnership formation between academy and industry**

Similarly to requirement 8, this requirement was not regarded in the context of XR, HDG, and Yao’s Proposal. In R&D Standard Process, the activity Intellectual Property Management was included but authors did not mention how it should be carried out.

In Table 1 we summarize results of this analysis. ‘Y’
means that the specific Pro-RD covers the requirement, ‘N’ means that the specific Pro-RD does not cover the requirement, and ‘P’ means that the specific Pro-RD covers the requirement partially.

Table 1. Relationship between requirements and Pro-RDs

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5. Concluding Remarks

In this paper we focused on processes for research development on applied computing. The goal was to indicate important elements helping to define and improve processes in research laboratories. Main contributions with this paper are: (1) a set of requirements for Pro-RDs, identified from literature, that can be helpful if researchers are interested in define their own processes or evaluate other Pro-RDs; and (2) a review of four Pro-RDs for applied computing, indicating characteristics, advantages, and disadvantages. It can be useful if researchers are interested in selecting and experimenting one approach.

In relation to Pro-RDs that we analyzed, it is important to highlight some key points. XR seems to be the Pro-RD more suitable for research development. This conclusion is based on main characteristics and activities of XR, such as inclusion of agile practices, usage of the prototyping paradigm, and emphasis on iterative development. Additionally, the majority of requirements was covered in XR, even partially.

The R&D Standard Process is the most traditional approach. It is strongly based on international standards for systems and software engineering. Particularly, life cycle and management activities were focused on. Clearly, additional effort is required for executing this process, because documentation is a key element.

HDG is a simple Pro-RD, suitable for researchers interested in beginning process improvement. Students and researchers are able to understand it easily.

The Yao’s Proposal covered few requirements. The proponents are interested in providing a software tool to support it, however, important elements, for example, life cycle activities were not mentioned.

Finally, we would like to mention open issues in the context of processes for research development on applied computing. Clearly, regarding the analyzed Pro-RDs, there are problems with covering requirements 5, 6, 7, 8, and 9. Therefore, as a result of this comparative review, we have defined a Pro-RD emphasizing such requirements [23]. Currently, we are using SPEM (Software Process Engineering Metamodel) [22] to model this process and we intend to develop a platform based on free software to support the process execution. Also, we have investigated how the design rationale approach may be used to improve documentation of research projects [24]. Another open issue is related to human factors and Pro-RD definition: it would be interesting if Pro-RD proponents could identify the user’s profile and regard this information during elaboration of the proposals.

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References


