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Ten years of Rich Internet Applications: a Systematic Mapping Study, and beyond

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BACKGROUND: The term Rich Internet Applications (RIAs) is generally associated with Web applications that provide the features and functionality of traditional desktop applications. Ten years after the introduction of the term, an ample amount of research has been carried out to study various aspects of RIAs. It has thus become essential to summarize this research and provide an adequate overview.

OBJECTIVE: The objective of our study is to assemble, classify and analyze all RIA research performed in the scientific community, thus providing a consolidated overview thereof, and to identify well-established topics, trends and open research issues. Additionally, we provide a qualitative discussion of the most interesting findings. This work therefore serves as a reference work for beginning and established RIA researchers alike, as well as for industrial actors that need an introduction in the field, or seek pointers to (a specific subset of) the state-of-the-art.

METHOD: A systematic mapping study is performed in order to identify all RIA-related publications, define a classification scheme, and categorize, analyze, and discuss the identified research according to it.

RESULTS: Our source identification phase resulted in 133 relevant, peer-reviewed publications, published between 2002 and 2011 in a wide variety of venues. They were subsequently classified according to four facets: development activity, research topic, contribution type and research type. Pie, stacked bar and bubble charts were used to visualize and analyze the results. A deeper analysis is provided for the most interesting and/or remarkable results.

CONCLUSION: Analysis of the results shows that, although the RIA term was coined in 2002, the first RIA-related research appeared in 2004. From 2007 there was a significant increase in research activity, peaking in 2009 and decreasing to pre-2009 levels afterwards. All development phases are covered in the identified research, with emphasis on “design” (33%) and “implementation” (29%). The majority of research proposes a “method” (44%), followed by “model” (22%), “methodology” (18%) and “tools” (16%); no publications in the category “metrics” were found. The preponderant research topic is “models, methods and methodologies” (23%) and to a lesser extent, “usability & accessibility” and “user interface” (11% each). On the other hand, the topic “localization, internationalization & multi-linguality” received no attention at all, and topics such as “deep web” (under 1%), “business processing”, “usage analysis”, “data management”, “quality & metrics”, (all under 2%), “semantics” and “performance” (slightly above 2%) received very few attention. Finally, there is a large majority of “solution proposals” (66%), few “evaluation research” (14%) and even fewer “validation” (6%), although the latter are increasing in recent years.

Categories and Subject Descriptors: General and reference [**Document types**]: Surveys and overviews; Information Systems [**World Wide Web**]: Web applications; Information Systems [**World Wide Web**]: Web Interfaces

General Terms: Algorithms, Design, Experimentation, Human Factors, Languages, Measurement, Performance, Security, Theory, Verification

Additional Key Words and Phrases: Rich Internet Applications, Systematic Mapping Study

ACM Reference Format:

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1. INTRODUCTION

The term *Rich Internet Application* (RIA) was coined in a white paper of Macromedia in 2002 covering the introduction of Macromedia Flash MX [Jeremy 2002]. The advent of Flash MX and similar so-called RIA technologies was fueled by the increased penetration and use of the World Wide Web in society, and with that, the raised demands of businesses and end-users for a richer, more qualitative Web experience. To date, a standardized, generally accepted definition of Rich Internet Applications is missing¹. Instead, Rich Internet Applications are qualitatively characterized as Web applications that aim to provide the features and functionality of traditional desktop applications. Rich Internet Applications strive for better responsiveness, improved interaction capabilities and a richer user interface to offer an overall richer user experience. They typically rely heavily on client-side technologies combined with asynchronous communication to achieve this.

Just over ten years after the introduction of the term *Rich Internet Application* a significant amount of research has been performed on the topic. Reflecting the multi-disciplinary nature of Web development and the wide variety of technological challenges involved, this research has been performed by different, often disjoint research communities and published in a broad range of venues. It therefore becomes important to summarize the results so far and present a consolidated overview of the field. The goal of this article is thus to present the scientific community with such a comprehensive overview and analysis of all research performed with respect to the development of RIAs, identifying trends and chart its evolution over time.

To achieve this goal, we conducted a systematic mapping study. Stemming from the medical field [Petersen et al. 2008] and recently being applied in software engineering (e.g., [Afzal et al. 2009; Barney et al. 2012; Condori-Fernández et al. 2009; Engström and Runeson 2011]), these studies aim to provide a thorough overview of a research field by using a scientific and repeatable method, and establish a baseline for further research activities, such as tracking research trends over time, performing in depth studies on specific topics, contextualizing reports and research articles by using a set of known references, or even as an education resource [Kitchenham et al. 2011]. A systematic mapping study is thus complementary to a systematic literature review, and a useful tool on itself as it is performed “at a higher granularity level with the aim to identify research gaps and clusters of evidence in order to direct future research” [Engström and Runeson 2011]. In accordance with [Kitchenham et al. 2011], the RIA systematic map here presented is therefore an ideal tool for:

- Beginning researchers that are initiated in the RIA field.
- Experienced researchers as a qualitative reference work which saves time for subsequent studies, provides an understanding of the existing literature on specific topics, and allows to identify the need for conducting additional research in specific areas. This is in particular important for highly multi-disciplinary fields, such as the RIA research field, where different sub-communities publish in different publication venues, and even experienced researchers are not necessarily aware of all facets and contributions in the broader research field.
- Industrial actors that need a thorough introduction and overview of the research field of study. A mapping study allows industry to get an overview of the state-of-the-art, identify trends and clusters of research studies that are suitable and applicable for their particular

¹In section 5.1, we provide a well-founded definition for RIAs, based on our extended literature study.

business use, thus aiding communication and knowledge transfer between academia and industry. Given the relative immaturity of the RIA research field, and the rapidly changing technologies, relevance for industry should however not be overstated, as e.g. standards, tools and case study, which are of particular interest for industry, are not yet sufficiently present in literature.

In this article, we first explain, in section 2, the research method (the systematic mapping study for RIA research) and the process we followed: definition of research scope, identification of primary studies, specification of the classification scheme and classification of publications. We also include a subsection describing the possible threats to validity. Next, in section 3, we analyze the extracted data and visualize the results using stacked bar, pie and bubble charts. Section 4 provides a discussion of the results in order to gain some interesting insights in the RIA research field. In section 5, we go beyond the systematic mapping study, and provide an in depth, qualitative analysis of the most remarkable results of the systematic mapping study, summarize the essence of RIAs and provide future prospects. Finally, in section 6, we draw conclusions.

2. RESEARCH METHOD

A systematic mapping study aims to find and classify the primary studies in a specific topic area [Kitchenham et al. 2010]. It specifies a well-defined, repeatable method to obtain a classification scheme, gather relevant studies, perform the classification and analyze the results [Petersen et al. 2008]. The analysis is focused to answer specific research questions, usually related to the identification and coverage of the field and its sub-fields, and possibly on the evolution over time. For our systematic mapping study, we deploy the process that Petersen et al adopted from the medical field and applied to software engineering [Petersen et al. 2008]. Our process thus consists of the definition of the research scope, the search process, definition of the classification scheme, the mapping of publications according to the classification scheme and the data analysis. A detailed overview of this process is shown in figure 1.

2.1. Research scope

The overall goal of this systematic mapping study is to provide a consolidated overview of (technical) research in the field of RIAs, its publication venues and evolution over time. This goal is reflected in the following research questions (RQs):

- RQ1:** What are the publication venues RIA research has been published in?
- RQ2:** Which phases of the RIA development cycle received most coverage, to what extent, and how is coverage evolving?
- RQ3:** What are the research topics being addressed in RIA research, to what extent are they covered and how is coverage evolving?
- RQ4:** What types of RIA research have been reported, to what extent, and how is the evolution?
- RQ5:** What type of RIA publications have been produced, to what extent did they receive coverage, and how is coverage evolving?

2.2. Search process

The search process aims to identify primary studies that are relevant within the research scope in a well-defined, repeatable way. We deployed a three step search process to identify such primary studies.

Step 1: initial search. To obtain the initial set of potentially relevant primary studies, from now on generally called “publications”, an extensive search was performed using scientific search engines. As our topic of interest lies within the broad field of computer science, we

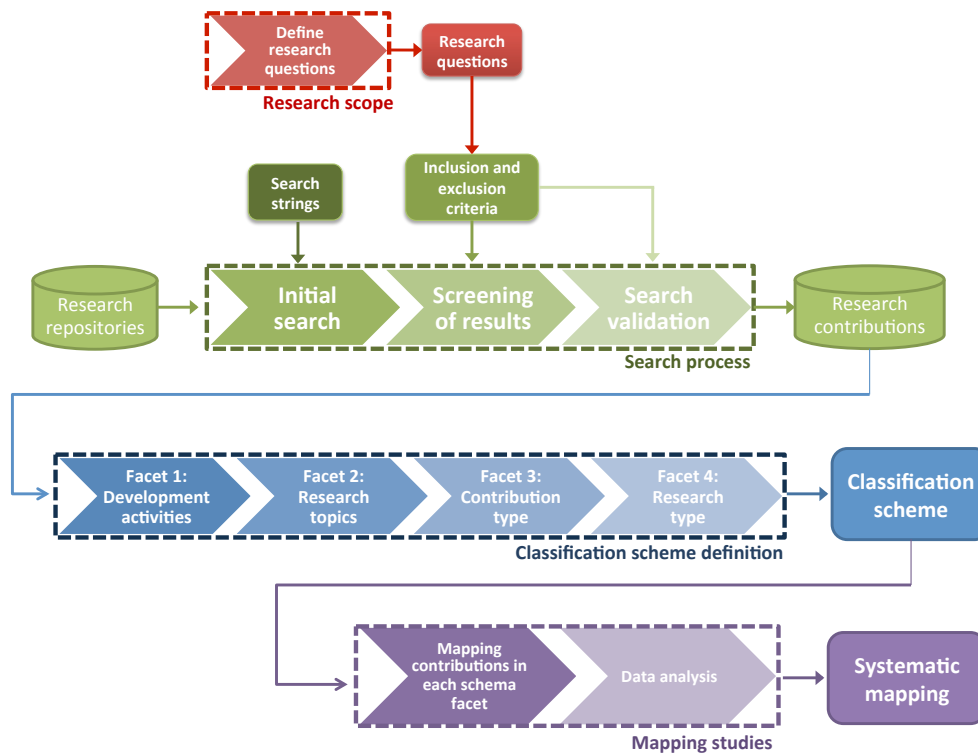


Fig. 1. Research process for the conducted systematic mapping study.

selected the search engines of the three major computer science publishing houses: Springer (SpringerLink²), IEEE (IEEE Xplore³) and ACM (ACM digital library⁴). At this point, we used the ACM digital library's restricted search, which includes only publications from ACM and affiliated organizations. In order to validate these search results, and to cover other publishers, we complemented these search engines with three generic search engines: Google scholar⁵, ACM digital library (extended search, including all publications indexed by ACM), DBLP CompleteSearch⁶. For these six search engines, we used the following search strings, both with and without quotes to include complete and partial string matching:

- Rich Internet Application
- Rich Internet Applications
- RIA

All searches were performed between 1st and 13th of March 2012. For each search, we inspected the first 100 results, totaling 3600 publications (i.e., 100 results for 3 search strings, each for 6 search engines, equals 1800 search results; times 2 for the quoted and non-quoted version, equals 3600 search results) to form the initial set. We hereby rely on the accuracy

²<http://www.springerlinks.com/>

³<http://ieeexplore.ieee.org/>

⁴<http://dl.acm.org/>

⁵<http://scholar.google.com/>

⁶<http://www.dblp.org/search/>

of each search engine ranking method, and assume that considering the first 100 results yields a relevant and representative result set⁷.

Step 2: screening of results. The initial set of publications contains irrelevant results that must be removed. In our screening process, all double entries are first eliminated. Next, every publication is inspected for relevance with respect to the research scope. To do so, we defined inclusion and exclusion criteria against which each publication was checked. We distinguish criteria related to form and content:

Form

Inclusion: all publications in English that underwent a competitive, peer-review process, and where the full text is available. This includes all short and full research papers published in peer-reviewed journals, conferences, symposia or workshops.

Exclusion: all sources that did not go through a competitive peer-review process or are not pure research contributions, i.e., books, Phd and master theses, patent descriptions, standards and recommendations, book or thesis summaries, technical reports, white papers, invited talks, demo papers, tutorial papers, poster publications, posters, editorials, prefaces, articles or columns in non-peer reviewed magazines, newsletters, encyclopedia entries or blog posts. We further exclude sources where the full text is not published, i.e., abstract, extended abstracts and presentations (slideshows).

Content

Inclusion: all publications fulfilling the previous inclusion criteria, and complying with at least one of the following two conditions:

- 1.a the abstract or introduction explicitly mentions Rich Internet Application(s) or an intended synonym (i.e., RIA, rich web client, rich web application),
- 1.b the abstract or introduction explicitly uses technological terminology used as an intended synonym for Rich Internet Application(s) (i.e., Ajax (Web) application, Ajax (rich) interface, Flash application).

The second condition ensures not to exclude technical, mostly implementation-oriented publications, performed using a particular technology, but nevertheless addressing general (technical) RIA problems. Additionally, the following mandatory conditions need to be fulfilled:

- 2 it can be deduced from the abstract or introduction that the research is explicitly performed within the context of software engineering in general, and within the context of Rich Internet Applications in particular, and
- 3 it tackles one or several research topics directly relevant for the development of Rich Internet Applications as main topic.

Exclusion: all publications that either

- (1) do not explicitly mention Rich Internet Application(s), nor an intended synonym (i.e., RIA, rich web client, rich web application), nor use technological terminology used as an intended synonym for Rich Internet Application(s) (i.e., Ajax (Web) application, Ajax (rich) interface, Flash application) in the abstract or introduction, or
- (2) do mention any of the aforementioned terms, but do not present research explicitly performed within the context of software engineering in general, and within the context of Rich Internet Applications in particular.

⁷Our search validation phase provides support for this assumption.

The second condition excludes research of RIA-relevant topics outside the software engineering field (e.g., studies of return of investment of RIAs, business administration w.r.t. RIAs), or within the software engineering field but performed in general terms, not particularly applied to Rich Internet Applications (e.g., client/server architecture research). It also excludes research that presents an application of a RIA (e.g., a RIA for online traffic control) rather than research about (technical aspects of) RIAs.

As studying the evolution over time is one of the objectives, we did not restrict our search based on publication year. As a starting point we consider 2002, the year the term was first coined [Jeremy 2002]; as endpoint we took 2011 (included), the last full year prior to this study. As such, we cover 10 years of RIA research.

The screening process was performed rigorously, applying the above inclusion and exclusion criteria. To ensure correct decisions, each publication of the initial set was randomly assigned to two of the authors. In case of disagreement, the remaining author gave his assessment, and the result was discussed to come to a final decision. Thirteen publications needed discussion, of which 4 were excluded and 9 included in the final set. In this way, the initial set was reduced to 123 relevant publications.

Step 3: search validation. Three steps were undertaken to validate the aforementioned search process, in order to ensure our screening process produces a complete set. In each step, the inclusion and exclusion criteria of the screening process are re-applied.

- (1) We took the transitive closure of the relevant publications using their references.
- (2) For each research venue where more than one relevant publication was found, we checked all issues and proceedings (from 2002 until 2011).
- (3) We repeated all our previous searches, and checked the next 30 search results (i.e., entries 101 - 130).

Step 1 was performed iteratively until no new results complying with the inclusion criteria were found. This resulted in 10 additional publications. All of these, with the exception of one ([Linaje et al. 2009a], which is a lowly visible workshop publication, consisted of publications that do not literally mention the term “Rich Internet Application” or “RIA”, but are relevant based on the use of technological terminology used as an intended synonym for Rich Internet Application(s) (see Inclusion criteria - content - 1b). Step 2 and step 3 did not result in any new publications, indicating that our search process can be considered complete. The final set of relevant publications thus consists of 133.

2.3. Classification scheme definition

After obtaining the final set of publications, we devise a classification scheme that corresponds with the research scope and research questions set in section 2.1. Based on those research questions, we considered four facets for classification: development activity, research topic, contribution type and research type.

Facet 1: development activities

Description: those activities that are required to be performed in the RIA development process

Derivation method: the activities are extracted from the online evolution model for Web applications [Casteleyn et al. 2009], describing the development activities for modern Web application development, and more generally, Boehm’s spiral process model for software engineering development [Boehm 1988], which inspired the former. We hereby cover software development activities in general, and RIA development activities in particular.

Classification scheme:

- requirements
- design
- implementation & deployment
- testing
- maintenance
- evolution
- others

Facet 2: research topics

Description: the main research topics in RIA research

Derivation method: the topics are extracted from the call for papers of the five most popular publication venues as determined in the search process. For conferences, the call for papers of the last three years (2009, 2010, 2011) were considered, for journals, the journal’s call for papers, and if applicable, the call for papers for a special issue on RIAs, were considered. From all these sources, only the topics relevant for RIAs were considered, and irrelevant issues were omitted. Where necessary, detailed and similar topics were grouped in a more general category. From our study, the top five publication venues are International Conference of Web Engineering (ICWE), International Conference on Web Information Systems Engineering (WISE), International Cross-Disciplinary Conference on Web Accessibility (W4A) , IEEE Internet Computing (IEEE IC) and International Symposium on Web Systems Evolution (WSE). In this way, nineteen research topics we identified.

To validate the initial classification scheme and to ensure that the keywords extracted from the call for papers are those related to research in RIA, we used the “keywording” technique as described in [Petersen et al. 2008]. In case a particular research topic did not show up using the keywording technique, it was discussed among the three authors to verify relevance, and rejected if it was not relevant. One (partial) topic did not show up in the keywording technique, namely “localization, internationalization & multi-lingual”, but was nevertheless judged relevant. The keywording technique also allowed us to extend the classification scheme with one additional research topic, namely “user interface” (indicated with a “*” below). Note that we purposely did not base our classification scheme solely on the “keywording” technique, as this method does not allow to identify blind spots in coverage of the research area.

Classification scheme:

- adaptivity, personalization & contextualization
- architecture & application frameworks
- business processing
- data management
- deep Web
- design patterns
- event processing & event-driven systems
- localization, internationalization & multi-linguality
- migration & re-engineering
- mobility & device dependency
- models, methods & methodologies
- performance
- quality & metrics

- security & trust
- semantics
- testing & evaluation
- tools & languages
- usability & accessibility
- usage analysis
- user interface (*)

Facet 3: contribution type

Description: type of contribution of the publication

Derivation method: the contribution types were extracted from existing systematic maps in software engineering [Engström and Runeson 2011; Petersen et al. 2008]

Classification scheme:

- method: a method or process (i.e. describing how to do something).
- methodology: overviews, comparisons, surveys, studies of technologies/methods/models/techniques.
- metric: a way to measure certain properties of a method, model, process or system
- model: a (conceptual) representation of a subject of study.
- tool: any software artifact related to RIAs, including frameworks, development tools, languages or algorithms.

Facet 4: research type

Description: type of the reported research

Derivation method: the type of research is not specific to the particular topic of RIAs, yet generally applicable. As other systematic maps in software engineering [Engström and Runeson 2011; Petersen et al. 2008], we therefore use the classification scheme proposed by Wieringa et al [Wieringa et al. 2006].

Classification scheme:

- solution proposal: describes a solution, usually illustrated with an example, case study, running example, etc. The work is barely or not validated (see next); the proposal is only explained, and it is shown how to apply it.
- validation research: describes validation of research that is not deployed in practice, for example, by an experiment, performing some kind of tests, lab studies, etc. Usually it follows a solution proposal. It answers the question: is the proposed solution “good”?
- evaluation research: describes an evaluation of research, usually by seeing how the solution works in practice, or comparing it with other solutions, pointing out positive and negative points. It is more extensive than validation and it is often carried out within an industrial setting. It answers the question: is the proposed solution the “right” solution?
- philosophical or conceptual proposals: sketch a new way of looking at existing things, provides a vision or philosophical view on a subject matter.
- opinion paper: describes the opinion of the authors, usually taking a positive or negative stance. It may also present an overview of a field or a comparison of techniques from the viewpoint of the author. Generally, it does not rely on related work or a research methodology.
- experience paper: describes the experience of the authors, usually in practice, using a certain method, technology, etc. Often, these papers are written by people from industry.

2.4. Mapping studies

With the classification scheme in place, we classify each of the 133 relevant publications according to each facet. To ensure correctness and consistency of the classification process, all of the 133 publications of the final set were randomly assigned to two of the authors for classification. For each facet, each publication was classified into one or more categories by both authors. In case of conflicting results, the third author was asked to classify, and the results were discussed to come to a final outcome. 53 publications required discussion; about one third of them were publications that were classified in multiple categories, but one of the two assigned authors failed to classify the publication in one or more of these multiple categories. The remaining two thirds contained vague or incorrect formulations regarding their contributions, and needed in-depth reading and discussion to determine the correct classification. Examples of vague formulations include “approach” or “system”, which may refer to a method, model, methodology, or combinations of these. Examples of incorrect terminology includes “case study” when in fact only a proof of concept or illustrative example was given. Similar problems were reported in other systematic mapping studies or reviews, e.g., [Mendes 2005].

2.5. Threats to validity

There are several factors that may threaten the validity of systematic mapping findings. In literature, the main shortcomings of systematic maps have been identified as (i) bias in the screening of publications [Barney et al. 2012], and (ii) errors when classifying the publications into detailed categories [Engström and Runeson 2011]. Here, we acknowledge one additional threat: (iii) possible misleading summarization data due to a large amount of so-called “delta papers”. While a formal definition is lacking, delta papers are informally characterized as “papers that provide no or only minor additions compared to previously published work of the authors”.

To address the first issue, we undertook several measures to minimize the risk. First, the selection of search engines was designed to cover the targeted research area in depth and width. We selected specific search engines to target the biggest publishing houses covering the research field (i.e., ACM, IEEE and Springer), and complemented them with general-purpose search engines to validate the results of previous engines, and to cover other publication venues. Second, we have to ensure that all publications on the selected topic are found. To do so, we introduced the search validation step (see section 2.2, step 3) after screening of publications, which was designed to identify missing publications. Three actions were undertaken to ensure a complete set (in each, the inclusion/exclusion criteria were re-applied): expansion of the set by (i) iteratively screening all references of the initial set of publications, (ii) screening all publications of identified research venues, and (iii) repetition of the search process to screen the next 30 entries for missing publications.

To address the second issue, the screening process was performed rigorously by randomly assigning each publication of the initial set to two of the authors, and having the third author act as referee when the first two authors disagree. To address the terminology problem, mentioned in section 2.4, in case of doubt, we extended our screening of a publication from the abstract and introduction, to the conclusion and subsequently, the full paper.

The final issue refers to the fact that a straightforward counting of publications may paint an incorrect picture, *if* many delta papers exist. This threat was not considered in previous systematic mapping studies, which may be explained by a multitude of reasons. First, due to the nature of systematic mapping studies, identifying delta papers may be considered out of scope, for two reasons: (i) typically, only the abstracts are considered to categorize publications, which provides too few information to detect a delta contribution; (ii) the aim is to provide quantitative results (i.e., amount of publications), not qualitative results (i.e., aggregate and summarize research contributions). But more importantly, quantifying

a publication's (additional) research contribution, compared to the respective author's previous work, is a time-consuming and extremely hard task, for which no objective criteria are available, and which thus unavoidably involves a certain subjectivism. Nevertheless, a large amount of delta papers may indeed cause an incorrect view of a research field, and therefore, we addressed this issue in the following way. First, we grouped all publications based on authors: all publications where at least 50% of the authors are the same, are clustered together. In this way, we obtained nineteen clusters that contained more than one publication: nine of 2 publications, three of 3 publications, one of 4 publications, two of 5 publications, two of 6 publications, one of 7 publications and one of 14 publications; totaling 74 possible delta papers. Second, each publication is read, its detailed research contributions summarized, and compared with all other publications within the same cluster for possible delta papers. Possible delta papers are discussed among the three authors to come to a final decision. This resulted in eight delta papers: one in a cluster of 2 publications, two in a cluster of 5 publications, one in a cluster of 6 publications and four in the cluster of 14 publications, all of them spread over all categories in each of the four facets. With 8 out of 133 (= 6%) total publications delta papers, spread over all categories in each facet, we consider this threat negligible in our study.

3. DATA ANALYSIS

In this section, we present the data analysis that was performed on the set of 133 identified relevant publications. In the next section, we answer the research questions based on this data analysis, and discuss the results in more detail.

The data analysis is guided by the research questions defined in section 2.1. We use stacked bar charts to visualize the results, per year, according to each of the four facets discussed in section 2.3. Stacked bar charts were elected as they allow to (i) give a visual overview of both the total yearly publication frequency, and the frequency for the different categories within a facet, (ii) visualize the relative weight of each category and compare them with others, (iii) represent the evolution of each category within a facet over time, and (iv) convey the overall evolution of all categories within a facet. Each stacked bar chart is complemented with a pie chart, to show the aggregated results over the full time period. A pie chart is also used to visualize the distribution of publications over publication venues. Finally, we use bubble charts to visualize the relations between the different facets and as such represent the systematic map(s) of Rich Internet Application research. Bubble charts are traditionally used for this purpose, as they allow three-dimensional representation of data, where each bubble represents the publication frequency with respect to two facets.

Before presenting the details of our analysis we make two general observations. First, based on our analysis, no relevant publications regarding Rich Internet Application were found in the first two years after introduction of the term, i.e. 2002 and 2003. Therefore, although these years were included in our search, we do not include these years in any of our graphs, and we refer to the year 2004 as the first year of Rich Internet Application research. Second, we remark that the total amount of publications in the different charts may slightly differ, due to the fact that a single publication may be classified in several categories within a single facet. E.g., many publications contribute both a model and a method to derive these models; as a result, they are counted both as method and as model in the publication type facet.

The full list of relevant publications, and their classification according to the four facets, can be found in the summary table in appendix 2.

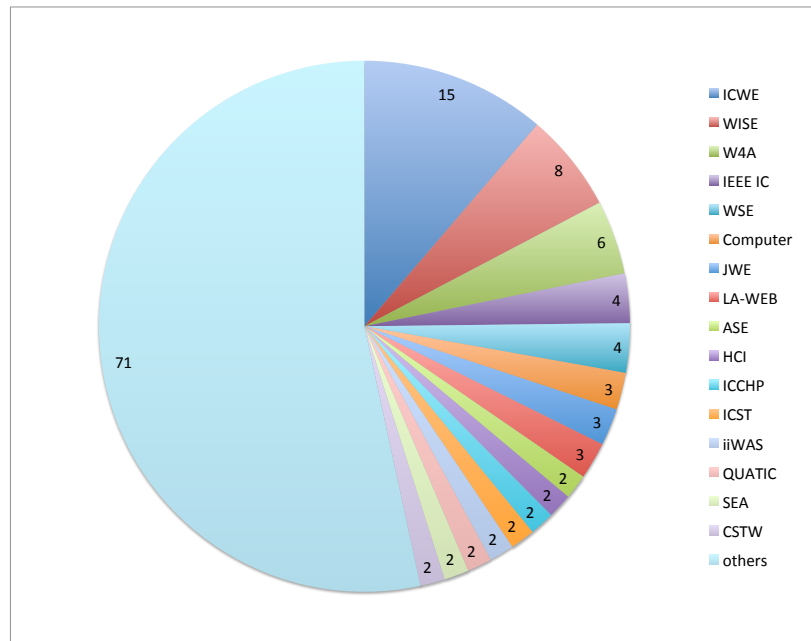


Fig. 2. Pie chart representing the distribution of publications over publication venues.

3.1. Publication venues

From figure 2⁸, we observe that the International Conference of Web Engineering (ICWE) is the prime publication venue for Rich Internet Application research (15), followed by the International Conference on Web and Information Systems Engineering (WISE) (8) and the International Cross-Disciplinary Conference on Web Accessibility (W4A) (6). The top five is completed by IEEE Internet Computing (IC) and the International Symposium on Web Systems Evolution, both with 4 publications. More than half of the publications (71) were unique in the venue they were published in, i.e. indicated as “others” in figure 2.

3.2. Facet 1: development cycle

From the accumulated results shown in figure 3, we observe that the “design” (33%) and “implementation” (29%) phase are most covered. Other phases are covered significantly less, with the “requirements” phase least covered (4%).

In the stacked bar chart, we observe publications starting from 2004 (1), and slowly increasing in 2005 (3) and 2006 (6). The phases covered during these initial years focus on “implementation” issues, with the first publications addressing “design” appearing in 2006. From 2007 there is a noticeable turning point, with a significant increase in the total amount of publications, a heavy emphasis on the design phase, closely followed by the implementation phase, and a broader, yet limited amount of coverage of all development cycles. Overall, the ratio between coverage of design and implementation on one hand, and other development phases on the other, is roughly 2:1. From 2010, we observe a decrease in total amount of publications, and in particular a decrease of design phase coverage and, to a lesser extent, implementation coverage. In 2011, there is a better spread of coverage over all design phases.

⁸All used acronyms can be found in appendix 1.

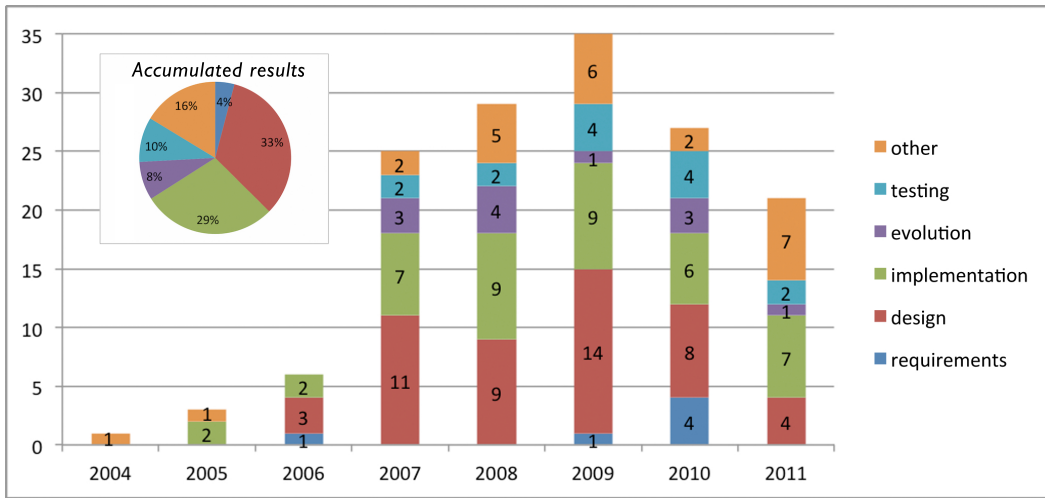


Fig. 3. Bar chart representing the Development Cycle facet over time.

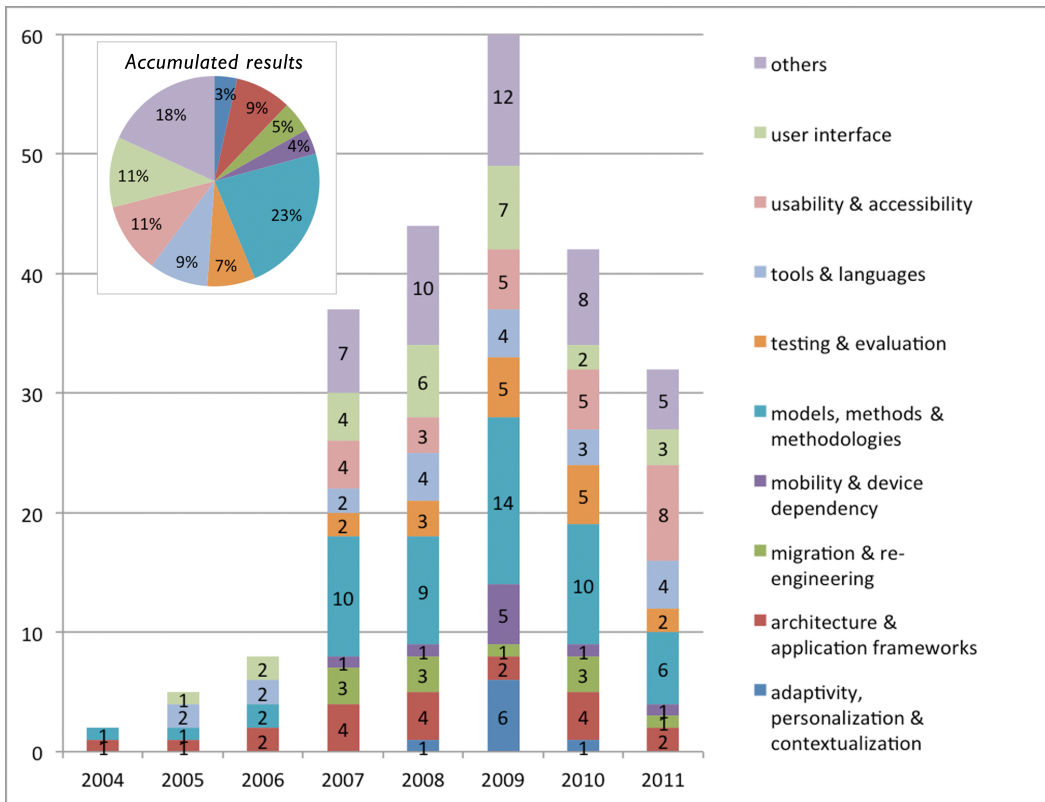


Fig. 4. Bar chart representing the Research Topics facet over time.

3.3. Facet 2: research topics

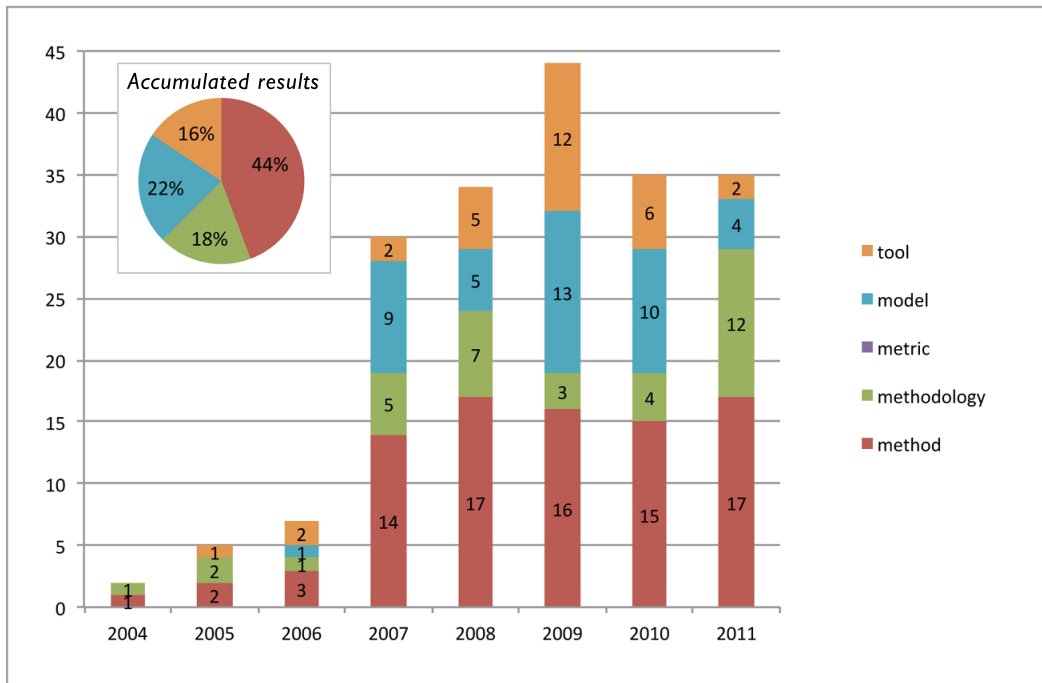


Fig. 5. Bar chart representing the Contribution Type facet over time.

From the accumulated results shown in figure 4, we observe that the topic “models, methods & methodologies” received the most attention (23%), followed by “user interfaces” and “usability & accessibility” research (both 11%). All other topics attribute for less than 10% of coverage. We did not find coverage for the topic “localization, internationalization & multi-linguality”.

In the stacked bar chart, we observe that publications in the initial years 2004, 2005 and 2006 were focused on the following research topics: “models, methods & methodologies”, “user interfaces”, “tools & languages”. From 2007, new topics appear and are relatively balanced until 2011. Nevertheless, the number of publications related with “model, methods & methodologies” is clearly the highest during all these years, and the number of publications focused on “usability & accessibility” is steadily increasing, reaching a significant percentage in 2011.

3.4. Facet 3: contribution type

From the accumulated results shown in figure 5, we see that almost half of the publications concern methods (44%). All other contribution types are comparable in amount and attribute for around 20% each. Remarkably, we did not find any publication focusing on “metrics” for RIAs.

From the stacked bar chart, we see mixed contribution types in initial years of RIA research (2004, 2005, 2006), and a sharp increase in “method” and “model” publications starting from 2007, followed by “methodological research” and to a lesser extent, “tools”. In 2009, there is a peak of publications focusing on “tools”. During 2011 there was a significant increase of publications related to “methodologies”.

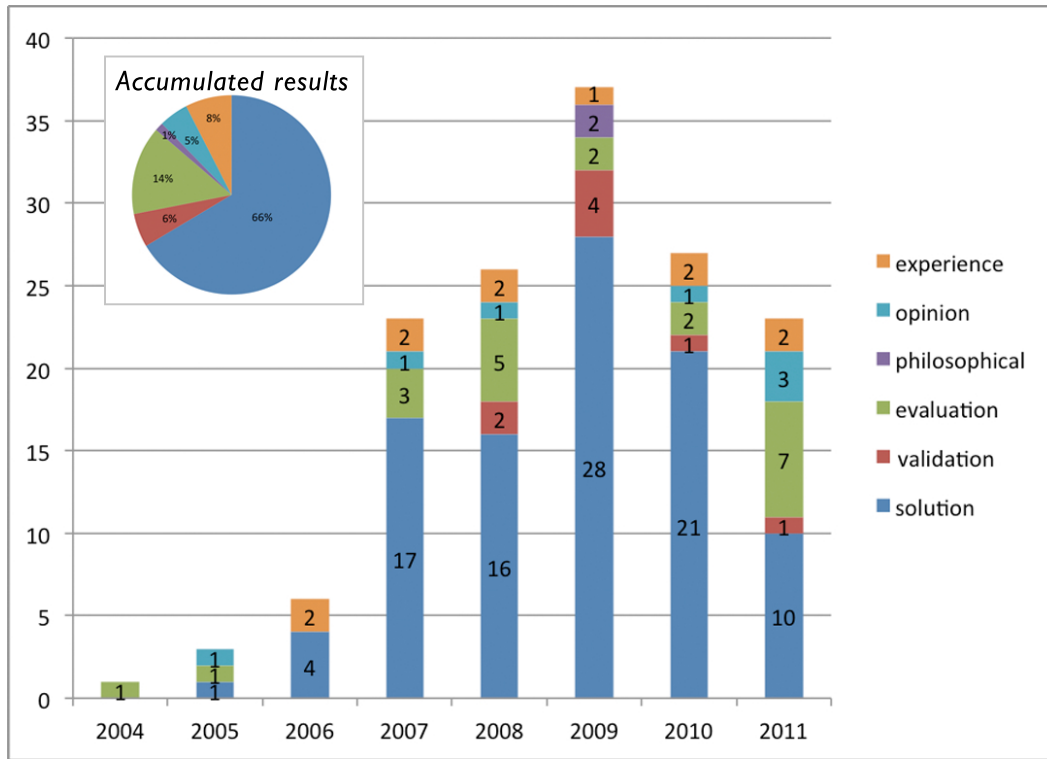


Fig. 6. Bar chart representing the Research Type facet over time.

3.5. Facet 4: Research Type

From the accumulated results shown in figure 6, we observe that the large majority of publications are “solution proposals” (66%). There is some “evaluation research” (14%); other research types attribute for less than 10% of coverage.

From the stacked bar chart, we observe that in the first two years, 2004 and 2005, there were few publications, which were of different research type. From 2006, we see an increase of “solution proposals”, a trend that is confirmed between 2007 and 2010. There is an absolute peak of “solution proposals” in 2009 (28). On the other hand, during these years, we see that there are far fewer publications of other research types: the first “validation proposal” only appears in 2008, and there are few experience and opinion contributions every year. Only 2 “philosophical proposals” were identified, both in 2009 [Dworak 2009; Velasco et al. 2009]. In the last year, 2011, we note a sharp decrease of solution proposals, and an increase of evaluation research.

3.6. Combining facets: the Systematic Map(s)

Figure 7 shows a bubble chart representing the systematic map over the contribution type (north axis), research topic (east axis), research type (south axis) and development phase (west axis). Several observations can be made related to this chart.

First, we focus on the research topic facet and contribution type facets (north-east area). We see a high importance of the research topic “models, methods & methodologies” (68 of 271), where the contribution type of these publications are mostly “models” and “meth-

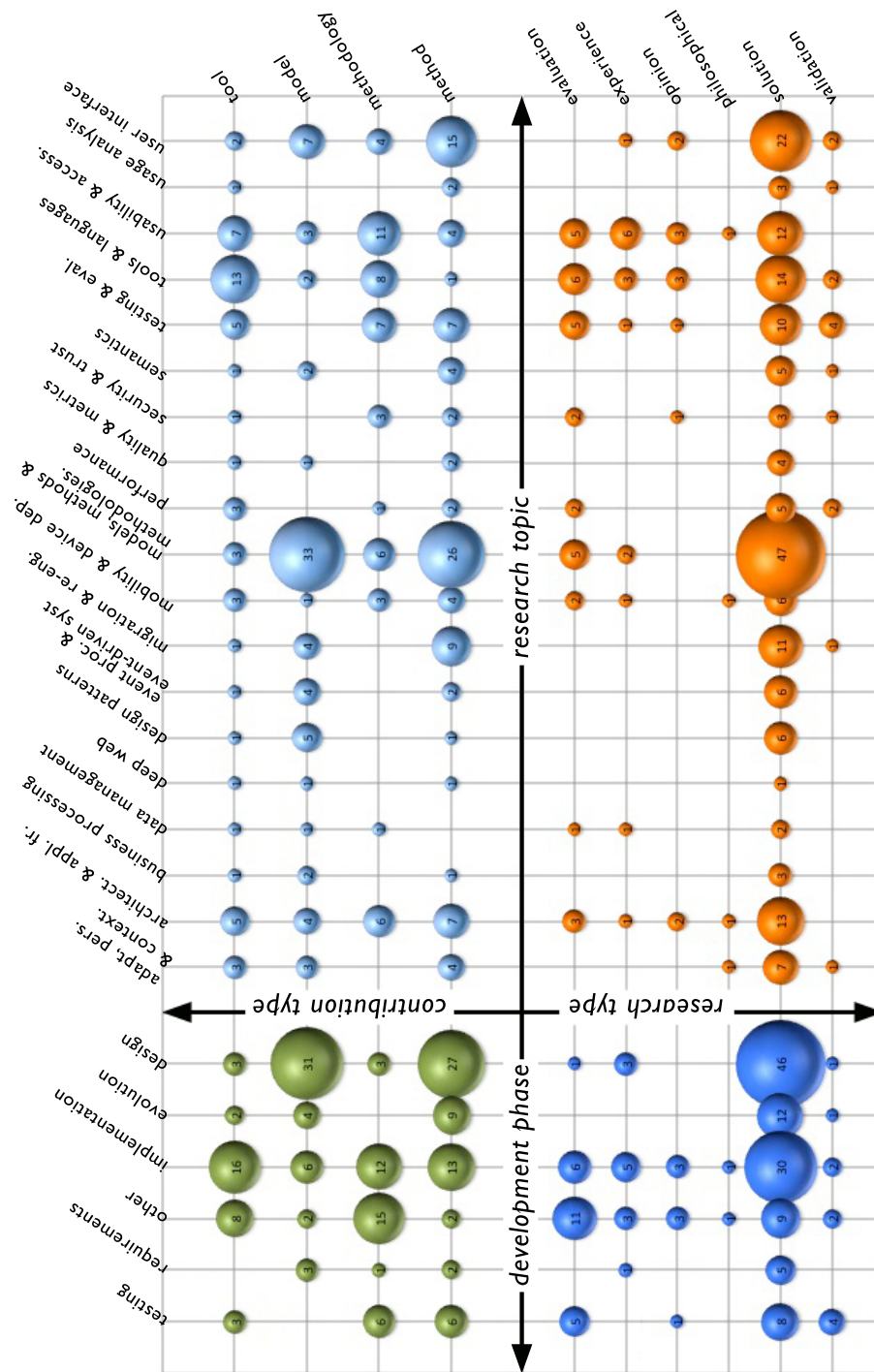


Fig. 7. Systematic Map over contribution type (north), research topic (east), research type (south), development phase (west).

ods” (59 of 68), and few “methodologies” (6 of 68) and “tools” (3 of 68)⁹. Other popular research topics are “user interface” (north-east, 28 of 271), mainly contributing “methods” and “models”, “usability & accessibility” (25 of 271), mainly contributing “tools” and “methodologies”, and “tools & languages” (24 of 271), mainly contributing “tools” and “methodologies”, . These research topics are closely followed in popularity by “architecture & applications frameworks” (north-east), contributing evenly over all contribution types, and “testing & evaluation” (19 of 271), contributing evenly over all contribution types but lacking any “model” publications. The other research topics are represented to a lesser extent, with various contribution types depending on the topic. From the perspective of contribution type, and disregarding “models, methods & methodologies”, we notice that “models” and “method” contribution types are spread over almost all research topics, with few lacks and local peaks in certain topics. On the other hand, we note that for quite some research topics, there are no publications of type “methodology”, while some topics (i.e., “architecture & application frameworks”, “testing & evaluation”, “tools & languages”, “usability & accessibility”) show higher amounts of methodological contributions. Finally, “tools” publications are reported for all research topics, many however constituting only one, some research topics (i.e., “architecture & application frameworks”, “testing & evaluation”, “tools & languages”, “usability & accessibility”) reporting higher amounts.

Considering research topic versus research type (south-east area), we notice a predominance of solution proposals, distributed over all research topics, but clearly most for “models, methods and methodologies” (47 of 180). For all research types, there are significantly less publications, and they are spread out over some research topics, with all other topic/type combinations receiving no coverage at all. In particular, there are many blind spots for “philosophical” and “opinion” contributions. From a research topic point of view, the topic “models, methods & methodologies” is most popular, where the vast majority of these publications concern solutions. For this topic, we only counted some “evaluation research” (5 of 54) and “experience papers” (2 of 54), and no “philosophical” or “validation research”. Also in the “user interface” research topic, we see a high amount of “solution proposals” (22 of 27), with no “evaluation” and only few “opinion” (2 of 27) and “validation research” (2 of 27). Only for few topics (i.e., “tools & languages”, “usability & accessibility”), the publications are distributed over the different research type in a balanced manner.

In some specific research topics, i.e. “models, methods and methodologies”, “testing & evaluation”, “tools & languages” and “usability & accessibility”, there is some evaluation research, but only half or less compared to solution proposals.

With respect to the development cycle versus research type (south-west area) we observe that the “solution proposals” are dominant (110 of 164), but well-spread over the whole development cycle, with peaks for “design” (46 of 110) and “implementation” (30 of 110). When discarding “solution proposals”, we notice that some development phases, such as “evolution” and “requirements” received few attention, and in particular lack “validation” and “evaluation research”. On the other hand, publications that do not address one particular development phase (“other”), and those tackling the implementation phase, are spread over all research types.

Considering the development cycle versus the contribution type (north-west area) we observe that the contribution type is generally well spread over the development phases. In the design phase, there is a clear focus on “model” and “method” publications (combined, 58 of 64). Regardless the contribution type, there are very few publications in the “requirement” phase, and few in “evolution” and “testing”. We even notice some blind spots, such

⁹In fact, statistical analysis using Cramer’s V test shows there is a weak correlation (Cramer’s V value is 0,394807299) between “models, methods & methodology” on one hand, and “model”, “method” and “methodology” on the other hand.

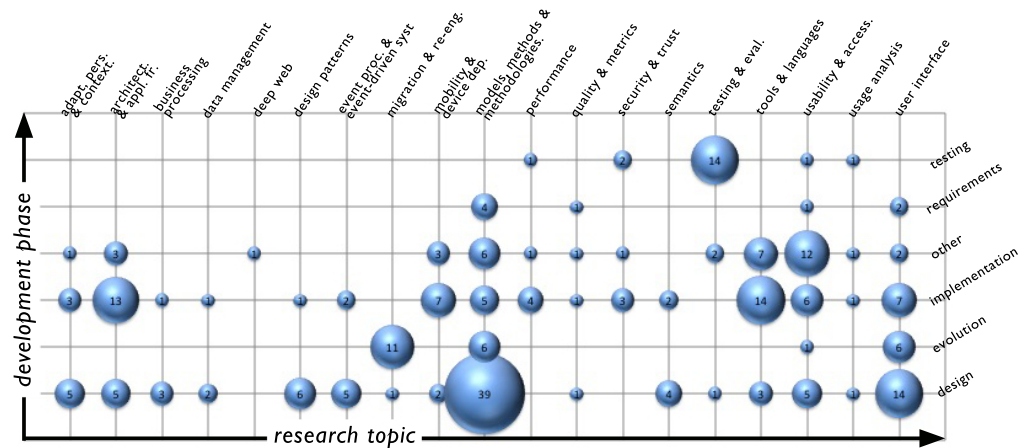


Fig. 8. Systematic Map over development phase (north) and research topic (east).

as methodologies for the evolution phase, models for the testing phase and tools for the requirements phase.

Figure 8 shows the systematic map plotting development phase and research topic. Generally, there is a good spread of research in all research topics for the development phases “implementation” and “design”. On the other hand, there is clearly fewer research in the “requirements” phase (8 of 260), and only slightly more in “evolution” (24 of 260) and “testing” (19 out of 260) phases. Furthermore, research in those development phases are localized in only a few research topics, leaving a large amount of research topics uncovered. Within the most popular topic “models, methods & methodologies” (60 of 260) there is a particular focus on the “design” phase (39 of 60), a further balanced distribution over other phases, and a lack of research situated in the “testing” phase. A similar situation is found for the second popular topic, “user interface” (31 of 260). For the other most popular topics, i.e. “usability & accessibility” (26 of 260), “tools & languages” (24 of 260) and “architecture & application frameworks” (21 of 260), the majority of research is performed in the “design”, “implementation” and “other” development phases.

Figure 9 shows the bubble chart of the systematic map plotting the research type and contribution type. There is a clear emphasis on “solution proposals” (121 of 174), mainly spread over “method”, “model” and “tool” contribution types, and only few “methodology” publications (2 of 121). On the other hand, methodological research is well represented in other research types, excluding “philosophical” and “validation” research. We also observe that, although ample solutions are proposed over all contribution types (except “methodology”), only some “methods” (6 of 10) and “tools” (4 of 10) have been validated. Evaluations are mostly done in methodological form (19 of 22), and some for tools (3 of 22). Only few publications address other research and contributions type combinations, and several blind spots are visible, such as evaluation of methods.

4. DISCUSSION

The data analysis objectively describes the amount of publications for each facet, taking into account the evolution over time. In this section we discuss the analysis in order to answer the research questions highlighting the identification of well covered research areas, gaps, trends and open research issues.

RQ1: What are the publication venues RIA research has been published in? The distribution of publications over publication venues is graphically shown in figure 2 in section 3.1.

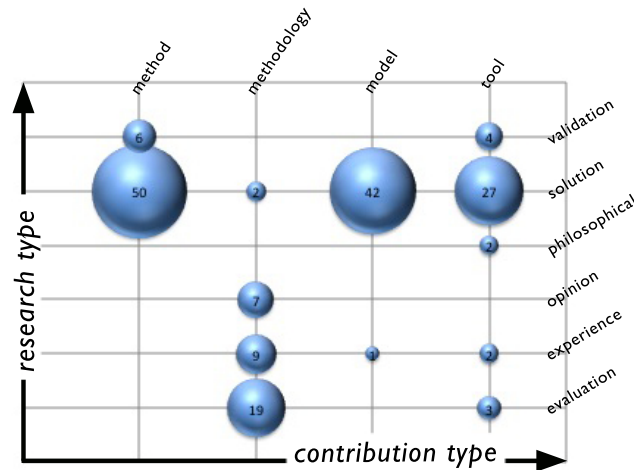


Fig. 9. Systematic Map over research type (north) and contribution type (east).

In this figure, venues in which only one publication was published are aggregated in the category “others”. A full alphabetical list of all venues can be found in appendix 1, along with the amount of RIA research publications (between brackets).

From figure 2, we can deduce that the main research community addressing Rich Internet Application research is the Web Engineering community, with the International Conference of Web Engineering (ICWE; 15 publications) and International Conference on Web and Information Systems Engineering (WISE; 8 publications) as top publication venues, the Journal of Web Engineering (JWE; 3 publications) to a lesser extent, and the Latin-American Web conference (LA-Web; 3 publications) as local community. The IEEE Internet Computing (IEEE IC) journal attributes for 4 publications, half of which are made by authors from the Web Engineering community [Trigueros et al. 2007a; Meliá et al. 2010a].

We furthermore see an important amount of publications appear in the accessibility community, with the International Cross-Disciplinary Conference on Web Accessibility (W4A; 6 publications) as main contributor, and to a lesser extent the International Conference on Computers Helping People with Special Needs (ICCHP; 2 publications). Evidently, these conferences focus specifically on accessibility, and thus do not attract RIA researchers in general.

The final remarkable fact is that RIA research is published in a broad variety of venues, spanning various research communities and covering a diverse range of topics. Many publication venues only published one RIA related publication (53%). This reflects the multi-disciplinary nature and the variety of challenges involved in Web engineering, and in RIAs particularly, as they represent a class of Web systems that are more advanced than regular Web applications.

RQ2: Which phases of the RIA development cycle received most coverage, to what extent, and how is coverage evolving? From figure 3, we conclude that there is an overall clear focus on the “design” (33%) and “implementation” (29%) phase, together good for 62% of all research performed. The other phases receive significantly less attention, and are more or less equally represented, with the “requirements” (4%) phase the least studied. The first research on the “implementation” phase appeared in 2005, while the first “requirements” and “design” phase publication appeared in 2006. During 2007, 2008 and 2009, research in RIAs boomed, with a significant increase of both “design” and “implementation” phase research. From 2007, we also see coverage for the “testing” and “evolution” phases, which

is continued in the following years. While overall research coverage of RIAs decreases in 2010 and 2011, the “implementation” phase coverage remains strongly represented, while “design” phase research consistently decreases.

From these data we can conclude that the research effort in RIA is not balanced regarding the development cycle. There appears to be room for additional requirements, evolution and testing related research. Novel requirements approaches are required in order to satisfy the browsing experience expectations of RIA users (which are more demanding in comparison to traditional Web systems). Also, testing approaches are needed to ensure that the application requirements are realized, in particular, that RIAs bring the improvement in non-functional properties (e.g., responsiveness, usability) as promised. Finally, as RIAs offer a better Web user experience, evolution approaches that allow to evolve traditional Web applications into RIAs are welcome.

RQ3: What are the research topics being addressed in RIA research, to what extent are they covered and how is coverage evolving? The research topics that were considered in this study are listed in section 2.3 (facet 2). We found coverage for all of them, except for “localization, internationalization & multi-linguality”. The most investigated topic is “models, methods & methodologies” (see figure 4): 23% of all research covered this topic. The next two popular topics are “user interface” and “usability & accessibility”, each receiving 11% of total research coverage. Other topics receive less than 10% of total research coverage. Topics that received fewest attention include “deep Web”, only covered by one publication, and “business processing”, “data management” and “usage analysis”, each covered by three publications, and “quality & metrics”, covered by four publications.

It is worth noting that some topics that seem highly relevant a priori in RIA research (“usage analysis”, “data management”, “mobility & device dependency” and “adaptation, personalization & contextualization”) received few attention from the research community. As the research topics studied were checked against the main related conferences we can conclude that the fewest studied topics described above are open research issues that need to be furthered considered.

In initial years (2004, 2005 and 2006) there was fewer research, and different topics were covered. Two of the three most investigated topics, “models, methods & methodologies” and “user interface” are present from the early years, and steadily gain importance over the next years. In 2007, there is an explosion of publications, with dominant coverage for “models, methods & methodologies”, and initial coverage for “usability & accessibility”, the third important topic. The growing trend continues until 2009, in which there is a peak of publications, and all three of the aforementioned topics receive increasing attention. Next to high coverage for these topics, we also see sudden and one-time higher coverage for the topics “adaptivity, personalization & contextualization” and “mobility & device dependency”, which can probably be attributed to the increased usage of mobile devices caused by to a significant technological leap forward in prior years.

In 2010 and 2011, research interest for RIAs is overall decreasing, with 2011’s amount of publications below the 2007 amount. This fact could indicate a starting point towards a stabilization of the research which may indicate that the RIA research hype is somehow over and it is becoming a mature research area (although other factors should be considered to assess the level of maturity, e.g. the type of publication, as stated below).

Remarkable is the growing trend of the topic “usability & accessibility”, which has the highest amount of publications in 2011. This is partly due to coverage in dedicated accessibility conferences (e.g., W4A), but the topic is also addressed in general purpose conferences.

RQ4: What types of RIA research have been reported, to what extent, and how is the evolution? From figure 5, we see a clear focus on “method” publications, with almost half (44%) of all research contributing a method. Publications contributing “model”, “methodology” or “tool” follow, each with a comparable amount of coverage which is however only

half or less the amount of “method” publications. There is no coverage for the “metric” research type. Research that contributes a “method” dominated publications over all years. From 2007, when there was an overall sharp increase of RIA research, there was an equally sharp increase of “method” type of research. The amount of “method” research remains high until (including) 2011. However, from 2007, we also see a sharp increase of the amount of “model” publications, and to a lesser extent, “methodology” research. This trend continued until (excluding) 2011. In 2011, the “model” publications drop, while we see a significant rise of the amount of “methodology” research. Another remarkable fact is that “tool” publications started in 2005, slowly increased in the next three years, boomed in 2009, to slowly decrease again in the last two years.

Usually when developing a method or proposing a model, an accompanying tool should also be developed. We note that 10 demo papers were excluded from our search according to our exclusion criteria (see section 2, step 2), but even so, many method and models publications do not have tool support or the tool is not available. There was a shortage of methodological research, but the research community seems to be aware of this, and is catching up in 2011. On the other hand, the complete lack of metrics is problematic, as this prevents to accurately measure functional and non-functional properties of RIAs, and prevents solutions to be adequately compared.

RQ5: What type of RIA publications have been produced, to what extent did they receive coverage, and how is coverage evolving? There is a very clear focus on “solution” proposals, amounting for 66% of all publications (see figure 6). Evaluation research (14%) is second at a large distance, while there are fewer “experience”, “opinion” and “validation” proposals reported. There were only two philosophical proposals encountered.

The first “solution” proposal is detected in 2005, and several more in 2006. From 2007 however, there is a sharp increase of “solution” proposals, while the amount of other research remains low. The boom in RIA research in 2007 and subsequent years is almost solely attributable to “solution” proposals; the amount of other research type publications remain low. Particularly remarkable is the fact that the first two “validation” proposals only appeared in 2008. Their amount slightly went up in 2009, but decreased again in 2010 and 2011. In 2011 there seems to be a turning point, with a sharp decrease of amount of “solution” proposals, and an increase of “evaluation” research.

We conclude that generally, the type of research is unbalanced, with a large majority of solutions proposed, but few evaluation and fewer validation to support these. This is not a RIA-specific problem, and has been unveiled by systematic mapping studies in other software engineering fields, e.g. [Engström and Runeson 2011; Barney et al. 2012]. While there is a huge amount of “models, methods & methodologies” publications, most of them propose a solution and contribute models and methods, while there is a clear lack of validation and evaluation of the proposed models and methods, and a lack of experience reports.

Although there are several publications that describe tools that support the RIA approaches, the lack of validation proposals of tools (as shown in figures 7 and 9) entails that research artifact produced by RIA researchers are still too immature for potential transfer to the industrial field.

On the other hand, although it is too early to speak of a trend, the decrease of solution proposals combined with the increase of evaluation research in 2011 could denote a beginning maturation of the field. Indeed, it appears a sufficiently large amount of solutions has been proposed in and by the RIA community, leading to a certain consolidation thereof. As a result, fewer new solutions are being proposed, and existing proposals are being compared and evaluated. It remains to be seen if this trend will continue in the following years.

5. BEYOND THE SYSTEMATIC MAPPING STUDY

Next to a quantitative analysis of the research that was performed under the umbrella of "Rich Internet Applications" over the last ten years, which was presented in the previous sections, we now go beyond the systematic mapping study, and present a qualitative analysis of the results. We hereby primarily focus on interesting observations resulting from the quantitative analysis, such as unexpected lacks in the research landscape, or sub-areas where a large amount of publications were presented.

5.1. The Essence of RIAs

As stated in the introduction, a standardized definition of RIAs was never articulated. Nevertheless, during our elaborated study of ten years of Rich Internet Application research, we gained a good insight on the meaning of the term RIA, and the properties that are generally associated with it. We thus capture the essence of RIAs in the following definition: *RIAs are Web applications that aim to provide the features and functionality of traditional desktop applications¹⁰, thereby offering a richer, more satisfying user experience compared to traditional Web 1.0 applications¹¹. Therefore, RIAs must (i) strive for better responsiveness¹², (ii) improve interaction capabilities¹³, and (iii) provide a richer user interface¹⁴.* This is realized using three fundamental technologies: (i) asynchronous communication between client and server, (ii) distribution of data and operations among client and server, and (iii) rich client-side GUI libraries.

Asynchronous communication is key when it comes to avoiding unnecessary data transmission, thus keeping the network traffic as low as possible and preventing to refresh unchanged page fragments [Benjamin et al. 2010]. Client-side operations, which synchronize with the server only when necessary, further reduce data communication and increase responsiveness. Techniques for reducing the data communication load, such as caching, proxy servers and fragment-based resource change estimation and reduction, are thus at the core of RIAs [Mesbah and van Deursen 2008]. Several client-side technologies, such as Apache Flex¹⁵, Microsoft Silverlight¹⁶, JavaFX¹⁷, OpenLaszlo¹⁸, as well as

¹⁰[Bozzon et al. 2006; Urbietta et al. 2007; Amalfitano et al. 2008; Anantharaman et al. 2010; Blom et al. 2008; Brambilla et al. 2008; Dolog and Stage 2007; Farrell and Nezelek 2007; Garrigós et al. 2009a; 2009b; Heidenbluth and Schweiggert 2009; Koch et al. 2009; Paulson 2005; Trigueros et al. 2007a; Martínez-Ruiz et al. 2006; Meliá et al. 2010b; Meliá et al. 2010a; Powell et al. 2009; Preciado et al. 2008a; Preciado et al. 2005; Preciado et al. 2008b; Rosales-Morales et al. 2011; Schmidt and Stojanovic 2008; Schmidt et al. 2009; Snellman et al. 2011; Komischke 2011]

¹¹[Bozzon et al. 2006; Amalfitano et al. 2010a; Amalfitano et al. 2010c; 2010d; Benjamin et al. 2010; Blom et al. 2008; Dolog and Stage 2007; Fraternali et al. 2010; Garrigós et al. 2009a; 2009b; Trigueros et al. 2007a; Meliá et al. 2010a; Miyashita et al. 2007; Pang et al. 2010; Toffetti et al. 2011; Yu et al. 2011; Yu et al. 2006]

¹²[Bozzon et al. 2006; Amalfitano et al. 2010a; Amalfitano et al. 2009; 2010d; 2010c; Benjamin et al. 2010; Blom et al. 2008; Book et al. 2009a; Brambilla et al. 2008; Fukuda and Yamamoto 2008; Lawton 2008; Garrigós et al. 2009a; Koch et al. 2009; Paulson 2005; Meliá et al. 2010a; Powell et al. 2009; Gómez et al. 2011; Song et al. 2006; Yu et al. 2006]

¹³[Amalfitano et al. 2010a; Amalfitano et al. 2009; 2010c; 2010d; Andruszkiewicz et al. 2011; Lawton 2008; Garrigós et al. 2009a; 2009b; Koch et al. 2009; Trigueros et al. 2007a; Martínez-Ruiz et al. 2009; Meliá et al. 2008; 2010a; Moreno et al. 2011; Paiano et al. 2011; Powell et al. 2009; Snellman et al. 2011; Tanikella et al. 2006; Valverde and Pastor 2009; Wright and Dietrich 2008a; Yu et al. 2011]

¹⁴[Asakawa et al. 2007; Garrigós et al. 2009a; Hermida et al. 2011b; Koch et al. 2009; Linaje et al. 2009a; Meliá et al. 2008; 2010a; Morales et al. 2007; Rossi et al. 2008; Toffetti et al. 2011; Valverde and Pastor 2009; Watanabe et al. 2009; Yu et al. 2006]

¹⁵<http://flex.apache.org>

¹⁶<http://www.microsoft.com/silverlight>

¹⁷<http://www.javaafx.com>

¹⁸<http://www.openlaszlo.org/>

HTML5/Javascript/CSS3 and AJAX solutions, have been deployed to support these functions.

To further reduce unnecessary client-server round-trips, and support offline functioning, client-side operations require client-side storage mechanisms. Asynchronous calls assure the relevant data is transferred from server to client, and is kept up-to-date and synchronized as the user's workflow is progressing. A number of client-side storage solutions appear that facilitate handling data from the server, e.g. Flash Local Shared Objects (LSO), HTML5 Web Storage or Google Gears [Zhao et al. 2010].

Due to the fact that part of the computation is done on the client, and RIAs potential have client-side data access, RIAs are usually executed in an isolated area of the client, i.e. the sandbox. This allows access control to the file system and other OS functionalities of the client. Consequently, security issues are an important consideration in the development of RIAs.

Finally, user interfaces of RIAs must ensure that the browsing experience is rich enough to match their desktop counterparts. To satisfy this need, several GUI libraries (such as JQuery¹⁹, Raphaël²⁰ or Dojo²¹) were developed. They deploy the event-driven paradigm, allowing developers to adequately react on user interface changes [Amalfitano et al. 2008]. Additionally, the event-driven nature of RIA implementations, combined with server push support, allow for multi-client, collaborative RIAs that react both on local and remote events [Carughi et al. 2007].

5.2. Evolution of RIA research

The systematic mapping results show that, although the term “Rich Internet Applications” was coined in 2002 [Jeremy 2002], RIA research really started in 2004 [Lin 2004], with focus on identifying the requirements to consider when developing RIAs. Here, the need of researching new technologies for extending interface capabilities and for improving RIA performance was advocated. During the two following years (2005 and 2006), the following publications continued on this path, focusing on the improvement of user interface features (with the aim of overcoming limited interactivity) and the development of new methods for improving the performance of RIAs. At these initial stages, research was mainly driven by the desire for a richer user experience in Web applications, and the then emerging RIA technologies (e.g., AJAX), which still suffered from teething problems, such as usage complexity, the lack of toolkits and frameworks, and security issues [Paulson 2005]. Interoperability problems were also highlighted, as there were differences in JavaScript implementations across browsers, which initially hindered RIA implementations. It is interesting to note that these early works already highlighted the importance of considering other client platforms apart from (desktop) computers, such as wireless mobile devices [Paulson 2005; Chang et al. 2005], even before the big mobile revolution marked by the introduction of the first iPhone in 2007.

After this initial implementation-driven perspective, from 2007, there is a distinctive rise in publications addressing design issues, which are only to a small extent supported by implementation research. Therefore, we notice a clear traceability gap between approaches focusing on the design cycle of RIAs, and those focused on the implementation issues. The model-driven paradigm is omnipresent in the former category. This is consequence of the “extensibility” viewpoint encouraged by some publications such as [Preciado et al. 2005], which focus on extending existing modeling methods for traditional Web applications, such as WebML or UWE, to address RIA specific research challenges in modeling approaches, rather than creating them from scratch. The main motivation for this is that concepts

¹⁹<http://jquery.com/>

²⁰<http://raphaeljs.com/>

²¹<http://dojotoolkit.org/>

for designing classical Web applications are still valid in the RIA context, but are not sufficient to capture the new features of RIAs [Mesbah and van Deursen 2008; Trigueros et al. 2007b]. Consequently, a large body of research focuses on extending existing Web modeling approaches with novel data, hypertext, page content, and operation modeling constructs and their code derivation [Bozzon et al. 2006]. As stated in [Trigueros et al. 2007b], these extensions must provide mechanisms to support the designer in two tasks: in the design phase, where the focus is on capturing the high-interactive and rich-presentation user interfaces of RIAs, while in the implementation phase, the importance is on providing balanced distribution mechanisms to adequately share the load of business logic and data persistence between client and server sides. There are only few approaches that focus on both stages of the development cycle, such as [Häsel 2007] that proposes architectural models for RIA-based games, in which not only design but also implementation issues are addressed.

However, as acknowledged in a later stage by researchers focusing on design issues, adapting a Web modeling approach for RIAs should be a repeatable process, with re-usable modeling concepts and architectural solutions. In this spirit, a sound summary is presented in [Fraternali et al. 2010], where the authors present an evolutionary approach to incorporate RIA features into an existing Web engineering method, methodology and notation. Within their approach, the authors also include details for modeling the partition of data and computation between the client and the server, bidirectional and asynchronous communications, generalized events, and flexible page computation. All this is done with eye for generalizability and re-usability. Furthermore, on the implementation side, the authors detail automatic code generation by using a model-driven approach for both client- and server-side.

On the other hand, and largely disconnected from the design-focused research (both in content and publication venues) the implementation-oriented research tackled a variety of issues, such as technological difficulties in building RIAs [Paulson 2005], performance issues [Dahlan and Nishimura 2008], service-oriented architectures for RIAs [Zhao et al. 2010], component-based RIA development [Chang et al. 2005], implementation support for large-scale RIAs [Fukuda and Yamamoto 2008], thin and fat RIA clients [Dworak 2009], architectural styles [Lin 2007], implementation support for client-side event processing [Schmidt et al. 2009], adhering to accessibility standards [Thiessen and C 2007], code optimizations for mobile devices [Alor-Hernandez et al. 2009], security issues [Livshits and Erlingsson 2007; Kontaxis et al. 2011], adaptivity in RIAs [Cosmin and N 2009] and distributed data access [Zhao et al. 2010]. Remarkably, the majority of this work is spread over different research communities and publication venues, thereby confirming the multi-disciplinary nature of RIAs, but also keeping the body of knowledge dispersed.

A major change in RIAs compared to classical Web 1.0 applications is marked by moving certain functionality to the client-side. This is mainly supported by client-side event handling to avoid client-server round trips, and local data storage to maintain and make the necessary data available on the client side. Furthermore, asynchronous calls allow seamless client-server communication to avoid task-disruptions. However, these changes also caused a paradigm shift, of which the consequences are recognized by the research community. Nevertheless, some aspects are still surprisingly under-investigated. As some authors have pointed out [Schmidt et al. 2008; Amalfitano et al. 2010a; Ostrowski and Birman 2010], guidelines, established software engineering solutions, architectural styles or design patterns for RIAs, and in particular novel types of RIAs (e.g., mashup-based, targeted at mobile devices), are largely lacking [Alor-Hernandez et al. 2009]. Given the relative recentness of the field, and the still evolving technologies, this is perhaps not so surprising. The complicated interplay between the user, the client and server applications, and underlying asynchronous communication, nevertheless require solid, well-proven architectural and software engineering solutions. Despite this general lack, we signal interesting work in this area by Mesbah

and colleagues on architectural styles for AJAX (e.g., [Mesbah and van Deursen 2008]), but still, a larger body of knowledge is lacking.

Although often advocated as two of the main advantages of RIAs, there is also a clear lack of performance and usability studies [Alor-Hernandez et al. 2009]. Under changing technological conditions, and evolving frameworks and standards, the former may be explained, but regarding usability, we do not see a rational explanation. Furthermore, although event-processing in RIAs has a crucial role in providing better responsiveness, relatively few attention has been paid to this in the research community. The importance of client-side event handling is recognized, both to handle and react to (UI) events generated on the client-side (e.g., [Schmidt et al. 2009]), as well as asynchronous client-server communication to handle complex, mixed events (i.e., UI events, service notifications) [Carughi et al. 2007]. In both, responsiveness and UI reactivity is the underlying goal, while pointing out the possibility for collaborative RIAs. Most authors indicate that implementation frameworks provide support for event-processing, and, although RIAs operate under specific technological constraints specific to the web environment (e.g., security constraints, fixed communication protocols), solutions may be borrowed from older event-oriented research fields (e.g., event-driven programming). Therefore, research effort was put in providing modeling level support [Carughi et al. 2007; Dolog and Stage 2007; Valverde and Pastor 2009; Carughi 2007], and few work on higher level implementation support.

Finally, given the high number of publications classified as solution proposals, we point out the relatively low number of publications performing a validation or an evaluation of these solutions, in order to study their viability and compare the weaknesses and strengths of different solutions. Only 8 validation papers and 21 evaluation papers were unveiled in our systematic mapping. As mentioned earlier, this confirms results from other fields, such as software product line testing [Engström and Runeson 2011] and software quality trade-offs [Barney et al. 2012], where the same lack was found. This nevertheless raises the question *why most of the solution proposals were not subjected to empirical validation?* One reason may be that proposing a solution is easier than validate/evaluate an existing one, both to perform and get it published. However, it is important for ensuring the correctness of the methods. Even negative results, although harder to publish, are important to be shared with other researchers. We do notice an increasing amount of validation/evaluation papers towards the end of our study, indicating the maturing of the research field.

5.3. RIA challenges

Lured by the promises of richer, more dynamic user interfaces, better responsiveness and an overall better user experience, migrating legacy applications, both desktop- and Web-based, has received some attention in the research community. Hereby, key challenges to address include client/server distribution, synchronization of data and functionality, and availability of a richer set of UI elements. The bulk of the solutions reside on model-level, where re-engineering or refactoring techniques are applied to existing, rich (conceptual) models. Several existing model-driven Web engineering approaches were migrated to support RIAs. Examples include [Meliá et al. 2008], extending the OOH method, [Machado et al. 2009] extending UWE, and [Fraternali et al. 2010] extending WebML. In all of these proposals, particular attention was paid to UI research. In this respect, we mention the RUX-Method [Preciado et al. 2008a], which is complementary to existing (Web 1.0) methods and focuses exclusively on migrating the UI of Web 1.0 applications to RIAs. Unfortunately, all these approaches suffer from the fact that in practice, rich conceptual models are seldom available for existing websites.

A second strain of research tackles this issue, and attempts to extract sufficiently expressive models from existing Web 1.0 applications. For this aim, static and dynamic analysis techniques are deployed to reverse engineer legacy Web 1.0 applications into navigation models [Amalfitano et al. 2008; 2009; Pang et al. 2010], and clustering techniques are used

to identify candidate pages to be re-factored in single-page RIAs [Mesbah and van Deursen 2007]. Nevertheless, these techniques are in their infancy, often being described on the basis of a single case study, and based on a specific technology. We can conclude that the research community has detected the importance of modeling in RIA development, which has resulted in a myriad of extensions on existing Web engineering model-driven methods. Nevertheless, there exists a gap between existing model-driven approaches on one hand, and re-engineering and reverse engineering techniques necessary to extract the required rich conceptual models necessary to allow effective evolution of Web 1.0 application to RIAs. Therefore, we urge the research community to consider both research areas, and converge both so each can reap the fruits of each other's work.

On the other hand, few exceptions aside, we found very few evidence of research in RIA-relevant issues such as offline functionality, multi-device RIAs, performance or security. Given the huge amount of legacy application in the real world, and the willingness of cooperation to bring these into the RIA age, additional research starting from practical problems (e.g., legacy HTML code), is needed.

The paradigm shift caused by RIA principles also fundamentally changes the understandability and analyzability of Web applications. Classical static analysis no longer suffices, and novel dynamic analysis techniques that are able to cope with client-side behavior are needed. Initial work in the area is performed by e.g. [Amalfitano et al. 2010a; Mesbah et al. 2008]. Performance and scalability assessment are vastly more complex, and require new measures and ways to cope with the increased complex client-server communication caused by asynchronous calls and the distribution of task functionality. Handling data in a uniform way at the client side, under various frameworks and browser support, is another recognized problem for which few generally applicable solution proposals have been formulated (we mention [Zhao et al. 2010] as a first attempt to unify RIA data access). Finally, security implications of the paradigm shift that RIAs embody, and that are highly relevant in an industrial setting, lack sufficient research to be considered solved (work specifically focusing on RIA security issues can be found in [Kontaxis et al. 2011] and [Livshits and Erlingsson 2007]).

As already stated, RIAs are complex Web applications in which the development of a highly interactive user interface plays an important role [Tanikella et al. 2006; Pandurino et al. 2010; Martínez-Ruiz et al. 2009; Martínez-Nieves et al. 2010]. However, according to [Tanikella et al. 2006], implementation decisions in RIA development are not a consequence of a detailed process of understanding user interface requirements, and the implemented RIA may fail in satisfying users' expectations. Therefore, it is crucial that RIA engineers pay particular attention in articulating and considering UI requirements to make informed implementation decisions in the development process. To this aim, requirement engineering for RIA should support and encourage closer collaboration between stakeholders (i.e. experts in UI/HCI and experts in the implementation of the solution), as is well understood in the requirements engineering community [Tanikella et al. 2006]. One approach that highlights the importance of sharing information among RIA engineers and designers is proposed in [Pandurino et al. 2010]. This is one of the few approaches that considers requirements as a first-class citizen in the RIA development process. Surprisingly, there are few requirements engineering methods specifically focusing on RIAs. The most popular approaches advocate a model-driven perspective for the requirement specification in RIAs, e.g. [Martínez-Ruiz et al. 2009]. A metamodel for RIA requirements (WebRE+) is proposed in [Luna et al. 2010] in which RIA features are incorporated as modeling artifacts. All these publications consider and model functional requirements related to user interfaces. However, there is a gap in researching non-functional requirements for RIAs to consider issues related to architecture, processing overload on Web server or performance issues. The only publication addressing this topic is [Meliá et al. 2010b] in which an extension to an existing model-driven approach for RIAs (OOH4RIA) is proposed for considering quality require-

ments in the systematic construction of RIA architectures, from a modeling point of view. Summarizing, although several works advocate the importance of RIA requirements, more research effort must be put in considering non-functional requirements, and novel techniques for elicitation and negotiation of requirements should be explored and proposed.

Increased usability has always been a spearpoint in advocating RIAs. In the age of e-government, where more and more civil services are online available and legislation forces governmental websites to be accessible, the accessibility of RIAs is a crucial challenge for their further widespread adoption. Accessibility and usability at first sight seem to be adequately addressed. Still, most of the publications on this topic appeared in a smaller venue (W4A), and focus on extending existing technologies, and are mainly classified as “tools”, or more recently (i.e. from 2011 onwards), as methodologies. This may indicate that at first, the research in usability and accessibility was technology-oriented (e.g., implementing accessibility standards), but later on, methodologies were required to formalize the inclusion of usability and accessibility issues in RIAs. Indeed, a lot of accessibility research consists of exploring the Accessible Rich Internet Application (WAI-ARIA) Suite ²², and constitutes practical, prove-of-concept implementations. The amount of research in the “usability & accessibility” topic may thus not be overstated, as fundamental research in the area seems to be missing. No new methodologies were proposed, but rather, existing, mainly model-driven approaches, were extended to include accessibility issues. For example [Pandurino et al. 2010] extends the IDM method, and [Trigueros et al. 2011] extends the RUX method.

Furthermore, it is worth mentioning that more than 50% of the 22 accessibility publications (12) only focus on visually impaired users, while the accessibility field is much broader. According to [Fogli et al.], RIA users that require support are not only visually impaired but also include people with physical or cognitive disabilities, or people who experience changes in hearing, dexterity, and memory as they age. Even people that navigate the Web through obsolete or limited hardware/software technologies require accessibility mechanisms to improve their browsing experience. Indeed, as RIAs are becoming cross-platform, and are increasingly deployed in Web 2.0 applications, satisfying usability and accessibility issues effectively enables - or disables - a wide range of users to participate in the modern online society. Finally, and very surprisingly, we found only 3 publications specifically addressing usability.

Mobility, and related topics such as adaptivity, personalization & contextualization, are other topics which, given the current shift of desktop-based to mobile-based internet access, should receive ample attention. Yet, relatively few attention has been paid to this by the research community, and was mostly done towards the end of our study, with a peak in 2009. Most of the publications on this topic focus on the adaptation of the interface on different mobile devices [Velasco et al. 2009; Trigueros et al. 2010; Cosmin and N 2009; Trigueros et al. 2007b]. Others focus on more specific problems, such as [Peintner et al. 2009] which defines a language for data interchange of embedded devices in RIA applications. At first sight, it seems surprising that, given the capabilities of modern mobile devices, few attention has been paid to personalization and contextualization. In a more general context, most of the works have focused on the adaptation of the user interface, considering both static and runtime personalization [Schmidt et al. 2008; Garrigós et al. 2009a; 2009b; Schmidt et al. 2009]. Personalization on the client side has also been considered by [Schmidt et al. 2007]. Almost all the publications consider in some way the context for adaptation (i.e. contextualization), focusing on the user browsing device. For instance, the work of [Velasco et al. 2009], considers static adaptation by means of defining different user profiles depending on the device used. [Trigueros et al. 2010; Garrigós et al. 2009a; 2009b] also take into account the device used in order to adapt the user interface. However, the overall number of publications considering these topics is low, and the exciting new capabilities of mobile

²²<http://www.w3.org/WAI/intro/aria>

devices, such as the plethora of sensor data, location-based data, or novel interaction capabilities driven by touch-based interaction, voice-enabled interfaces or built-in camera's, have not been considered. One explanation might be the fact that, although such support is already readily available in mobile apps, standardization in web standards, and accompanying programming API's and mobile browser support for these new interaction means are only slowly becoming available. Mixed solutions exist, e.g. the PhoneGap framework mixes web technologies with mobile app functionality [Charland and LeRoux 2011], but standard support, for example in the HTML5 standard and its implementation in various browsers, is currently developing. Consequently, we did not encounter any RIA research addressing these topics, but we expect see these topics emerging in the future.

As a final important yet under-investigated issue, we mention the difficulties that search engines experience in indexing information in RIA applications, as stated by [Paulson 2005]. The fact that information in RIAs may not be fully loaded at once, and new data can be dynamically retrieved based on user interaction poses a great challenge for search engines. Therefore, with the aim of making RIAs searchable and preventing them to remain in the "deep web", the indexing ability should also move to the foreground of RIA research [Duda et al. 2009].

5.4. The Future of RIAs

What does the future of Rich Internet Applications hold? As the famous physicist Niels Bohr (1885–1962) already knew, "prediction is very difficult, especially about the future". Nevertheless, based on our expert opinion and review of all 133 publications about Rich Internet Applications in the timeframe 2002 - 2011 (including), complemented with a small-scaled questionnaire among RIA experts, we attempt a peek into the future in this section.

As a first observation, we note that more and more features that were formerly exclusive to RIAs have now become de facto web application features. For example, where dedicated RIA frameworks, such as Adobe Flex or Macromedia Flash, pioneered multimedia support and client-side reactivity, these are now considered standard web application features supported by standard technologies such as javascript, the jQuery library and AJAX. We are currently seeing the first consolidations of this trend crystallized in new standards, such as HTML5²³, the new W3C HTML standard, or IFML²⁴, a recent OMG web interaction flow standard, which incorporate many feature formerly reserved for Rich Internet Applications, such as rich media types, client side storage, offline browsing support, advanced widgets, semantic annotations and advanced forms. In other words, Rich Internet Applications are slowly blending into "standard" web applications. This might also explain why we see a recent decrease in RIA research, as researchers no longer identify their work into the RIA category, but simply consider it "standard" web application research.

On the other hand, we see an increased importance of mobile devices in the computing landscape. While we currently see a proliferation of mobile apps battling web apps, we do expect that the Web, as a platform, will emerge as the dominant platform for universal, cross-platform and cross-device application development. Indeed, peeking into the future, we envision advanced web apps, running on any device, be it mobile, desktop, television, tablet, wall-displays, game console, or any other type of computerized device. They will not necessarily run in a browser, but nevertheless be built using future web technologies running on a web-enabled platform. As a result, these future web apps will require a responsive user interface that supports new interaction behaviors, such as voice-control or gesture-based interactions. Future web apps will thus embrace responsive, fluid designs, which seamlessly adapt to support multichannel and multi-device user experiences. The ability to work offline, and synchronize workflows among different devices, will become an important feature of

²³<http://dev.w3.org/html5/html-author/>

²⁴<http://www.ifml.org/>

future web apps, implying the ability to synchronize data and functionality, not only with the server, but also “in the cloud” and among devices.

Furthermore, from a developers point of view, the principles on which RIAs are based, such as the RESTful metaphor, may well become the standard interface to steer the “Internet of Things”, where essentially any device will be available and interface-able online. This, combined with elasticity and cloud computing, could have a profound impact on the computing landscape, and society in general.

In conclusion, predicting the evolution of the Web and its technologies is difficult. Nevertheless, as stated above, we note the adoption of formerly RIA specific features in Web standards and technologies, and therefore, the increased adoption of RIA features in mainstream Web programming. Indeed, RIAs are slowly blending into regular Web applications. In a broader context, the current large-scale adoption of Web technology, and the proliferation of the Web as a platform, makes these a prime candidate for future developments, e.g., in the “Internet of Things”.

6. CONCLUSION

A systematic mapping study has been carried out in this article in order to assemble, classify and analyze all research on Rich Internet Applications (RIA) performed between 2002 and 2011 (both inclusive) in the scientific community with the aim of (i) providing a consolidated overview of the research field, and (ii) identifying well-established topics, trends and open research issues.

Our study reveals several interesting facts:

- While RIA research started in 2004, there was a significant increase in research in 2007, a peak in 2009, and a slow decrease since.
- The main research communities contributing to RIA research are the web engineering, and the accessibility community.
- The design and implementation phases received most attention; other phases are underexposed.
- A wide variety of topics has been studied. “models, methods & methodologies” is the most popular research topic; “user interface” issues and “usability & accessibility” of RIAs also received a fair amount of attention; the latter topic is gradually receiving more attention.
- Surprisingly, some highly relevant topics are under-represented: “usage analysis”, “data management”, “quality & metrics”, and to a lesser extent, “mobility & device dependency” and “adaptation, personalization & contextualization”. There are also some other topics, such as “localization, internationalization & multi-linguality”, “deep web”, “business processing”, “semantics” and “performance”, that have received few attention and where there is opportunity for additional research.
- The majority of research contributes methods.
- There are no metrics proposed to measure specific properties of RIAs.
- The vast majority of research consist of solution proposals; there is a lack of validation and evaluation.
- Recently, we see some indications that the RIA research field is achieving maturity: the amount of research performed is consolidating, there are fewer solutions proposed and simultaneously, more evaluation work is performed.

Apart from the quantitative analysis provided by our systematic mapping study, a qualitative analysis was performed in order to express some insights we gained. In particular, we distilled the essence of what constitutes a Rich Internet Application, and coined a well-founded definition, in section 5.1, gave an insightful view on the evolution of RIA research in section 5.2, and on the most interesting results of our data analysis and the challenges that remain in section 5.3. Finally, we gave our own thoughts, aided by the opinion of some RIA experts, about the future of the field in section 5.4.

We hereby encourage the RIA research community to address the under-investigated topics and fill in the gaps in the research field.

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Publication venues

- AAAI Spring Symposium on Intelligent Event Processing (1)
- ACM Conference on Computer and Communications Security (1)
- ACM SIGCHI Italian Chapter International Conference on Computer-Human Interaction: Facing Complexity (1)
- ACM SIGCHI Symposium on Engineering interactive computing systems (1)
- ACM Symposium on Applied Computing (1)
- ACM Transactions on the Web (1)
- Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services (1)
- Asia-Pacific Conference on Conceptual Modelling (1)
- Asia-Pacific Web Conference (1)
- Business Information Systems (1)
- Computer (2)
- Conference on Current Trends in Theory and Practice of Computer Science (1)
- Conference on Human factors in computing systems (1)
- Conference of the center for advanced studies on collaborative research: meeting of minds (1)

- Conference of the Workgroup Human-Computer Interaction and Usability Engineering of the Austrian Computer Society (1)
- Distributed Computing, Artificial Intelligence, Bioinformatics, Soft Computing, and Ambient Assisted Living (1)
- EUROMICRO Conference on Software Engineering and Advanced Applications (1)
- European Conference on Software Maintenance and Reengineering (1)
- European Workshop on System Security (1)
- Extended Semantic Web Conference (1)
- Human Computer Interaction, design and development approaches (HCI) (2)
- IASTED Conference on Software Engineering and Applications (SEA) (2)
- IEEE/ACM International Conference on Automated Software Engineering (ASE) (2)
- IEEE/ACIS International Conference on Computer and Information Science (1)
- IEEE Electronics, Robotics and Automotive Mechanics Conference (1)
- IEEE International Conference on Multimedia and Expo (1)
- IEEE International Conference on Software Maintenance (1)
- IEEE Internet Computing (IEEE IC) (4)
- International ACM SIGACCESS Conference on Computers and Accessibility (1)
- International Conference on Advances in Mobile Computing and Multimedia (1)
- International Conference on Advanced Visual Interfaces (1)
- International Conference on Computer-Aided Design of User Interfaces (1)
- International Conference on Computational Intelligence and Software Engineering (1)
- International Conference on Computers (1)
- International Conference on Computer Design and Applications (1)
- International Conference on Computers helping people with special needs (ICCHP) (2)
- International Conference on Conceptual Modeling (1)
- International Conference on Data Engineering (1)
- International Conference on Dependability of Computer Systems (1)
- International Conference on Detection of Intrusions and Malware, and Vulnerability Assessment (1)
- International Conference on Digital Society (1)
- International Conference on Electrical Communications and Computers (1)
- International Conference on Grid and Pervasive Computing - Workshops (1)
- International Conference on Information Integration and Web-based Applications & Services (iiWAS) (2)
- International Conference on Information Technology Interfaces (1)
- International Conference on Internet and Web Applications and Services (1)
- International Conference on Next Generation Web Services Practices (1)
- International Conference on Quality of Information and Communications Technology (QUATIC) (2)
- International Conference on Service-Oriented Computing and Applications (1)
- International Conference on Software and Data Technologies (1)
- International Conference on Software Engineering (1)
- International Conference on Software Testing, Verification, and Validation (ICST) (3)
- International Conference on Software Testing, Verification, and Validation Workshops (2)
- International Conference on Trends in Enterprise Application Architecture (1)
- International Conference on Ubiquitous Information Technologies & Applications (1)
- International Conference on Web Engineering (ICWE) (15)
- International Conference on Web Engineering workshops (1)
- International Conference on Web and Information Systems Engineering (WISE) (8)
- International Cross-Disciplinary Conference on Web Accessibility (W4A) (6)
- International Journal on Software Tools for Technology Transfer (1)
- International Journal of Systems and Service-Oriented Engineering (1)

- International Symposium on Web Systems Evolution (WSE) (4)
- International Symposium on Search Based Software Engineering (1)
- International Conference on Universal access in human-computer interaction: applications and services (1)
- International Workshop Automated Specification and Verification of Web Systems (1)
- International Workshop on Web-Oriented Software Technologies (1)
- International Workshop on Adaptation and Evolution in Web Systems Engineering (1)
- Joint meeting of the European software engineering conference and the ACM SIGSOFT symposium on The foundations of software engineering (1)
- Jornadas de Ingeniera del Software y Base de Datos (1)
- Journal of Access Services (1)
- Journal of Symbolic Computing (1)
- Journal of Systems and Software (1)
- Journal of Universal Computer Science (1)
- Journal of Web Engineering (JWE) (3)
- Latin-American Web Conference (LA-WEB) (3)
- Model Driven Web Engineering workshop (1)
- Network-Based Information Systems (1)
- Nordic Conference on Human-computer interaction: building bridge (1)
- Operating Systems Review (1)
- Studies in Computational Intelligence, Emerging Intelligent Technologies in Industry (1)
- Transactions on Information Science and Applications (1)
- Universal Access in Human-Computer Interaction. Applications and Services (1)
- Web Information Systems Engineering workshops (1)
- Working Conference on Reverse Engineering (1)
- Workshop on Programming languages and analysis for security (1)
- Workshop on Web Quality, Verification and Validation (1)
- World Wide Web Journal (1)

Overview of classifications of all identified publications

Publication	Facet1	Facet2	Facet3	Facet4
[Alor-Hernandez et al. 2009]	implementation & deployment	performance mobility & device dependency	method	solution proposal
[Amalfitano et al. 2010a]	other	usage analysis tools & languages	tool	solution proposal
[Amalfitano et al. 2008]	evolution	migration & re-engineering	method model	solution proposal
[Amalfitano et al. 2009]	evolution	migration & re-engineering user interface	method	solution proposal validation research
[Amalfitano et al. 2010b]	testing	testing & evaluation	methodology	evaluation research
[Amalfitano et al. 2010c]	testing	testing & evaluation	method	solution proposal validation research
[Amalfitano et al. 2010d]	evolution	migration & re-engineering user interface	tool method	solution proposal
[Anantharaman et al. 2010]	implementation & deployment	architecture & application frame- works	method tool	solution proposal
[Andruszkiewicz et al. 2011]	implementation & deployment	mobility & device dependency tools & languages	methodology	experience paper
[Annett and Stroulia 2008]	design	tools & languages data management	methodology	experience paper
[Asakawa et al. 2007]	other	usability & accessibility	methodology	evaluation research
[Atterer and Schmidt 2007]	testing	usage analysis testing & evaluation	method	solution proposal
[Batusic and Steiner 2010]	implementation & deployment	usability & accessibility	methodology	experience paper
[Benjamin et al. 2011]	other	tools & languages	method	solution proposal validation research
[Benjamin et al. 2010]	testing	security & trust testing & evaluation	methodology	opinion paper
[Bezemer et al. 2009]	testing	testing & evaluation security & trust	method	solution proposal
[Blom et al. 2008]	implementation & deployment other	mobility & device dependency tools & languages	methodology	evaluation research
[Book et al. 2009a]	design	models, methods & methodologies testing & evaluation user interface	method	solution proposal
[Book et al. 2009b]	design	models, methods and methodologies business processing tools & languages	model tool	solution proposal
[Bozzon et al. 2006]	design implementation & deployment	models, methods & methodologies tools & languages	model tool	solution proposal experience paper
[Brambilla et al. 2009]	design	models, methods and methodologies	model method	solution proposal
[Brambilla et al. 2008]	design	models, methods & methodologies business processing user interface	model	solution proposal
[Buzzi et al. 2008]	evolution implementation & deployment	usability & accessibility	tool	solution proposal
[Carughi 2007]	design	event processing & event-driven sys- tems models, methods and methodologies	model	solution proposal
[Carughi et al. 2007]	design	models, methods & methodologies event processing & event-driven sys- tems	model	solution proposal
[Chang et al. 2005]	implementation & deployment	user interface tools & languages architecture & application frame- works	tool	solution proposal
[Chen and Raman 2008]	implementation & deployment	usability & accessibility	tool	experience paper
[Comai and Carughi 2007]	design	models, methods & methodologies	methodology	experience paper
[Connor 2010]	other	usability & accessibility testing & evaluation	methodology	experience paper
[Cosmin and N 2009]	implementation & deployment	adaptivity, personalization & con- textualization mobility & device dependency user interface	method	solution proposal
[Dahlan and Nishimura 2008]	implementation & deployment	performance	method	solution proposal validation research
[Dolog and Stage 2007]	design	models, methods & methodologies event processing & event-driven sys- tems	model method	solution proposal
[Duda et al. 2009]	other	deep web	method model tool	solution proposal
[Dworak 2009]	implementation & deployment	architecture & application frame- works	tool	philosophical pro- posal
[Farrell and Nezelek 2007]	implementation & deployment	architecture & application frame- works	methodology	opinion paper

Publication	Facet1	Facet2	Facet3	Facet4
[Fogli et al.]	design	usability & accessibility design patterns	model	solution proposal
[Fraternali et al. 2010]	design implementation & deployment	models, methods & methodologies	model method	solution proposal
[Fukuda and Yamamoto 2008]	implementation & deployment	tools & languages	tool	solution proposal
[Garrigós et al. 2009a]	design	adaptivity, personalization & contextualization models, methods & methodologies	model	solution proposal
[Garrigós et al. 2009b]	design	adaptivity, personalization & contextualization models, methods & methodologies	model method	solution proposal
[Geiger et al. 2010]	design	models, methods & methodologies	model	solution proposal
[Giraud et al. 2011]	other	usability & accessibility	methodology	evaluation research
[Gómez et al. 2011]	implementation & deployment	user interface	methodology	solution proposal
[Hailpern et al. 2009]	other	usability & accessibility models, methods and methodologies	model	solution proposal
[Häsel 2007]	design implementation & deployment	architecture & application frameworks	model	solution proposal
[Heidenbluth and Schweiggert 2009]	design	design patterns adaptivity, personalization & contextualization	tool model	solution proposal
[Hermida et al. 2011a]	design	models, methods & methodologies semantics	model method	solution proposal
[Hermida et al. 2011b]	design	models, methods & methodologies semantics	model method	solution proposal
[Johns and Lekies 2011]	implementation & deployment	security & trust	methodology	evaluation research
[Koch et al. 2009]	design	methods, models & methodologies design patterns	model	solution proposal
[Komischke 2011]	other	usability & accessibility user interface	methodology	opinion paper
[Kontaxis et al. 2011]	implementation & deployment	security & trust	methodology	evaluation research
[Kuuskeri and Mikkonen 2009]	implementation & deployment	architecture & application frameworks	method	solution proposal
[Laakso and Niemi 2008]	other	architecture & application frameworks	methodology	evaluation research
[Lawton 2008]	implementation & deployment	architecture & application frameworks tools & languages	methodology	opinion paper
[Lin 2004]	other	architecture & application frameworks models, methods & methodologies	methodology	evaluation research
[Lin 2007]	implementation & deployment	architecture & application frameworks	model	solution proposal
[Linaje et al. 2009a]	design	models, methods & methodologies usability & accessibility semantics	method	solution proposal
[Linaje et al. 2009b]	design	user interface models, methods & methodologies	model	solution proposal
[Livshits and Erlingsson 2007]	implementation & deployment	security & trust	method	solution proposal
[Lizcano et al. 2011]	implementation & deployment	models, methods & methodologies	model	solution proposal
[Luna et al. 2010]	requirements	models, methods & methodologies	model	solution proposal
[Lunn et al. 2009]	implementation & deployment	usability & accessibility semantics tools & languages	tool	solution proposal
[Machado et al. 2009]	design	models, methods & methodologies	model	solution proposal
[Marchetto et al. 2008a]	testing	testing & evaluation	methodology	evaluation research
[Marchetto and Tonella 2009]	testing	testing & evaluation	tool	solution proposal validation research
[Marchetto et al. 2007]	testing	testing & evaluation	methodology	evaluation research

Publication	Facet1	Facet2	Facet3	Facet4
[Marchetto et al. 2008b]	testing	testing & evaluation	method	solution proposal
[Martínez-Nieves et al. 2010]	requirements design	models, methods & methodologies	method	solution proposal
[Martínez-Ruiz 2010]	design	models, methods & methodologies user interface	method	solution proposal
[Martínez-Ruiz et al. 2006]	design	models, methods & methodologies user interface	method	solution proposal
[Martínez-Ruiz et al. 2009]	requirements design implementation & deployment	models, methods & methodologies user interface	method	solution proposal
[Meliá et al. 2008]	design	models, methods & methodologies	model method	solution proposal
[Meliá et al. 2010a]	design	models, methods and methodologies architecture & application frame- works	model method	solution proposal
[Meliá et al. 2010b]	requirements	quality & metrics architecture & application frame- works	model	solution proposal
[Mesbah et al. 2008]	other	models, methods & methodologies	tool	solution proposal
[Mesbah et al. 2009]	testing	testing & evaluation	method tool	solution proposal validation research
[Mesbah and van Deursen 2007]	evolution	migration & re-engineering	method	solution proposal
[Mesbah and van Deursen 2008]	design implementation & deployment	architecture & application frame- works	method	solution proposal
[Miyashita et al. 2007]	other	usability & accessibility tools & languages	tool	solution proposal evaluation research
[Morales et al. 2007]	design	design patterns	model	solution proposal
[Moreno et al. 2011]	other	usability & accessibility tools & languages	methodology	opinion paper evaluation research
[Ostrowski and Birman 2010]	design	data management models, methods & methodologies	model	solution proposal
[Paiano et al. 2011]	evolution	migration & re-engineering models, methods and methodologies	model	solution proposal
[Pandurino et al. 2010]	requirements	usability & accessibility models, methods & methodologies	model	solution proposal
[Pang et al. 2010]	evolution	migration & re-engineering	model	solution proposal
[Paulson 2005]	implementation & deployment	tools & languages	methodology	opinion paper
[Peintner et al. 2009]	other implementation & deployment	performance mobility & device dependency	methodology tool	evaluation research solution proposal
[Powell et al. 2009]	design	models, methods and methodologies	method model	solution proposal
[Preciado et al. 2007a]	design	models, methods & methodologies	model method	solution proposal
[Preciado et al. 2005]	other	models, methods & methodologies	methodology	evaluation research
[Preciado et al. 2008a]	design	models, methods & methodologies user interface	model method	solution proposal
[Preciado et al. 2007b]	evolution	models, methods & methodologies migration & re-engineering user interface	method	solution proposal
[Preciado et al. 2008b]	evolution	models, methods & methodologies migration & re-engineering user interface	method	solution proposal
[Quintela-Pumares et al. 2010]	implementation & deployment	quality & metrics architecture & application frame- works	method	solution proposal
[Richardson 2011]	other	usability & accessibility user interface	methodology	opinion paper
[Rodríguez-Echeverría et al. 2010]	evolution	migration & re-engineering models, methods & methodologies	model method	solution proposal
[Roest et al. 2010]	testing	testing & evaluation	method tool	solution proposal

Publication	Facet1	Facet2	Facet3	Facet4
[Rosales-Morales et al. 2011]	implementation & deployment	tools & languages	methodology	evaluation research
[Rossi et al. 2008]	evolution	models, methods & methodologies migration & re-engineering user interface	method	solution proposal
[Sandhya and Devi 2011]	other	usability & accessibility	methodology	experience paper
[Schmidt et al. 2008]	design implementation & deployment	adaptivity, personalization & contextualization usage analysis semantics user interface	method	solution proposal validation research
[Schmidt and Stojanovic 2008]	design implementation & deployment	architecture & application frameworks design patterns business processing event processing & event-driven systems user interface	method	solution proposal
[Schmidt et al. 2009]	implementation & deployment	adaptivity, personalization & contextualization event processing & event-driven systems	tool	solution proposal
[Shirogane et al. 2011]	design	usability & accessibility	method	solution proposal
[Snellman et al. 2011]	testing	testing & evaluation performance	tool	solution proposal validation research
[Song et al. 2006]	design	architecture & application frameworks	method	solution proposal
[Sorokin et al. 2007]	design	usability & accessibility models, methods and methodologies quality & metrics	method	solution proposal
[Stearn 2007]	implementation & deployment	tools & languages architecture & application frameworks	tool	solution proposal
[Sung and Lim 2009]	implementation & deployment	tools & languages mobility & device dependency	tool	solution proposal
[Tanikella et al. 2006]	requirements	user interface architecture & application frameworks	methodology	experience paper
[Thiessen 2011]	testing	usability & accessibility testing & evaluation	methodology	evaluation research
[Thiessen and C 2007]	implementation & deployment	usability & accessibility	methodology	experience paper
[Thiessen and Chen 2009]	other	usability & accessibility	methodology	experience paper
[Thiessen and Hockema 2010]	implementation & deployment	usability & accessibility tools & languages	tool	solution proposal
[Toffetti et al. 2011]	other	models, methods & methodologies architecture & application frameworks tools & languages	methodology	evaluation research
[Trigueros et al. 2007a]	design evolution	models, methods & methodologies migration & re-engineering user interface	method	solution proposal
[Trigueros et al. 2010]	design	models, methods & methodologies mobility & device dependency adaptivity, personalization & contextualization	method	solution proposal
[Urbietal et al. 2007]	design	models, methods and methodologies user interface	model	solution proposal
[Valverde and Pastor 2008]	design	models, methods and methodologies design patterns	model	solution proposal
[Valverde and Pastor 2009]	design	models, methods and methodologies user interface event processing & event-driven systems	model	solution proposal
[van Deursen and Mesbah 2009]	testing	testing & evaluation	methodology	evaluation research
[Velasco et al. 2008]	other	usability & accessibility quality & metrics testing & evaluation	tool	solution proposal
[Velasco et al. 2009]	other	adaptivity, personalization & contextualization usability & accessibility mobility & device dependency	tool	philosophical proposal
[Vikram et al. 2009]	other	security & trust tools & languages	tool	solution proposal validation research
[Watanabe et al. 2009]	design	models, methods and methodologies user interface	model	solution proposal
[Wright and Dietrich 2008a]	other	models, methods & methodologies	methodology	evaluation research
[Wright and Dietrich 2008b]	design	models, methods & methodologies	methodology	evaluation research
[Yu et al. 2011]	implementation & deployment	architecture & application frameworks	tool	solution proposal
[Yu et al. 2006]	implementation & deployment	tools & languages	tool	solution proposal
[Zhao et al. 2010]	implementation & deployment	data management tools & languages performance	tool	solution proposal evaluation research