15 Years of CBSE Symposium: Impact on the Research Community

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ABSTRACT

In 2012, the International Symposium on Component-based Software Engineering (CBSE) is being organized for the 15th time. This is a great opportunity to take a step back and reflect on the impact of the symposium over these 15 years. Several interesting questions immediately come to mind: What were the main topics of interest in the community? What is the maturity of the field? What is the research CBSE Symposia impact? Who are the mots involved researches and researchers centers? In order to answer these questions we have performed a systematic review of 318 papers published under CBSE. In this paper we provide answers about the impact of the event, list and categorize the most frequent topics, and give some statistical data about the event during this period.

Categories and Subject Descriptors

D.2.2 [Software Engineering]: Design Tools and Techniques;
D.2.13 [Software Engineering]: Reusable Software

General Terms

Measurement, Documentation.

Keywords

Component-based software engineering.

1. INTRODUCTION

In year 2012 the International Symposium on Component-based Software Engineering (CBSE)[1] is running for the 15th time. Though not in the same form, the symposium has continuously addressed aspects of the same topic, namely software engineering in building systems from reusable units (software components). This idea was not introduced by this symposium; on the contrary, it is as old as software engineering itself. At the software engineering (SE) conference in 1968, Douglas McIlroy introduced the concept of software components during his keynote speech: "Mass-Produced Software Components" [1] Curiously, this role of a component did not remain in the focus of SE; and for the next 30 years a component was understood as an architectural unit, i.e. part of a software design [2]. In the nineties, in parallel with the start of the CBSE symposium, components again gained the role of (executable) building blocks of software applications. During a decade in 2000s, component-based development (CBD) and CBSE became standard topics in many SE conferences, and several new conferences dedicated to components appeared [3]. Today, CBSE is a standard part of SE, although the interest related to components has somewhat decreased.

The aim of this paper is to provide an overview of what the CBSE events have contributed to CBSE and SE in general; to which extent has the symposium contributed to the development and practice of the CBSE principles, processes and technologies? Which topics were covered, what challenges have been addressed, and what was the impact of the publications, direct and indirect?

The rest of the paper is organized as follows. Section 2 gives a brief history of the CBSE events, and Section 3 shortly describes the systematic review method used. Section 4 provides statistics about the published papers, while Section 5 and 6 present categorizations of the topics and other data that were extracted from the papers. Section 7 presents an overview of some additional statistics about the conference itself. Section 8 briefly discusses the threats to the validity, while Section 9 concludes the paper.

2. HISTORY OF CBSE EVENTS

A list of CBSE events is presented at [4]. CBSE started as an ICSE workshop in 1998. During its 15 years, the evolution of the CBSE events can be divided into four phases.

Phase 1. Initiation (1998 – 1999). The first CBSE workshop was organized as an ICSE 1998 workshop held in Tokyo. The main goal of the workshop was to collect information about CBSE – different initiatives, approaches, challenges and implications that exist. The initiative followed the current trend: in the late nineties CBSE became an increasingly popular approach to software development, with the aim of building software from pre-existing reusable entities – components. This was the starting assumption of the first and the following workshops. While the first workshop can be viewed as "a trial" workshop, the second workshop had a more ambitious goal – to build up knowledge about CBSE and CBSE related topics. There was even a plan to start building a "CBSE body of knowledge" report. While this was never achieved, one of the results of the workshop was the initiative to

CBSE'12, June 25–28, 2012, Bertinoro, Italy.

[1] During its history the CBSE event started as a workshop and later continued as a symposium. To avoid ambiguity with the area of Software Engineering – CBSE (Component Based Software Engineering), in this paper we will use the term "CBSE event" when referring to all events (including the workshops).

start a book about CBSE. This goal was soon realized with a new a book "CBSE – putting pieces together" [5] in which many workshop participants contributed with their expertise. The first two workshops provided a solid base for building the community and have set foundations for the expansion of CBSE research.

Phase 2. Focusing (2000 – 2003). During this period a series of workshops associated with ICSE were organized. The workshops were rather small, with a focus on a particular topic of CBSE; often, specific topics with concrete requirements for the papers were defined in the call for papers (e.g. "predictable assembly", "component trust and specifications", "automated CBSE", and similar). These topics were often in the foci of the research groups participating on the workshops, but they also became inspirational starting points for new research groups. The forms of the workshops were adjusted to intensive discussions in working groups, while the paper presentations were placed in the second plan. The workshop discussion results were usually published in ACM Software Engineering News in a form of workshop reports.

Phase 3. Broadening Scope (2004 – 2006). The impact of the CBSE workshops has increased over time – the number of paper contributions and the workshop participants increased, and a need for enlarging the scope, as well as emphasizing the importance on the submitted papers became evident. The result was a decision by the organizers to move from the workshop format to that of a symposium, and an event independent of ICSE, with its own proceedings, was organized. In the first year (2004) the symposium was still co-located with ICSE, but later it became an independently organized event. At the same time the scope of the event increased: topics related to essence of CBSE (component specifications, compositions and composition predictability compositions of non-functional properties, components and component-based system modeling and design, testing component-based systems), topics related to CBSE technologies (component models, component deployment), and case studies (modeling and implementing component-based systems, industrial cases) were more explored. The impact of CBSE events increased significantly during this period.

Phase 4. Collaboration phase (2007 – 2012). This period (still ongoing) is characterized by the increased cooperation with other communities. CBSE symposium became a part the federated event Components and Architecture (CompArch) [6] in which several other conferences, related mostly to Software Architecture, participate. This is also a period in which similar and complementary approaches became established in SE research and practice, such as Service-oriented Development, Aspect-oriented Programming, or Model-driven Engineering. This period is also characterized by the use of component-based approach in software development of other domains, such as embedded systems.

3. CBSE EVENTS SYSTEMATIC REVIEW

The implementation of a systematic review designed in [7] is in this case somewhat simpler for our case, since the primary studies (to find relevant primary states is one of the goals of a systematic review) are known – all accepted papers from the CBSE events have been taken into account. We have stated the following research questions:

- What is the impact of the CBSE events?
- Which topics characterize the CBSE publications?
- What type of questions and results have CBSE events presented?
- Through which research lifecycle has CBSE passed?

To answer these questions we performed an iterative analysis process (based on grounding theory and our experience). By reading the studies we identified the main topics addressed in the paper. In several iterations these topics have been grouped and characterized. The values of some categories have been predefined (e.g. maturity, result type, research questions, validation), while others have been collected by individual characterization and then grouped. The characteristics types are described in the next section. In the first iteration the researchers have individually categorized a subset of the studies (using studies from three years) and then together analyzed the categorization and harmonized them. During the discussions the understandings of the topics between the researchers have been aligned. In the second iteration the rest of studies have been categorized individually. For a better efficiency of the characterization process, a database with the studies and all metadata, as well as a program for efficient browsing and classifying the studies has been created. The same choices that the researchers independently selected or defined have been automatically taken while the different choices have again been discussed in the workshops and the final characterization has been achieved with a consensus.

4. CBSE PRIMARY STUDIES

In total 318 publications have been included in the review process. In the period 1998-2003 the proceedings were published as ICSE workshops (and are not available in the digital libraries), and in the period 2004-2012 in digital libraries LNCS Springer and ACM. Table 1 shows number of submitted, published, and cited papers (on 2012-02-20).

Table 1. CBSE themes and publications

Year	Special themes in CFPs	# submit-ted	# publi-shed	# citati-ons
98	Component-management infrastructures- the software technology	N/A	22	307
99	Principles of CBSE, Practice for adopting CBSE, Technologies supporting CBSE, research issues	N/A	34	120
00	The case studies with focus on the technologies and engineering practices unique to CBSE	N/A	16	121
01	Component Certification and System Prediction	N/A	23	253
02	Benchmarks for Predictable Assembly	N/A	11	250
03	Automated Reasoning and Prediction	N/A	17	331
04	In-depth treatment of topics pertaining to predictability	82	27	769
05	Software Components at Work	91	23	376
06	Future Directions for CBSE	77	31	365
07	CBSE influence in the field of software and global enterprise technology	89	19	160
08	MDE, grid technologies, global software development, networked enterprise information systems	70	23	228
09	Components for Large-Scale Systems of Systems and Ultra-Large Systems	43	11	58
10	Components beyond Reuse	48	15	56
11	Components In and For Dynamic Environments	59	22	11
12	Components for Achieving Long-Lived Systems	50	23	N/A
Total:		~800	318	3405

The number of published papers includes both long and short papers, keynote summaries (if submitted), and the chairs introductions (which often included specific contributions in form

challenges defined to be main topics in the workshops, and similar). After 2004 when CBSE started as a symposium, the proceedings contained long and short papers. Around 30-35% of the published papers in the period 2004-2012 are short papers. All submissions from all CBSE events are presented in [8].

The number of submissions and citation numbers show clearly different cycles in the history of the CBSE events. The first year attracted many researchers which provided important questions, challenges, current state of the art and the practice related to CBSE, and future directions. Several of these papers were a source of inspiration and consequently more cited. The migration from a workshop to a symposium had as a consequence a significant increase of the submissions and the number of citations. In last few years this number has slightly decreased – partially due to a standard latency in citations, but also (which is visible from a number of submissions) a lower interest in the specifics of the area. This can be a sign that CBSE as a research area becomes less interesting either as it has been integrated as a standard approach in software engineering practice, or that the approach did not succeed to realize its promises. Table 2 shows the 15 best-cited papers (from Google scholar, cited 2012-04-01).

Table 2. Top 15 CBSE studies cited

Ref	Study	#citations
S04-02	Bruneton, Eric; Coupaye, Thierry; Leclercq, Matthieu; Quema, Vivien; Stefani, Jean-Bernard; An Open Component Model and its Support in Java, 2004	306
S99-1	PORE Procurement-Oriented Requirements Engineering Method for the Component-Based Systems Engineering Development Paradigm	118
S98-18	Aoyama, Mikio; New Age of Software Development: How Component-Based Software Engineering Changes the Way of Software Development ? 1998	115
S03-3	Cervantes, Humberto; Hall, Richard S; Automating Service Dependency Management in a Service-Oriented Component Model; 2003	103
S02-0	Chen, Shiping; Liu, Yan; Gorton, Ian; Performance Prediction of Component-based Applications, 2002	77
S05-13	Lau, Kung-kiu; Elizondo, Velasco, Perla; Wang, Zheng; Exogenous Connectors for Software Components, 2005	68
S06-25	Sentilles, Severine; Vulgarakis, Aneta; Bures, Tomas; Carlson, Jan; Crnkovic, Ivica; A Component Model for Control-Intensive Embedded Systems; 2008	65
S08-16	Seinturier, Lionel; Pessemier, Nicolas; Duchien, Laurence; Coupaye, Thierry; A Component Model Engineered with Components and Aspects, 2006	65
S98-10	Kruchten, Philippe; Modeling Component Systems with the Unified Modeling Language, 1998	63
S04-26	Bertolino, Antonia; Mirandola, Raffaela; CB-SPE Tool: Putting component-based performance engineering into practice; 2008	60
S04-9	Kulkarni, Sandeep S; Biyani, Karun N; Correctness of Component-Based Adaptation; 2004	56
S04-20	Sandstrom, Kristian; Fredriksson, Johan; Akerholm, Mikael; Introducing a Component Technology for Safety Critical Embedded Real-Time Systems; 2004	42
S05-03	Collet, Philippe; Rousseau, Roger; Coupaye, Thierry; Rivierre, Nicolas; A contracting Systems for Hierarchical Components; 2005	42
S06-13	Hnětynka, Petr; Plášil, František; Dynamic Reconfiguration and Access to Services in Hierarchical Component Models; 2006	41
S03-02	Bertolino, Antonia; Mirandola, Raffaela; Towards Component-Based Software Performance Engineering; 2003	38

The total h-index of the CBSE events is 30 (there are 30 publications that have at least 30 citations), and it has I10-index 110 (110 publications with at least 10 references). These numbers are the most interesting for comparison with other conferences. Unfortunately having not complete information from other conferences, it is difficult to compare the results. Here we provide the results from Microsoft Academic Search [7] for CBSE, and WICSA. Data provided from Microsoft Academic Search for CBSE is "Publications: 229; Citation Count: 1,967; Year Range: 1998 - 2010" and for WICSA is "Publications: 415; Citation Count: 3,355; Year Range: 1998 – 2011". This shows that WICSA has a larger impact in absolute terms, but the ratio of citation per submission is similar for both events.

In addition to direct impact, there is also an indirect impact, which is at least as important as the direct impact measured by the citations. The indirect impact can be measured by analyzing several aspects: a) impact of publications that cite the CBSE studies (backward references), b) impact of researchers which are active in the CBSE community and have publications in the CBSE area in journals, magazines or events; c) publications that are a direct result of the CBSE events, such as special issues in Journals or reports about the conference.

Table 3 shows the top 15 papers that indirectly have the largest impact. The indirect references show total number of citations of publications that refer to the particular CBSE study. The correlation between the direct cited and indirectly cited is visible: 10 top-cited papers are also between the 15 top indirectly cited papers (marked as bold fonts).

Table 3. Top papers by the number of backward references

#ID	**S04-2**	S00-9	S03-1	**S04-9**	**S99-1**	**S04-26**	**S03-3**	**S02-0**	S04-19	**S06-25**	**S98-18**	S02-08	S04-5	**S06-13**	**S05-13**
#ref	**2294**	1984	909	**899**	**840**	**832**	**817**	**810**	646	**555**	**543**	455	454	**450**	**447**

Table 4 lists the top 10 citations within CBSE published somewhere else, where the authors belonged to the CBSE community.

Table 4. CBSE community impact - top 10 cited publications

Ref	CBSE references outside CBSE events	#Citations
R1	GT. Heineman, WT. Councill, Component-based software engineering: putting the pieces together, 2001	924
R2	I Crnkovic, M Larsson, Building reliable component-based systems, 2002	451
R3	T Coupaye at all, The fractal component model and its support in Java, Software: Practice, 2006	443
R4	RH Reussner, HW Schmidt, IH Poernomo, Reliability prediction for component-based software architectures Journal of Systems and Software 66 (3), 241-252	189
R5	KK Lau, Software component models, Software Engineering, IEEE Transactions, 2007	180
R6	C Szyperski, Component technology: what, where, and how? ICSE 03,Proceedings of the 25th International Conference on Software Engineering	169
R7	S Becker, H Koziolek, R Reussner, The Palladio component model for model-driven performance prediction, Journal of Systems and Software, 2009	163
R8	J Stafford et all, Quality attribute workshops, SEI technical report, 2002	158
R9	K Wallnau et al, Volume III: A technology for predictable assembly from certifiable components, SEI tech. report 2003	156
R10	K Wallnau et al, Volume II: Technical concepts of CBSE, SEI technical report 2000	137

For example, R1 reference is a direct result of CBSE workshop 1999 in which the groups discussed about the possible topics of interest for a new CBSE book, which later become a result of cooperation of many authors. Similar, R2 is a result or cooperation of several authors form the CBSE community. The work at SEI (R8, R9 and R10) was closely related to the selected topics at the CBSE workshops. These publications are the most cited publications from CBSE submissions. Other publications are either extended versions of the CBSE papers (for example R2, R3), or the topics are strongly related to the topics at CBSE (for example the references R4, R7). Finally some of the publications (R5, R6) contributed to the popularization of CBSE to other, larger communities.

5. CBSE TOPICS

The area of CBSE interest is almost as wide as software engineering (SE) itself. Practically all concerns in SE are topics of interest in CBSE. The primary idea of CBSE goes beyond a technical solution, it originates from a business (faster time to market, price), and general engineering principles (divide and conquer, reuse, quality). For this reason the topics in CBSE are wide. Still the CBSE events were focused on a subset of SE issues, mostly related to modeling, analysis and design, and implementation.

To identify the topics of the CBSE events we have analyzed the studies, by assigning each paper at least one topic. After the first iteration, we grouped the topics and generalize them. Then, in the second iteration we have re-mapped the studies to the new generalized topics. The generalized list of topics appeared in the CBSE studies is the following:

- Component models
- Component technologies
- Extra-functional properties
- Composition & predictability
- Software Architecture
- Quality issues
- Lifecycle
- Domains
- Methodology

Each topic includes a number issues and subtopics which also address a number of issues. There is at least one study that refers to a particular subtopic. In some cases a study is dealing with several topics, and in that case all topics are included into the list.

Below we shortly describe each topic and subtopics with the associated studies, and summarize the list with the studies'. All references are presented in Table 5.

5.1 Components and Component Models

Component models define the rules for component specification (including functional and extra-functional properties) and component composition. Component specification, and component characterization was a very important topic in the first period of the CBSE events. The overall understanding of component specification is expressed by the following definition. Component is specified by a set of interfaces, and a set of properties:

$$C = < I, P >;\ I = \{i_1, i_2, \ldots, i_n\};\ P = \{p_1, p_2, \ldots, p_k\}$$

I defines a set of component functional interfaces $\mathbf{i_j}$ (typically implemented as signatures), and **P** a set of extra-functional properties $\mathbf{p_j}$.

A component confirms to a component model CM if both the interface and the properties confirm to the component model.

$$C \vDash CM \Rightarrow I, P \vDash CM$$

Two main important contributions from the symposia are: (i) it is a *component model specification* that matters, and not only the *component specification*; (ii) the extension of component specification with extra-functional properties specification.

The subtopics presented in the studies can be divided in three subcategories:

- Component models and component categorization include a wide range of topics such as specification languages, conformance checking, encapsulation, etc. For the full list of (sub)topics see Table 5.
- Component interface as the main means of component specification.
- Behavior which includes behavior analysis, models, adaptations, etc.

Not surprisingly, the topics "components and component models" have been addressed most frequently. In total 112 contributions deal with these topics.

5.2 Components Technologies

A component technology is an implementation of a component model. While it basically implements the rules specified by a component model, it also adds many important issues relevant for the implementation that are not visible in the component model. There are three types of studies related to component technologies: i) studies which described a design and an implementation of a new technology (a complete, or a part of, or a prototype), ii) studies which used a particular technology and extended it with some particular feature, and finally iii) studies which used a particular technology to demonstrate some features. Many studies related to component technologies are present

The studies focusing on a particular technology include the following component technologies: Fractal, JavaBeans, CCM, EJB, J2EE, OSGi, Robocop, ASP.NET, ProCom, Fractal, etc. COTS-related studies are also placed here as they refer to some technologies. Total number of studies from these topics is 31.

5.3 Extra-Functional Properties

Extra-Functional properties (EFP), or Non-Functional-Properties or Quality Attributes, or simply Properties, were the most frequent topics used in the studies. However, EFPs are as rules related with other topics, for example, components, compositions, composition, quality, etc. The main EFP issues in the studies are related to (i) EFP specifications – how to specify, how to model EFPs, and how to measure them; (ii) EFP management – how to achieve or/and guarantee a particular EFP (iii) how to analyze EFPs, and (iv) how to compose EFPs? There are numerous studies that refer to EFPs - in total 61. Many studies (more than 20) consider general questions valid for all or certain classes of EFPs. Other studies focus on these questions for a particular property. In most of the cases it is about run-time properties.

Table 5 lists the particular EFPs and concerns related to them. The majority of EFPs are related to dependability properties, in particular reliability, but there are also issues related to safety, security, and to the means to achieve dependability, such as fault tolerance and system recovery. Performance, related to predictability, evaluation, and in general performance engineering is addressed in many studies (17). Finally, the concerns related to resource constraints are present in the studies.

5.4 Compositions and Predictability

Composition has been the main concern of CBSE events. Similarly as in specification of component models, one of the important contributions of CBSE event is the emphasis of extended definition of composition. Here the composition includes a composition of functional and extra-functional properties. The specification is as follows. Assembly C is a set of components C_1 and C_2 that communicate via their interfaces.

Assembly: $\mathrm{C} = \{\mathrm{C}_1, \mathrm{C}_2\},\ \mathrm{A} = < \mathrm{I}_\mathrm{A} > \mid \mathrm{I}_\mathrm{A} = < \mathrm{I}_1 \oplus \mathrm{I}_2 >$

This assembly is not necessary a component that conforms to the same component model. If it does, then both the assembly interface and the assembly properties conform to the component model.

$$\mathrm{C} = < \mathrm{I}, \mathrm{P} >; \mathrm{I} = < \mathrm{I}_1 \oplus \mathrm{I}_2 >, \mathrm{C} \vDash \mathrm{CM} \Rightarrow \mathrm{I}, \mathrm{P} \vDash \mathrm{CM}.$$

Further, when refereeing to a component composition, it is not the functional composition that matters, but both the compositions of interfaces and the composition of other properties (extra functional properties) are parts of the composition.

$$\mathrm{C} = < \mathrm{C}_1 \oplus \mathrm{C}_2 > \Rightarrow \mathrm{I} = < \mathrm{I}_1 \oplus \mathrm{I}_2 > \text{ and } \mathrm{P} = < \mathrm{P}_1 \oplus \mathrm{P}_2 >$$

One of the main concerns of the CBSE events was composition of EFPs: Which EFPs are composable, which are the composition operators, under which restrictions it is possible to compose certain EFPs? CBSE also introduced the term of "predictable assembly" aiming to predict an assembly property from component properties and given restriction of the external context. In total 37 studies addressed this topic explicitly (though more studies addressed this topic implicitly when focusing on particular EFPs, or a particular type of interoperability between components, architectural styles, and similar).

5.5 Software Architecture

Software Architecture (SA) is tightly related to CBSE; components are first class citizens in SA – the main elements of an SA are components. Many researchers do not distinguish specifics of components in CBSE and components as architectural elements. In CBSE there is a difference between "architectural components" that are architectural elements of a structure, and components that conform to a component model. In the CBSE events several studies keep the focus on a general SA level discussing architectural decisions and constraints, trade-off analysis, and similar, while most of the studies focus on some specifics in SA that are of particular interest for CBSE: SA elements such as connectors and containers, then design patterns in a component-based approach, ADLs with component specification, and in earlier works dependency management. Total number of studies directly related to SA is 29.

5.6 Lifecycle

Lifecycle includes a broad range of topics related to the different phases of a component and component-based system lifecycle. The basic phases in a component life cycle are: modeling & design, packaging and storing, deployment, execution [12]. There were many research and engineering challenges in supporting different issues. The main topics addressed in the studies were: Requirements management of components and component-based systems, component management in general, modeling and design, component selections, components adaptations, synthesis, deployment and run-time issues such as dynamic deployment and interaction optimization. In total 69 studies contributed in issues related to component lifecycle and to component-based system lifecycle.

5.7 Domains

The Domains category includes all studies that are domain-specific. This category has many strong contributions – applying CBSE in different domains, defining component models and requirements for them within different domains, demonstrating benefits and difficulties in using the CBSE approach in these domains. Several of these studies expanded the usage area of CBSE. The following domains are addressed. Financial Systems, Product Lines, Enterprise Systems, Service Oriented Systems including Web Services, Telecommunication domain, Aspects and Aspect-oriented Systems, and a large group of Embedded and Real-time Systems. A total number of 68 studies are included here.

5.8 Methodology

Methodology studies include work on different CBSE approaches, methods, processes, and combinations with similar and complementary approaches in SE. Model-based Engineering with some studies related with model-driven engineering describes CBSE use in early design phase. There are several studies on reuse, though one could expect more since one of the motivations of CBSE is effective reuse. Similarly only to a smaller extent the CBSE processes were presented. The tradition of the CBSE events is more attached to technology development than processes. Finally, in this category we have placed "experiences" which could be classified as a separate topic, but a rather small number of the contributions (only 9), and their content prevailed us to define it as a subcategory of methodology. This category has in total 68 studies.

5.9 Topics Summary

Table 5 summarizes the main topics and the issues addressed in the studies within the topics. Further, each topic includes a number of subtopics with their own issues. We also provide a number of studies per main topic. Due to space limitations we do not present a number of studies per subtopic and issue. Each issue has been addressed at least in one paper, but in mot of cases several times. This list of studies (in the table denoted Syy-n, where yy is the publication year of the study) and be found in [8].

Table 5. CBSE topics distributions

Topic	**Component models** (Components, Component Frameworks, Modular Systems) – **109 studies**
Subtopics	**Component Characterization** (Component Communication, Certification, Specification Languages, Interoperability, Component specification, Messaging Protocols, Data Encapsulation, Specification, Conformance Checking, Compatibility, Component Hierarchie Generation), **Interfaces and services** (Interfaces, Component Services, Services), **Behavior** (Data-flow analysis, Behavior Analysis, Behavior adaptation, Behavior Specification, Behavior Models, Information flow).
Studies	S98-8, S00-2, S00-15, S04-2, S04-10, S04-20, S06-21, S06-25, S06-26, S06-29, S08-3, S08-16, S09-9, S11--12, S11-15, S99-2, S99-6, S98-0, S98-7, S98-19, S01-18, S98-1, S98-2, S98-9, S98-13, S98-14, S98-16, S98-20, S00-1, S00-4, S00-6, S00-8, S00-10, S00-13, S01-8, S01-9, S01-12, S01-13, S01-17, S02-1, S02-2, S02-7, S04-15, S04-24, S05-0, S05-2, S05-4, S05-17, S05-21, S06-3, S06-4, S06-6, S06-8, S06-20, S07-6, S07-14, S08-0, S08-6, S08-15, S09-1, S09-10, S10-0, S10-2, S10-3, S10-7, S99-5, S99-7, S99-8, S99-11, S99-13, S99-17, S99-18, S99-20, S99-23, S99-26, S11-6, S01-1, S01-2, S01-6, S01-7, S03-1, S04-1, S05-14, S06-18, S07-8, S07-17, S09-0, S99-15, S08-2, S11-21, S04-7, S99-0, S08-11, S05-1, S06-19, S06-24, S07-11, S06-22, S08-10, S05-19, S11-9, S11-1, S12-07, S12-11, S-12-10, S12-13, S12-14, S12-15, S12-19
Topic	**Component technologies – 31 studies**
Subtopics	**JavaBeans, COTS, OSGi, CCM, EJB, Robocop, ASP.NET, Fractal, J2EE** (Java EE)
Studies	S98-8, S00-2, S00-15, S04-2, S04-10, S04-20, S06-21, S06-25, S06-26, S06-29, S08-3, S08-16, S09-9, S11-12, S11-15, S99-2, S99-6, S98-0, S98-7, S98-19, S01-18, S98-1, S98-2, S98-9, S98-13, S98-14, S98-16, S98-20, S00-1, S00-4, S00-6, S00-8, S00-10, S00-13, S01-8, S01-9, S01-12, S01-13, S01-17, S02-1, S02-2, S02-7, S04-15, S04-24, S05-0, S05-2, S05-4, S05-17, S05-21, S06-3, S06-4, S06-6, S06-8, S06-20, S07-6, S07-14, S08-0, S08-6, S08-15, S09-1, S09-10, S10-0, S10-2, S10-3, S10-7, S99-5, S99-7, S99-8, S99-11, S99-13, S99-17, S99-18, S99-20, S99-23, S99-26, S11-6, S01-1, S01-2, S01-6, S01-7, S03-1, S04-1, S05-14, S06-18, S07-8, S07-17, S09-0, S99-15, S08-2, S11-21, S04-7, S99-0, S08-11, S05-1, S06-19, S06-24, S07-11, S06-22, S08-10, S05-19, S11-9, S11-1, S12-04, S12-12
Topic	**Composition & predictability** (Component composition, Component Assembly, Predictable composition) – **37 studies**
Subtopics	**Predictable assembly**, **Compositional reasoning** (Exogenous Composition)
Studies	S01-5, S01-16, S02-2, S02-3, S02-6, S03-6, S05-11, S06-1, S06-2, S06-9, S07-6, S07-7, S07-8, S07-14, S07-17, S09-2, S09-8, S10-3, S10-9, S10-12, S99-16, S04-24, S99-17, S01-10, S01-14, S01-15, S01-21, S02-4, S02-8, S02-9, S03-14, S03-15, S04-5, S06-12, S12-01, S12-15, S12-16
Topic	**Extra Functional Properties** (QoS, Component Properties, Policies, Policy Enforcement, Quality properties, Quality, Non-Functional Properties, Quality Optimization) – **60 studies**
Subtopics	**Dependability** (Reliability, Availability, Reliable Systems, Safety, Scheduling, Reliability analysis, Security, Safety-Critical), **Adaptability**, **Performance** (Performance prediction, Performance Analysis, Performance Evaluation, Performance Models, Performance Engineering), **Vulnerability**, **Maintainability**, **Resource Constraints** (Resource Consumption, Resource Optimization, Energy Consumption)
Studies	S11-13, S01-14, S01-21, S04-6, S04-13, S04-19, S05-22, S06-16, S07-13, S04-26, S02-4, S04-4, S11-4, S02-7, S03-13, S06-5, S01-22, S06-27, S11-11, S07-1, S08-15, S00-9, S01-11, S02-6, S02-8, S03-10, S04-21, S06-10, S07-2, S10-4, S10-10, S11-5, S03-11, S05-9, S08-22, S11-7, S05-10, S11-1, S04-0, S02-0, S03-2, S03-14, S03-15, S04-5, S05-14, S05-20, S06-28, S07-4, S07-10, S08-10, S08-12, S08-18, S08-21, S09-5, S08-14, S99-27, S03-9, S05-8, S08-17, S12-20
Topic	**Software Architecture** (Architectural Constraints, Architectural Support, Trade-off analysis, Architectural properties) – **29 studies**
Subtopics	**Architectural Components** (Connectors, Exogenous Connectors), **Design Patterns** (Architectural stlyes), **Containers**, **Dependency Management** (Dependency analysis, Dependencies, Dependency resolution), **ADLs**
Studies	S01-0, S05-1, S05-5, S05-12, S05-22, S06-7, S06-23, S03-4, S04-14, S06-5, S07-12, S98-19, S04-15, S05-13, S08-1, S02-3, S03-11, S03-12, S10-9, S01-21, S02-9, S04-22, S03-3, S01-19, S09-6, S10-8, S11-20, S99-31, S12-09
Topic	**Lifecycle – 69 studies**
Subtopics	**Component Management** (Reconfiguration, Package management), **Synthesis**, **Component adaptation** (Adaptation frameworks, Component adapters, Adaptation Techniques), **Requirements Engineering** (Consistency, Constraints), **Dynamic Reconfiguration** (Dynamic update, Update, Dynamic Adaptation, Update Management, Self-healing), **Software Release**, **Component selection** (Component Broker, Component Matching, Component lookup, Component identification), **Deployment** (Integration, Predictable deployment), **Modeling and design** (End-user modeling, Modelling, Design, Early analysis, Feature models), **Runtime** (Memory Profiling, Memory Managers, Execution Environment, Runtime monitoring, Control Encapsulation, Runtime Evolution)
Studies	S98-13, S04-9, S04-14, S05-6, S06-11, S06-13, S07-15, S10-1, S10-10, S11-18, S07-18, S11-0, S01-8, S02-1, S05-10, S08-1, S11-3, S01-13, S04-15, S06-19, S10-7, S08-7, S99-3, S04-8, S99-1, S09-7, S03-4, S11-20, S02-5, S07-16, S07-3, S10-5, S11-6, S04-23, S06-6, S06-8, S08-6, S99-26, S00-13, S05-21, S06-4, S09-1, S06-17, S07-9, S08-18, S10-11, S11-2, S11-16, S98-9, S98-10, S08-9, S01-3, S02-3, S03-11, S03-12, S05-0, S10-9, S06-10, S10-3, S07-12, S05-16, S06-5, S06-28, S09-8, S12-02, S12-04, S12-05, S12-21, S12-22
Topic	**Domains – 58 studies**
Subtopics	**Financial Systems**, **Product Line**, **Enterprise systems** (large-scale enterprise systems, ERP), **Service Oriented** (Web Services, Service policy), **Telecommunication**, **Aspects** (Aspect Oriented), **Grid**, **Games**, **Workflows** (Workflow), **Legacy applications**, **Embedded and Real Time** (Pervasive Computing, Controllers, Control systems)
Studies	S09-9, S00-10, S02-4, S06-7, S10-3, S99-21, S02-0, S02-9, S10-11, S99-10, S03-0, S03-3, S04-3, S05-1, S06-19, S07-11, S06-9, S07-0, S07-6, S09-4, S05-2, S05-11, S06-23, S06-25, S06-26, S07-3, S11-17, S03-13, S05-15, S07-5, S11-5, S10-0, S01-4, S01-5, S04-12, S04-16, S04-17, S04-20, S05-8, S06-0, S06-20, S07-15, S08-13, S08-16, S09-3, S09-10, S10-6, S10-12, S10-13, S11-3, S11-16, S11-18, S11-19, S04-10, S05-10, S06-5, S10-1, S99-4
Topic	**Methodology** (research method, Business Processes, Software Process, CBSE, Process, Formal methods) – **68 studies**
Subtopics	**Reuse** (Component reuse, Opportunistic Reuse), **Evolution** (Evolution Management), **Repositories**, **Education**, **Empirical** (Experience), **Model Driven** (Model Transformation, Model-Based,, Model Checking)
Studies	S98-2, S98-11, S02-2, S03-5, S04-18, S06-15, S06-5, S99-5, S99-8, S99-9, S99-12, S99-24, S99-25, S99-27, S99-28, S99-30, S99-32, S99-29, S98-13, S01-9, S01-12, S08-8, S98-15, S06-27, S11-4, S11-6, S11-10, S11-17, S99-19, S99-21, S98-18, S99-14, S00-3, S00-7, S02-7, S03-6, S06-6, S08-12, S00-1, S00-4, S00-8, S00-10, S00-11, S00-12, S03-1, S04-3, S04-16, S05-0, S05-1, S05-2, S05-5, S07-10, S07-15, S09-6, S99-3, S99-22, S03-16, S05-9, S09-3, S11-12, S06-10, S09-9, S04-11, S05-18, S06-30, S08-2, S08-22, S10-13, S12-01, S12-07, S12-10, S12-11, S12-12, S12-13, S12-14, S12-17, S12-18, S12-21

6. CBSE STUDIES CHARACTERISTICS

What are the characteristics of CBSE studies? A research area typically passes through different phases, from new ideas and basic concepts to development of formalisms, technologies and use in practice. Contribution types indicate the maturity level of the area. Other types of characteristics are related to research approach – to the types of research questions, results, and validation. To analyze CBSE events we have provided two types of characteristics: a) related to the lifecycle of a research area, and b) related to the types of the research approaches.

6.1 CBSE Maturity Level Lifecycle

According to [8] a research area has its lifecycle which is characterized by different phases (shown as software technology maturation process):

- *Basic research* – starting with basic ideas and concepts, initial structure on the problem, critical research questions.
- *Concept formulation* - developing a research community, solutions to specific subproblems.
- *Development and extension* - preliminary use of the technology, clarification, generalization, formalization.
- *Internal enhancement and exploration* - using technology for real problems, enhancing technology, showing value in results.
- *External enhancement and exploration* - involving a broader community, extending the principles and technologies to other domains, showing substantial evidence of value and applicability.
- *Popularization* - developing production-quality, supporting different versions of the technology, using technologies in practice.

CBSE events did not start from the very beginning of CBSE research. Actually there are a few seminal papers publisged before CBSE events that were an inspiration for the event start (e.g. [10] and [11]). For this reason we have in our classification merged "basic research" with "concept formulation".

Figure 1 shows the classified studies with respect to their maturity characteristics. The figure shows a domination of "concept formulation" in first five years with its graduate decrease after the third year. The "Development and Enhancement" starts unexpectedly already first year, drops down and then increases again. The first year shows "low hanging fruits" – extensions of some principles from the existing technologies (OO technologies and first component models), but later development refers mostly to the development of the concepts created in the initial phase of the CBSE events.

Figure 2 shows the total distribution of the studies maturity. The values are quite typical for a mature research area. A small contribution in "external enhancement" and no contribution in "popularization" is however surprising. A small contribution to external enhancement can be explained by the classification criteria – many studies refer to different domains in which they adopt the CBSE principles (and by this contribute to the internal enhancement). We have classified these contributions as "development and extension", although one can argue that they are actually external enhancements. Having in mind that in total 59 studies refer to different domains, and that they could also be classified as "external enhancement" it would then reach around 20% of all studies. The popularization-type contributions were not present at the symposia. Simply this type of event does not have this tradition, but the members of the CBSE community have been active in popularization in different forms (keynotes, special journals and magazine issues, guest lectures, and some industrial collaboration projects).

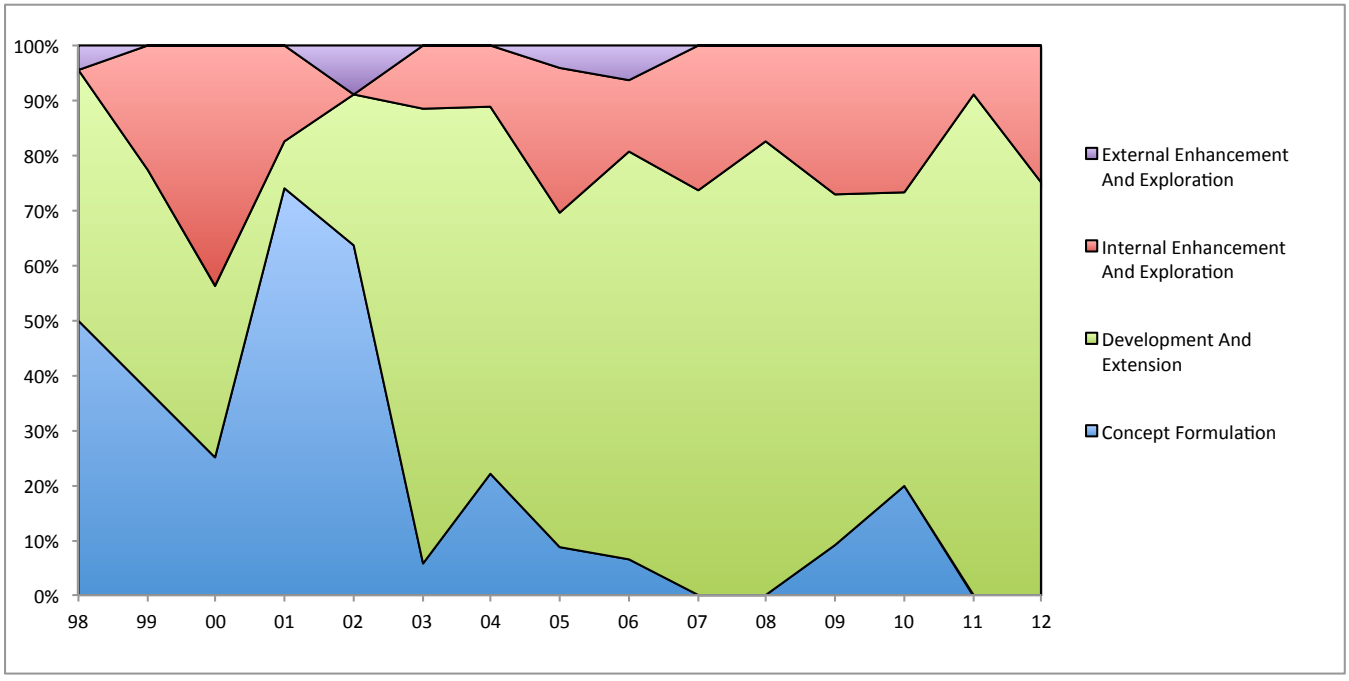

Figure 1. CBSE research maturity phases from 98 to '11

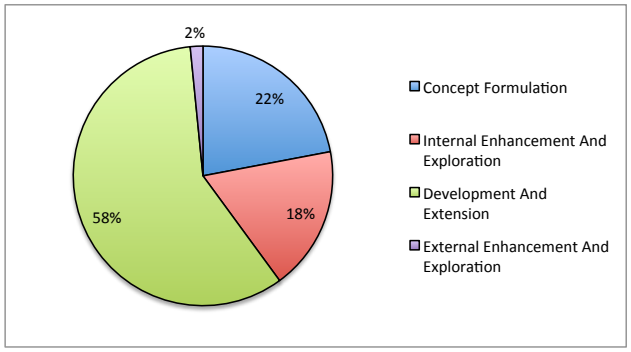

Figure 2. Distribution of CBSE research maturity phases

6.2 Questions, Results and Validation

In addition to the level of maturity, according to the classification presented in [9], a research area is also characterized by the types of research questions, results and validation. We have extracted these categories from the studies. Sometimes they are explicitly referred to in the studies, but more often they have to be derived (especially the questions).

According to [9] there are 5 different types of research questions in the SE community, which we have used to classify papers published in the CBSE events.

- *Method or means of development***.** Example: How can we do/create (or automate doing) X? What is a better way to do/create X?
- *Method for analysis.* How can we evaluate the quality /correctness of X? How do I choose between X and Y?
- *Design, evaluation, or analysis of a particular instance.* What is a (better) design or implementation for application X? What is property X of artifact/method Y?
- *Generalization or characterization.* Given X, what will Y (necessarily) be? What, exactly, do we mean by X? What are the important characteristics of X?
- *Feasibility.* Does X even exist, and if so what is it like? Is it possible to accomplish X at all?

The results of the classification are presented in Figure 3. Since CBSE is a software engineering event, it is not a great surprise that the majority of papers are falling in the category of "Method or means of development". Some studies stated several type of questions, so the total number of questions (330) is somewhat larger than the number of studies.

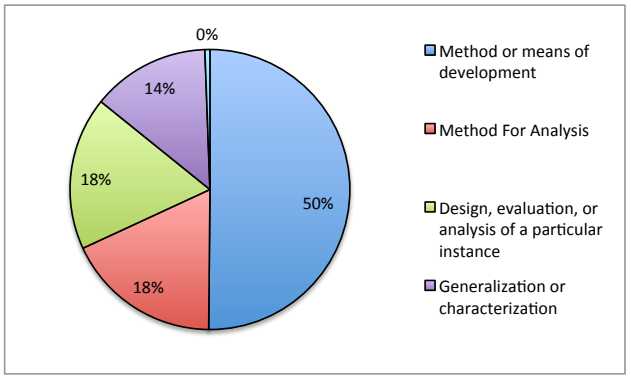

Figure 3. Question type distribution

According to the same reference ([9]), the results can be categorized into 8 different categories:

- *Procedure or technique***.** New or better way to do some task, such as design, implementation, measurement, evaluation, etc.
- *Qualitative or descriptive model.* Structure or taxonomy for a problem area, non-formal domain analysis, well-argued informal generalizations, etc.
- *Empirical model.* Empirical predictive model based on observed data.
- *Analytic model.* Structural model precise enough to support formal analysis or automatic manipulation.
- *Notation or tool.* Formal language to support technique or model, implemented tool that embodies a technique
- *Specific solution*. Solution to application problem that shows use of software engineering principles
- *Answer or judgment.* Result of a specific analysis, evaluation, or comparison
- *Report.* Interesting observations, rules of thumb.

The CBSE events results distribution is shown in Figure 4. For the same reasons as in the research questions section, it is not surprising that the majority of research as a result produces "A procedure or a technique" followed by "Report". Notation and tools is a rather small part, assuming that most of the work is related to development and enhancement. The reason is that in most of the cases the development was not a development of a (professional) tool but rather of a prototype, demonstrator, or just an example. Empirical models are present in a very low percentage (only 2 studies). The reason is the CBSE community culture – the empirical methods and models simply are not popular. Similar as to the questions section, a single study can have more than one type of result. For this reason here we have a total of 405 results.

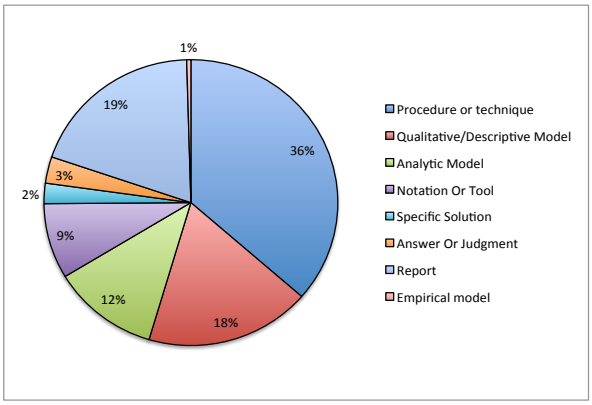

Figure 4. CBSE Results distribution

The last data that we present is the validation data – we were interested to know which types of validation is mostly used in the CBSE community. Here, we also differentiate between different categories:

- *Not presented.* No attempts to validate the results;
- *Simple example.* Illustration the approach;
- *Academic case study*. A realistic system is used, but it is still simpler than a commercial application;
- *Industrial case study.* A system used by the industry;
- *Experiments;*
- *Formal specification;*
- *Literature comparison.*

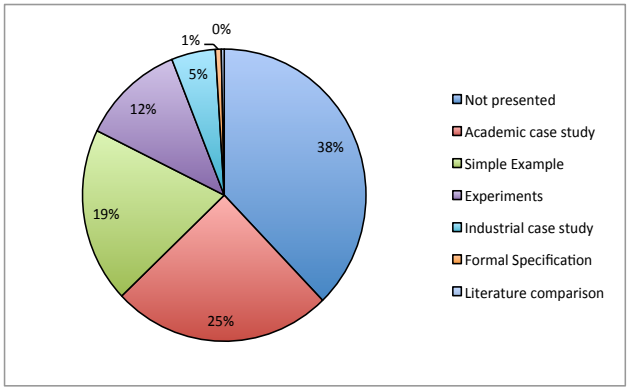

Figure 5. Types of validation CBSE 1998-2011

In this case, the overall data might be misleading, because it presents that the considerable amount of papers does not provide any validation. However, this is mostly because in the early years of CBSE events (while it was still a workshop), there was a considerable number of position papers, which usually do not present any validation. For this reason, we also present validations obtained by only analyzing papers in a more mature phase of the CBSE events lifecycle (2004-2011). Here we can see that a considerably lower number of the papers do not have any (proper) validation.

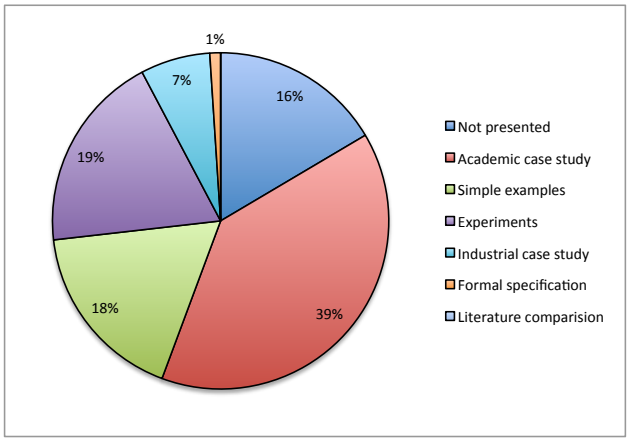

Figure 6. Types of validation CBSE 2004-2011

7. ADDITIONAL STATISTICS

Here we provide additional statistics related to the CBSE events and the CBSE community that was built around these events: authors' affiliation statistics, authors' geographical distributions, and the most active research centers.

7.1 Affiliation statistic

We have categorized authors' affiliation in three categories: *i*) Univesity, *ii*) Institute, and *iii*) Private Company, see Figure 7. Even though the percentage of industrial contribution could be higher, it nonetheless shows that there are strong connections between this research community and the industry.

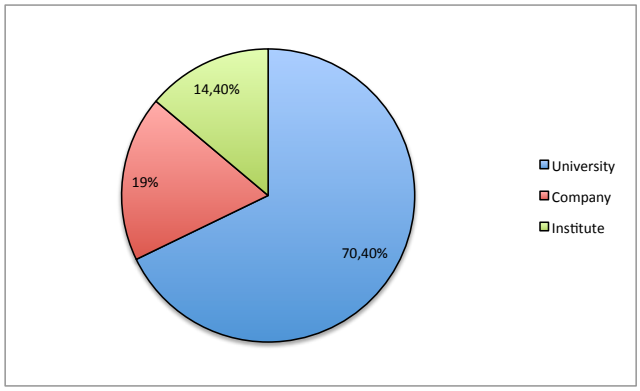

Figure 7. Affiliation Statistics

Geographical distribution – based on the authors' affiliation, we have also categorized the papers according to continents and countries, see Figure 8.

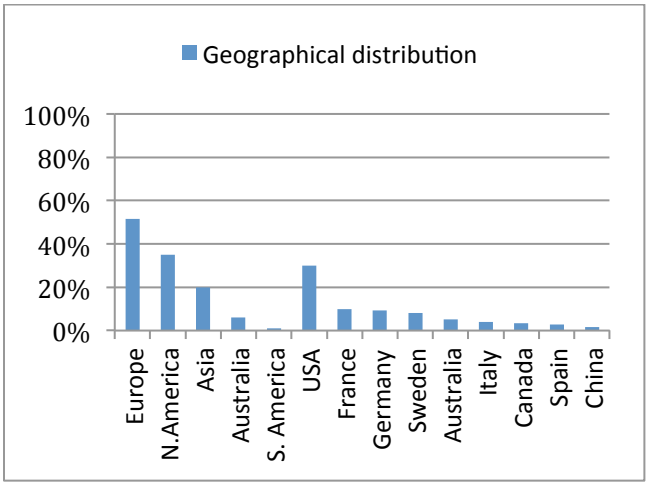

Figure 8. Paper distribution by continents and countries

In addition to these statistics, we also though that it would be beneficiary to note the top ten research centers contributing in CBSE events – shown in Figure 9.

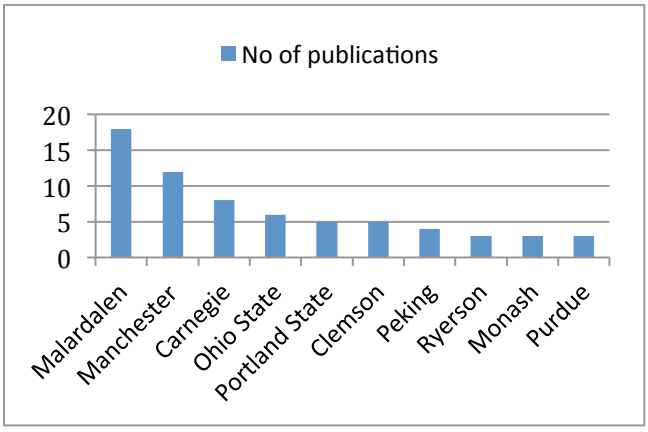

Figure 9. Top Ten Contributors Research Centers in CBSE

7.2 The most active authors

The authors sorted with the highest number of publications, and the total citations of these papers are shown in Table 6. Note that the introductions written by the general and PC chairs are not included into the list.

Table 6. Top ten most active authors

Author	# publications in CBSE	# citations
Kung-Kiu Lau	13 publications: S01-10; S05-13; S06-18;S07-7;S07-8;S07-9;S09-8; S09-9; S10-9;S06-17; S11-12; S12-08; S12-23	126
Ivica Crnković	8 publications: S99-22; S00-3; S02-2; S02-4; S06-20; S08-16; S09-3; S12-19	116
Ralf Reussner	6 publications: S04-1; S08-9; S08-10; S08-12; S09-5; S11-11	74
Ian Gorton	5 publications: S02-0; S05-14; S07-6; S07-10; S09-4;	113
Raffaela Mirandola	5 publications: S03-2; S06-10; S10-4; S11-5; S04-26;	116
Judith Stafford	5 publications: S01-17; S02-2; S02-8; S03-10; S04-22;	115
Salah Sadou	5 publications: S06-15; S06-27; S08-6; S10-0; S11-20;	19
Jan Carlson	5 publications S08-16; S08-20; S11-3; S12-14; S12-17	14
George Heineman	4 publications. S03-7;S04-6;S09-6;S99-3;	90
Thierry Coupaye	4 publications: S04-;S05-3;S06-25; S10-10;	423

8. VALIDITY OF THE SURVEY

Data provided in this paper falls into two basic categories: a) extracted data, i.e. the exact data (for example number of papers, authors, number of citations), and b) derived data based on subjective classification (for example the types of questions, results, and validation). Since we developed a tool that extracts data, and the tool was simple to test, the possible errors and a threat to internal validity is minimal. The derived data was based on the reasoning from the researchers' side, and can be considered subjective. To decrease subjectivity, the data assessment and the classification was done in several iterations, first individually and then in meetings to achieve a consensus. While the main classification is subjective (and as a such the actual contribution) it is based on the authors' wording, terms and definitions, and for this reason based on the objective facts. The conclusions based on data have also been discussed on the meetings, and as such they are the contributions from the researchers.

9. CONCLUSION

This paper gives an analysis of 15 years of activities of CBSE events. During these 15 years more than 300 co-authors contributed with 318 contributions to a continuous and a long life of the CBSE community. CBSE has come to a mature phase where many challenges stated in early years have been solved, or it was realized that they are unsolvable. During this period, CBSE has been applied to many different domains, and has become an integral part in some of them (e.g. CBSE in embedded systems). It has been demonstrated that new domains and new technologies require new and adopted CBSE approaches (for example dynamic compositions, improved and more efficient certifications, dynamic adaptation, different types of component models, etc.). This gives promises to the continuation of the community. At the same time, since CBSE become an immanent part of SE, there is a serious risk that CBSE, as a separate topic, will not keep the same interest from the researchers and practitioners. The next few years will show that. In order to keep CBSE an attractive field of research, it should be profiled better in practice – CBSE events should strive to bring more contributions that demonstrate the practical usage of CBSE. We could also suggest to organize panels "future of CBSE" in the text CBSE events.

10. ACKNOWLEGEMENT

This work was partially supported by the Swedish Research Council project Contesse (2010-4276).

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