Architecting for Sustainability[1]

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Abstract: Sustainability is becoming an increasingly important topic. Information Technology (IT) is an important factor for sustainability; it consumes a substantial, and growing, part of the world supply of energy, but it can also enable significant insights and improvements related to sustainability. These factors need to be taken into account in the design of IT systems, meaning that we need to architect for sustainability. This paper provides insights into the experience and beliefs of IT practitioners and researchers into current and desired practices of architecting for sustainability. It reports on the results of three workshop sessions with practitioners and researchers, providing insight into the state of research and practice.

Keywords: sustainability; software architecture; software design; Information Technology; energy efficiency; maintainability.

Addresses Sustainable Development Goal 12: Responsible consumption and production

1. Introduction

The subject of sustainability, in Information Technology (IT) and software engineering in general, and software architecture in particular, has been receiving increasing attention in both practice and research. In spite of that, the field is still missing knowledge on how to design for software to address the sustainability goals it is meant to help achieve.

As discussed in Andrikopoulos et al. [An22], research in sustainable software engineering has focused on topics from software energy efficiency e. g. [Hi16] to other dimensions as discussed in secondary studies e. g. [Pe12]. This holds for research in the intersection between software architecture and sustainability, too. Some studies [Ve18, An22] provide overviews, while others zoom into specific software architecture topics such as metrics [Ko11], reference architectures [Vo17], technical and economic sustainability in architectural technical debt [VML18], and the implications of software architecture on the social sustainability dimension [Gr21].

In spite of the frequent research efforts, practice is missing consolidated and reusable knowledge that helps attain the sustainable development goals. In this direction, with this work we aim at getting insight into the experience and beliefs related to architecting IT-systems that take sustainability into account. This study is the result of a common activity,

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in which two workshops were organised to collect data on the subject.

2. Study Design and Execution

The study presented in this paper is illustrated in Fig. 1. After the preliminary Study Design, it is organised in two types of sessions: a Practitioners Workshop and an Academics Workshop, the latter split in two parts for data collection and reflection, respectively. Finally, we analysed the collected data which resulted in a preliminary list of solutions, open problems, impediments, drivers for change, and open research topics/questions, which we used as a taxonomy. These results will hopefully trigger the conversation with interested researchers and practitioners, on effective collaborations to embed sustainability in architecting.

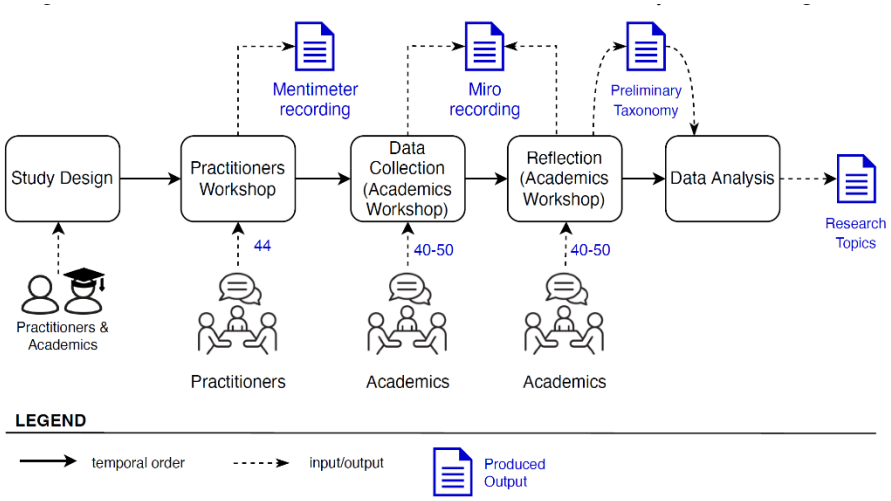


Fig. 1: Overview: Study Design and Execution

2.1 Practitioners Workshop

In January 2021 we have organised a digital workshop with IT-professionals in the Netherlands. There were 44 participants all from different organisations, of which around half of them work as IT-architects or IT-consultants and the remaining in other IT-related professions. The participants are active in a broad range of industry sectors, private and public. The aim of the session was to gain a better understanding of how sustainability can be incorporated into system design. The session was organised in a semi-structured way, with a collection of predefined questions that the participants answered via Mentimeter[5],

[5] www.mentimeter.com

with each question followed by a short reflection carried out collectively. We also asked the participants for their ideas about sustainability in general, for themselves as individuals, for their organisation, for their design practice and for their profession. Most questions were open questions, with the possibility to provide multiple answers. Not all participants answered all questions.

2.2 Academics Workshop

In March 2021, we organised a digital workshop in the context of the International Conference on Software Architecture[6] with the aim of engaging the SA research community to reflect on the research directions needed in software architecture to address sustainability. There were 23 participants, all active in software architecture research, practice, or both. The workshop started with a short presentation introducing software sustainability and how software architecture can address sustainability goals. The workshop was then organised in two parts.

The first part of the workshop created a shared understanding of the state of the art, the state of practice and the open research challenges in the intersection between software architecture and sustainability.

In the second part of the workshop we briefly reviewed the results of the first part and then asked the participants identify resources available to assist practitioners with achieving sustainability in their systems.

Both workshop parts were organised in a virtual digital setting, and were very well attended, each counting between 40 and 50 participants.

3. Results

3.1 Results from Practitioners Workshop

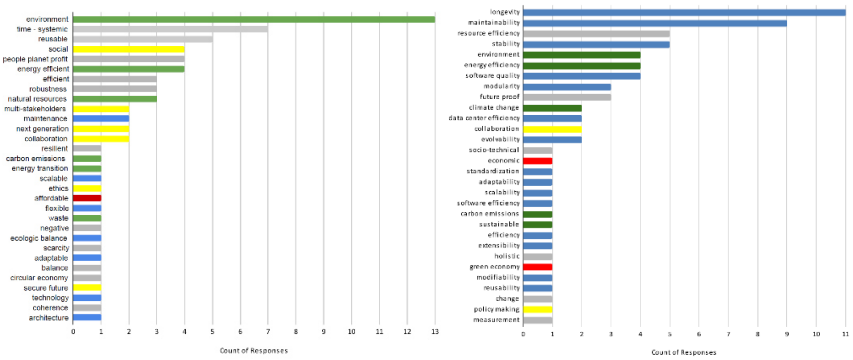
Notion of sustainability. The term sustainability does not have the same meaning for everyone. We asked the participants which terms they associate with sustainability and found that associations with ecological goals (green, environmental, planet) and social goals (yellow, social, people) predominate. Economic goals (red, economic, prosperity) are mentioned less often and the association with technology as a goal of sustainability is not often mentioned (blue, technology). The concept of sustainability also evokes associations with robustness, resilience and adaptability (grey, neutral).

Importance of sustainability. When asked whether it is important to explicitly include sustainability in a design, 29 participants answered positively and 6 negatively. So the

[6] Icsa-conferences.org

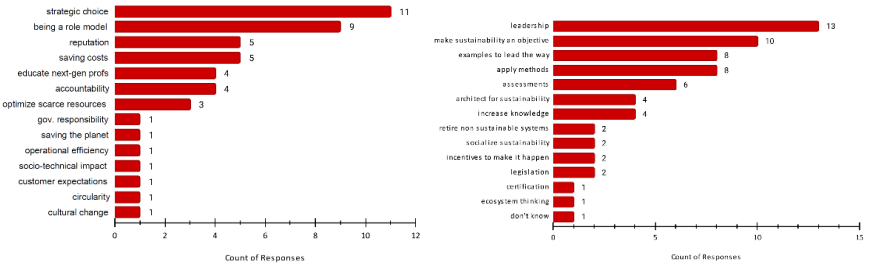
importance of sustainability in design was generally recognised by the participants.

Organisational drivers. We then asked the participants what they thought were the main motivations for organisations to be active in the field of sustainability. Their answers are summarised in Fig. 3a. According to the participants, this mainly has to do with strategic choices made by organisations (11 out of 38 responses) and that such organisations want to set an example (9 out of 38).

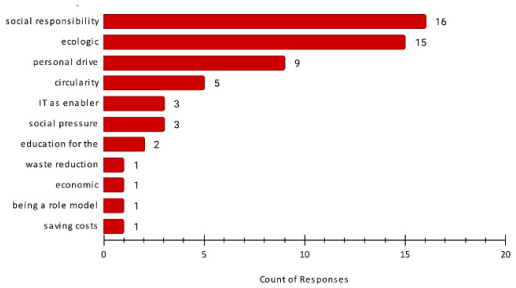


(a) Practitioners Workshop (b) Academics workshop

Fig. 2: Word associated with the notion of sustainability



(a) Organizational drivers: importance for own company (b) personal drivers: importance for oneself



(c) Aids for making sustainability actionable

Fig. 3: Practitioners workshop: specific perspectives

Personal drivers. We asked the participants why sustainability is important for them personally. A classification of their answers (reported in Fig. 3b) shows that a lot of them feel a strong social and ecological responsibility (16 answers). Another class of answers showed a personal drive for the subject (15 answers). The remaining 17 answers were more specific.

Obstacles. We asked what the main obstacles are to embedding sustainability in the design practice of the participants. The answers are summarised in Fig. 4a, which shows that short-term thinking is the biggest obstacle. In addition, lack of knowledge and the financial-economic model of the organisation are explicitly mentioned as obstacles to giving sustainability significant attention.

Making it actionable. We asked how sustainability can be made more actionable and the answers are summarised in Fig. 3c, which shows that the participants believe that more leadership, more examples, concrete sustainability objectives and the application of methods would help. The attention given to the (often abstract) notion that *sustainability is important* can be made more concrete by formulating specific objectives in one's own context. The participants felt that development of working methods would help to give sustainability a place in daily practice.

Incentives. We asked which incentives would provide motivation to make sustainability an integral part of design. The main classes of answers show that goals for sustainability need to be translated into concrete objectives and KPI's. Also the benefits of sustainability need to be made more concrete for organisations and more attention is needed for governance of sustainability.

Closing the gap. We also asked what participants can do themselves to close the gap between designers and sustainability. They indicated that as IT-professionals they can at least explicitly put the subject on the design table. Furthermore, IT-professionals can also show leadership themselves by drawing explicit attention to the subject. Also, the importance of examples was described as helpful for this question.

Role of professional organisations. We finally asked what IT-professional organisations could do to address sustainability in design. According to the participants these organisations can contribute by sharing knowledge, joining forces and communicating about it.

It appears that practitioners are personally motivated to strive for sustainability and see that they can show leadership by incorporating sustainability in design. In contrast, the organisations that they work for seem to be less motivated, often prioritising bottom-line financial results over sustainability. More senior management focus on sustainability is needed, along with concrete objectives for sustainability and governance of the results.

Takeaways Practitioners Workshop:

- Organisational and Personal drivers can accelerate sustainability by complementing each other, e. g. by defining strategies that align with the organisation's goals and motivate employees by leveraging on their personal drivers.
- The business motivation for sustainability needs to get more attention. Many organisations lack a business driver for sustainability, leading to insufficient focus, awareness and understanding, resulting in sustainability not being a priority.
- IT practitioners have trouble translating sustainability to their own work. They feel that sustainability is mostly related to aspects outside of their sphere of influence. They also miss concrete guidance to embed sustainability in IT design.

3.2 Results from academics workshop (Part 1)

The interaction with the participants focused on gathering information about the following aspects.

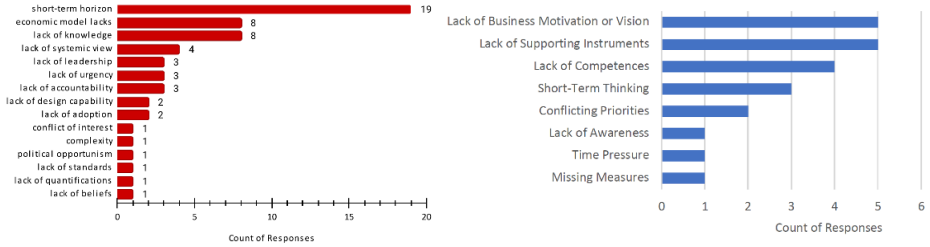
Notion of sustainability. We then asked the participants which words they associate with sustainability. We classified the results as illustrated in Fig. 2b. The top terms were related to longevity, maintainability stability and resource efficiency. We also color-coded the results to relate them to the sustainability aspects we discern: blue for technology, green for environment, yellow for social, red for economic and grey for terms that cannot be clearly positioned in one of the aspects above. The results show that most of the terms are related to technology, followed by environment.

Obstacles. We asked the participants what they think are the main obstacles for companies to embed sustainability in architecture design. We classified the answers, and show the results in Fig. 4b. The top three obstacles that participants identified were lack of supporting instruments, lack of business motivation/vision, short term vision and lack of competence. This can be summarised as: sustainability is not a driver for companies and companies do not know how to operationalise sustainability.

Existing software architecture research for sustainability. We asked what software archi- tecture research already exists for sustainability and the answers are summarised in Fig. 5b. The most important type of research identified was related to software architecture assess- ment methods, software architecture viewpoints, general software architecture guidelines, software architecture debt (management), software architecture styles and patterns, software architecture reconstruction,
https://www.overleaf.com/project/62b8c8721afe4822090ebc3a empirical measurements, standards and software architecture analysis tools.

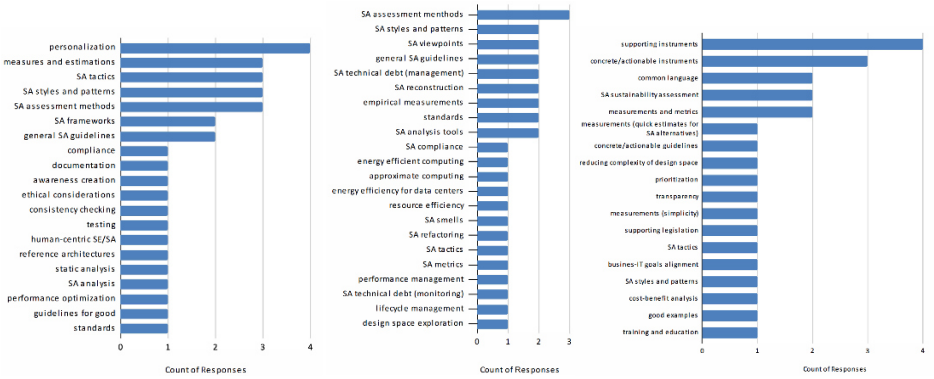
Existing software architecture practices for sustainability. We asked the participants which software architecture practices to support sustainability already exist. The results are shown in Fig. 5a. The most important practices are related to collaboration (personalisation mechanisms). The other top classes of answers are measures and

estimations, software



(a) Practitioners (Obstacles encountered) (b) Academics workshop

Fig 4: Obstacles for industry to embed sustainability in the design practice



(a) Reported SA practices (b) Reported SA research (c) Reported open problems

Fig. 5: Academics workshop: specific perspectives

architecture tactics e. g. [LL15], software architecture styles and patterns and software architecture assessment methods.

Open problems. We ended the first part of the workshop with a question on the open problems that participants are aware of. The results are summarised in Fig. 5c. The top problem areas that the participants identified were: supporting and concrete/actionable instruments, measurements and metrics, a common language and a software architecture sustainability assessment. The time left for the question was short, so they chose to elaborate on the open problems in the second part of the workshop.

Takeaways Academics Workshop (Part 1):

- The focus of researchers with respect to sustainability in software architecture is mainly on software maintainability and software energy efficiency.
- Two key aspects of embedding sustainability in software architecture are: identify the right measures (patterns, guidelines, frameworks, styles, tactics) and assess the impact of these measures on sustainability.
- Identifying measures and assessing their impact are the overarching themes for future research, too.

3.3 Results from academics workshop (Part 2)

The workshop continued into a second session where we explored solutions to the problems that had been identified in Part 1 and then the drivers for change that are opportunities to improve sustainability in this field and open research questions for future research work.

Solutions. When asked to consider *solutions* to the problems from Part 1, 34 candidate solutions were suggested, which were then classified by the leaders and participants into 7 themes of varying strengths. The top three solutions were: architectural knowledge, implementation analysis and human aspects. Architectural knowledge includes artefacts such as reference architectures, tactics and patterns. Implementation analysis includes various forms of analysis such as static analysis and testing. Human aspects includes aspects such as ethics, compliance and impact on processes and societies.

Open problems. Moving on to *open problems*, the participants listed 48 open problems that they identified as being significant barriers to practice in architecture for sustainability. When these ideas had been classified into themes, the most important of these were: “industrial perspectives and motivation”, “definition” and “techniques and measurements”. Industrial perspectives and motivation includes raising awareness, business prioritisation and cost-benefit analyses. Definition mostly refers to common terminology. Techniques and measurements mostly refers to techniques and metrics for measuring sustainability.

Impediments. The next area that the participants considered was the impediments that they believe exist to implementing possible solutions to the problems facing sustainability in architecture. The participants identified 31 possible impediments to solution implementation and when analysed and sorted into groups, the most important impediments mentioned were “definitions, awareness, competence and business impact and prioritisation”.

The final part of the workshop focused on exploring what the future of this field is likely to be. With this aim, we addressed two questions, (i) What are the drivers for change in the current industrial environment?, and (ii) What are the open research questions which academic researchers should be exploring? The results are summarised below.

Driversforchange. When we asked the participants to identify the likely drivers for change, we identified 19 proposals which resulted in the themes "personal factors", "government action", "industry and academic collaboration", "definition and education" and "awareness and education".

Open research questions. When we moved on to identification of the open research questions, 9 suggestions were made for research topics, which we did not attempt to classify into themes, as we wished to preserve the intent of each suggestion. The suggested research topics/questions are:

- (Assessing the) efficacy of the existing techniques
- Sustainability analysis and assessment framework
- New architectural paradigms (for sustainable architecture)
- What business culture needs to be in place for sustainable software to be successful?
- (Creating a) clear definition of sustainability that we can agree about
- How to make (the) sustainability impact of architectural decisions visible?
- How to trade-off different sustainability dimensions and aspects?
- (Creating) metrics and associated tools for sustainability assessment
- (Creating) a clear definition framework for sustainability of software (should take main- tainability and long-lived software but also the second and third impact into account)

These research questions reveal that there are some fundamental aspects of this topic which still need investigation but that there is also a need for practical guidance and assistance for those trying to improve the sustainability of their software through software architecture.

Takeaways Academics Workshop (Part 2):

- Researchers perceive industry awareness and prioritisation as critical for research to be effective.
- There is a lack of common language on sustainability in software architecture; more (and better) definitions are needed.
- Collaborative research and education are needed to increase and spread the knowledge on sustainable software architecture.

4. Reflections and Conclusions

Through two workshops we have been able to establish an insight into the experience and beliefs of practitioners and researchers into current and desired practices of architecting for sustainability.

From our analysis, we see that both researchers and practitioners consider business motivation and short term thinking as obstacles. Also, both groups agree that key obstacles are the lack of agreement on why sustainability is important, and the absence of knowledge on what concrete measures can be taken.

The lack of concrete measures is a possible bridge between these groups, if they work together on to address it. Solutions and techniques that are available from industry can be assessed by researchers to validate their effectiveness. In turn, researchers can develop new techniques which can be tested in practice.

Research can also provide useful input to create business motivation by providing a clear definition of sustainability, making the impact of sustainability measures explicit and determining the business culture that needs to be in place for sustainable software to be successful. In a more general sense, research can provide analysis and assessment techniques to help organisations achieve their sustainability goals.

From this work we conclude that sustainability requires contributions and commitment on all levels, from senior management to practitioners to research and education.

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