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Development and Validation of a Reference Architecture for the Smart Schoolhouse

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Abstract. The last decades have shown a great many changes in the field of education, especially in the transition to a more learner-centred and technology-enhanced approach in the teaching and learning process. These changes have been brought about by both a need for it, but also by the opportunities that have risen from the rapid development of technology and the diversity of technological solutions. Technology can be used in the learning and teaching process to make learners' more engaged and allow them to take greater responsibility for shaping the their learning goals, process and environment, for instance, by accepting the BYOD model of technology use (Bring Your Own Device). The choice and ways of using the specific technologies should be defined by the purpose of the learning and teaching process itself and the requirements for the knowledge, skills, attitudes, and values of learners striving to become engaged members of both the knowledge society at large and also their chosen professional communities. Digital transformation of the European society creates demand for creative users of technology, i.e. is the need for innovative makers who can implement their knowledge in all kinds of different situations to create something new. This paper introduces a Smart Schoolhouse concept that has been designed to spark an interest in exploration among learners and to help them develop the proactive Maker mindset. As part of a four-year case study conducted in five Estonian schools, the possibilities of implementing the Smart Schoolhouse concept were analysed and evaluated. Suitable IoT technologies were tested, and the necessary support system was mapped. This process was supported by a comprehensive literature analysis, which provided an overview of the input collected during the case study for the creation and evaluation of the Smart Schoolhouse Reference Architecture. The article presents the development of RASS, which is based on the Industry 4.0 Reference Architecture Model (RAMI 4.0), created by the German Electrical and Electronic Manufacturers' Association (ZVEI). The conformity and completeness of RASS were validated using the RATE method to ensure that it meets stakeholders' expectations and requirements. The article concludes with an overview of the evaluated RASS and recommendations for its implementation.

Keywords: Smart Schoolhouse, reference architecture, reference architecture evaluation

1. Introduction

Global digitisation has brought about changed expectations for today's learners, i.e., members of society who will soon enter the workforce. In addition to their own chosen field they must be digitally competent and know how to solve interdisciplinary problems in cooperation with experts of other fields. Although for the last few decades schools have gone through big changes in their use of technology in the teaching and learning process, from simple content delivery on multimedia CDs to complex enterprise-level online learning systems (Moodle, EIS, eKool), the use of BYOD, cloud-based services, and IoT is pushing us towards another "*digital turn*" in schools: "*smart schoolhouse*".

The potential of IoT that links physical and virtual worlds and is used ever more in teaching and learning context has not yet been systematically researched, a coherent "*big picture*" is missing. Due to this the project "*Smart Schoolhouse by means of IoT*" was launched.

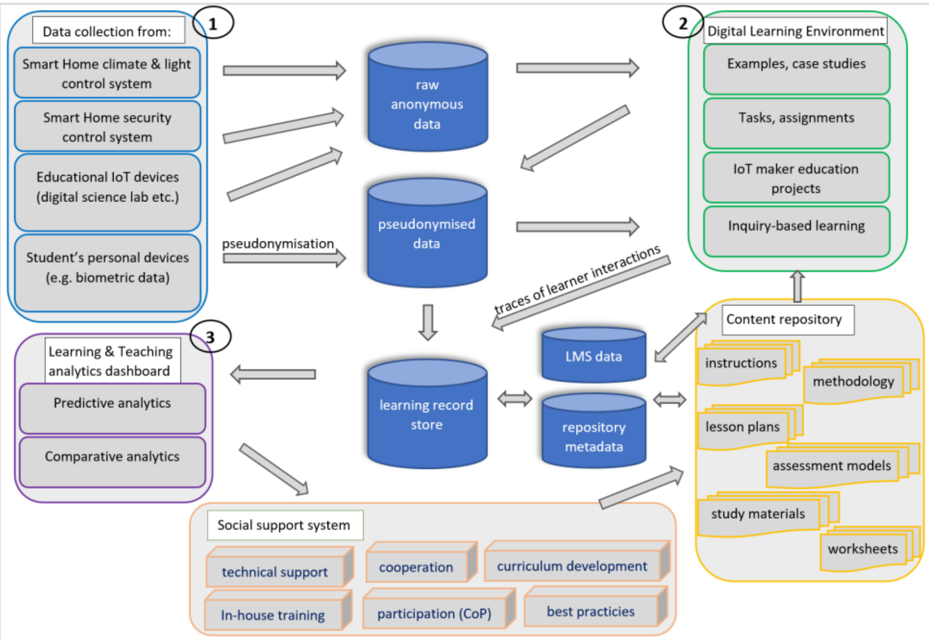

Figure 1. The data collection, handling, and use in a Smart Schoolhouse concept, and systems that support it.

This brought with it the opportunity to implement IoT devices and the data collected by them into the learning process, using various teaching methods and approaches (inquiry-based, problem-based learning, productive failure caused by ill-structured problems, learn-by-doing, Maker mindset and Maker movement, etc.). Also, the standardisation of their use in the everyday learning process. The goal was to provide a solution (shown in Figure 1) that 1) would make the background data collected by the Smart Home system, which is generally inaccessible to users, easily and conveniently available to learners for use in their studies; 2) would allow the use in combination of pseudonymised data from IoT devices and learners' digital footprints, along with data from the Smart Home system, to enhance STEM education (utilising this data in inquiry- and problem-based learning, research, etc.); 3) would allow the use of this data in a personalised form in learning analytics to gain a better understanding of the learning and teaching process, i.e. to identify the strengths and weaknesses of both the general and individual learning and teaching processes.

To generalise our research results, we decided to create a service oriented reference architecture that may be the best solution to describe the opportunities of Smart Schoolhouse to various stakeholders, e.g. in a context of preparing a large-scale software/hardware procurements and implementation in hundreds of schools simultaneously. Our paper outlines critical discussion points that aid in comprehending the probable technological, administrative and pedagogical solutions associated with Smart Schoolhouse. Furthermore, during the implementation phase, it promotes a more rapid, efficient, and seamless execution.

This research consists of two complementary parts: a theoretical part, involving a systematic literature review to establish a theoretical framework; and a practical part, in which this framework is applied to develop and evaluate the Reference Architecture for the Smart Schoolhouse (RASS). Given the complexity of the main goal, the study focused on answering the primary research question: How can a Reference Architecture for the Smart Schoolhouse be developed, validated, and implemented? This central question is further divided into five sub-questions (see Chapter 3.2). The results of the research questions are presented in both the theoretical see (Chapter 2), where initially the theoretical background is clarified, and the methodological (see Chapter 3), where it is demonstrated how theory is applied in practice, sections. In the final chapter, we summarise the topic and highlight limitations that future studies need to address.

2. Theoretical background

2.1. Related Research

To establish the context and foundation for our research and to address the research questions RQ1, RQ2, RQ3, and RQ6 (see section 3.2 below), we undertook a systematic literature review using a mapping technique (Kitchenham and Charters, 2007) and the guidelines for literature search, evaluation, and synthesis guidelines by vom Brocke et al. (2015).

Table 1. Articles selected for analysis in various fields, upon which this article and the research were based.

Key words	**Number of analysed papers**
Reference architecture	209
Service-oriented (reference) arhcitecture	84
Reference architecture in education	68
Reference architecture life cycle	27
Reference architecture evaluation	72

An iterative methodology was adopted, succinctly characterised as an iterative literature review approach geared towards an enhanced comprehension, wherein search, analysis, and synthesis are conducted concurrently and are interlinked. The search for relevant sources was progressively broadened in each iteration, both thematically and by authors, to delineate the lifecycle of the developed reference architecture—development-evaluation, usage, disposal—with a particular focus on its rigorous validation. It was also pivotal to ascertain the most recent information on architectures devised for the education sector to identify extant solutions and get confirmed the novelty of our design concept. While searching for relevant research literature, we used keywords "reference architecture", "reference architecture" + "education" (with alternatives replacing "educatio*": school, university, laboratory, classroom, teaching, learning, campus), + "lifecycle", + "evaluation" (with alternatives replacing "evaluat*": assess*, validate* AND method, framework), + "service oriented". Initially, a linear literature analysis process was utilised (sequential searching, analysing), reviewing articles from various repositories: Scopus, IEEE Xplore, ACM Digital Library and SpringerLink, with the search initially spanning a broader timeframe from 2010-2016. However, the approach soon became iterative, as the analysis of articles revealed the field's experts and most significant authors, leading to further iterations. Subsequent iterations primarily concentrated on IEEE Xplore to minimise duplicates and focused mostly recent four years.

The article selection process in these iterations was consistent: following the elimination of duplicates, we utilised analytical tools in MS Excel to identify key words from abstracts, which informed the selection of articles for in-depth review. The Table 1 below offers an overview of the research papers that were eventually shortlisted and closely examined, with the most significant ones being referenced in this article.

2.2. Reference Architecture

A reference architecture (RA) has been referred to as a blueprint or template for creating (software) systems, which, according to (Ünal, 2019; Abu-Matar and Mizouni, 2018), is claimed to offer a high-level structure and instructions for building applications in a specific context or domain, as by (Knodel and Naab, 2016) it helps to „*transform concerns within the problem space into decisions in the solution space*“. Due to these (Hoel and Mason, 2018) states that it rather serves as a framework for designing a variety of systems. An explanation has also been used that RA is an accumulation of best practices (Ünal, 2019; Nakagawa et al., 2014), design patterns (Szwed et al., 2013), principles, and constraints (Cloutier et al., 2010; Weinreich and Buchgeher, 2014) over time within a specific application domain.

The RA „*provides, according to its objectives, discussion points for stakeholders*“ (Ataei and Litchfield, 2022). It is used "*implicit knowledge and articulate it explicitly, facilitating the development of new products and product families*" (Cloutier et al., 2010). Reference architecture helps to "*understand the forms of likely solutions to certain domain problems*" (ISO/IEC/IEEE, 2019b), while providing "*a common (architectural) vision, lexicon and taxonomy*" (Cloutier et al., 2010) and guiding "*the development and deployment of applications of specific systems*" (Galster, 2015), "*implementation of new system architectures*" (Cloutier et al., 2010) or "*concrete architectures*" for specific instances of complex software systems (Angelov et al., 2009; Nakagawa et al., 2014). In general, majority of authors agree that a RA is used for development of concrete and standard architecture.

Concrete architecture, as implied by its name, is developed from an RA (Gidey et al., 2017) through the incorporation of specific software products and protocols (Angelov et al., 2009), and it is designed in a specific context and reflects specific objectives (Angelov et al., 2012). Considerably less abstract is the standard architecture, which is a specialisation of the RA within a specific organisation (Saay and Norta, 2016).

Angelov et al. (2012) conclude that architecture can only be an RA at higher levels of abstraction, reflecting the requirements of stakeholders and "*allowing its usage in differing contexts*": "*The RA is a generic architecture for a class of information systems, which is* *used as the basis for the development of concrete architectures*" (Angelov et al., 2009). While Cloutier et al. argue that the high level of abstraction in an RA makes understanding its role more complex, since several additional steps are required to create real software from it, the same article also explains the benefits it provides: RA (1) enables the reuse of good concepts and implementations in future projects, (2) may help control the complexity of an architecture, (3) provides a common understanding among stakeholders, and (4) helps mitigate risks. Therefore, the RA is deliberately maintained at an abstract level and designed with generality in mind (Kuppusamy & Suresh, 2020) to ensure its suitability for wide applicability (Guth et al., 2016).

2.3. Development of Reference Architectures

For the successful development of a reference architecture, it is imperative to comprehend the problem space and make design decisions within the solution space. According to the objectives, goals, and scope of reference architecture, it is primarily prescriptive (to recommend uniform solutions), descriptive (to create abstractions that simplify complexity), or predictive (to avoid reliance on trial and error). This, in turn, necessitates the selection of an appropriate style (e.g., Client-server, Component-based architecture, Data-driven architecture, Event-driven architecture, Layered architecture, Object-oriented architecture, Service-oriented architecture, etc.) and approach (such as Bottom-Up, Top-Down, Forward, Reverse, Zigzagging, etc.) suitable for its development (ISO/IEC/IEEE, 2019b).

Service-Oriented Architecture (SOA) is an architectural style that focuses on utilising services to meet software users' needs. By adhering to the service-oriented support architecture, organisations can design and implement software systems that are modular (Rabelo et al., 2015), flexible (Alsobhi et al., 2015), reusable (Alsobhi et al., 2015; Lopes et al., 2019; Kuppusamy and Suresh, 2020), and are capable of adapting to the changing needs. An essential aspect is the separation of these services from technology (Ataei and Litchfield, 2022).

Although there are several approaches to creating an RA, the most common is shown in Figure 2. These are top-down (Figure 2a) ("*comprehensive, technology-neutral coverage, often from the perspective of a particular Smart X application sector*") (Kearney and Asal, 2019) and bottom-up (Figure 2b) ("*user organisation creates first a standard architecture out of multiple concrete-architecture experience that matures into a RA*" (Norta et al., 2014).

The choice of which style or approach to use is largely determined by the objectives (starting points) of the RA being created, including the complexity of the system of interest, novelty, implementation mechanisms, and so on.

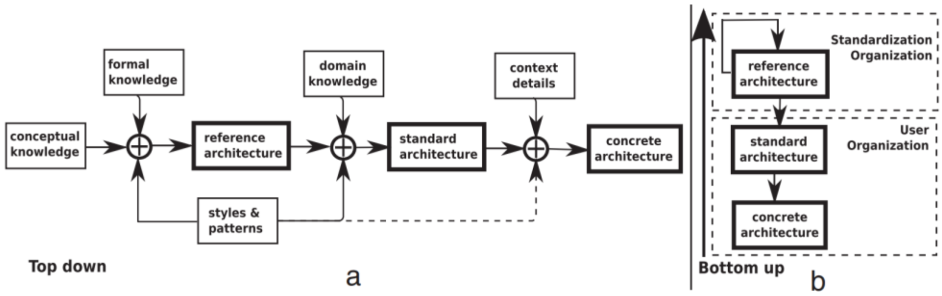

Figure 2. (a) Top-down architecture-framework process (b) Bottom-up practitioner process. (Norta et al., 2014)

Angelov et al. (2008) refers to the bottom-up approach as Practice-driven RA, as its creation is possible only when there is sufficient knowledge of the specific field to apply best practices. The top-down approach is described as Research-driven RA, also the "*greenfield*" approach (ISO/IEC/IEEE, 2019b), or Futuristic RA (Angelov et al., 2008; Abu-Matar and Mizouni, 2018) because these architectures are expected to become important sometime in the future (Angelov et al., 2008). Quite often, research centres are at the forefront of designing these preliminary architectures. These RA embody innovation and delineate the necessary components for systems implementing them. Angelov et al. argue that the origin of these RA lies predominantly in research-oriented environments that focus more on architectural innovation than on addressing the needs of domain stakeholders.

Therefore, Gidey et al. contend that the development of new RA requires attention to 1) architecturally significant requirements, and 2) the selection of appropriate architectural design decisions to implement these requirements (Gidey et al., 2017). To prolong the lifespan of the created RA, removing replaceable elements such as communication standards and protocols is necessary. Otherwise, the RA can quickly become obsolete. These architectures have to remain abstract, lacking specific technological implementations, standards, or protocols. The higher the level of abstraction at which the RA is presented, the longer its relevance endures (Angelov et al., 2009). However, an overly abstract RA can challenge stakeholders' understanding and may overwhelm them. Although it is often difficult to find the right level of abstraction (Cloutier et al., 2010), the RA must be abstract enough to allow for alternative decision-making while, at the same time, effectively ensuring the achievement of stakeholders' objectives (Galster, 2015).

The reference architecture life cycle comprises distinct phases or stages that an architecture undergoes, commencing with the recognition of the necessity for the architecture and concluding when it is deemed unnecessary or the architecture becomes obsolete (ISO/IEC/IEEE, 2019b). Multiple models, which can be characterised as structured frameworks comprising processes and activities arranged in sequential stages, have been put forward in (ISO and IEC, 2023) to enhance the management of the reference architecture lifecycle. Based on them, there are at least three main stages in the lifecycle of reference architecture: (1) development, (2) usage, and (3) discard. All of them may consist of multiply sub-stages. (ISO/IEC/IEEE, 2019b) presents sub-stages, that is grouped into three interacting processes (Conceptualisation, Elaboration, and Evaluation). These sub-stages are defining the problem, setting architecture goals, outlining its scope, and presenting potential solutions in a format suitable for stakeholders. Also, a mapping of quality indicators that enable the assessment of the value of the reference architecture, and finally, find a suitable evaluation method to assess the compliance of the reference architecture with the needs and concerns of stakeholders. Based on these steps, the final chapter of our paper proposes evidence-based recommendations for implementing the developed RASS to make it useful and meaningful to various stakeholders.

2.4. Evaluation of Reference Architectures

Architecture evaluation can be conducted at various stages of the system life cycle—from conceptual design to deployment and maintenance (ISO/IEC/IEEE, 2019a). However, the early evaluation of reference architectures (RAs) is particularly important to ensure alignment with stakeholder expectations and to mitigate risks related to quality, time, and budget (Knodel and Naab, 2016; Karlsson, 2016). While the primary aim of evaluation is to determine whether architectural objectives have been, or are likely to be, achieved, thereby supporting informed decision-making (Karlsson, 2016), the process also serves to validate architectural feasibility and minimise trial-and-error methods (Knodel and Naab, 2016), thus avoiding costly redesigns (Clements et al., 2010).

Although every software system is context-specific (Knodel and Naab, 2016), a wide range of evaluation methods has been developed. The literature review confirmed the dominance of scenario-based techniques, such as Architecture Level Modifiability Analysis (Garcés and Nakagawa, 2017; Batista et al., 2022; Fatima and Lago, 2023; Zbick, 2017; Ataei and Litchfield, 2020; Boyanov et al., 2020; Morkevicius et al., 2017), followed by experience-based approaches (e.g., focus groups) (Garcés and Nakagawa, 2017; Fatima and Lago, 2023; Zbick, 2017), prototyping (Ghantous and Gill, 2020; Palkar and Kamani, 2018), simulation (Garcés and Nakagawa, 2017; Baek et al., 2020; Li, et al., 2019; Fatima and Lago, 2023), model-based approaches (e.g., Architecture Description Languages) (Baek et al., 2020; Fatima and Lago, 2023; Nicolaescu and Lichter, 2016), and metric-based approaches (e.g., Software Productivity Metrics) (Fatima and Lago, 2023).

Angelov et al. (2008), applying the ATAM approach (ISO/IEC/IEEE, 2019a), argued that traditional evaluation techniques are frequently ill-suited to reference architectures due to their inherently high level of abstraction. This perspective is echoed by Ataei and Litchfield (2022), who point to the "*lack of dedicated evaluation methods for RAs.*" As a result, several frameworks have been developed as enhancements (Fatima and Lago, 2023; Boyanov et al., 2020; Knodel and Naab, 2016; Ehrlich et al., 2020), adaptations (Islam and Rokonuzzaman, 2009; de Oliveira Neves et al., 2018) or extensions (Fatima and Lago, 2023; Knodel and Naab, 2016) of existing methods. The choice of method depends on the type of architecture, the development stage, stakeholder interests, and specific evaluation objectives (ISO/IEC/IEEE, 2019a).

ATAM (Kazman et al., 2000), one of the most widely recognised evaluation methods, focuses on quality attributes such as modifiability, performance, and security. It promotes dialogue among stakeholders and supports informed architectural decision-making. This method was further developed from the Software Architecture Analysis Method (SAAM) (Kazman et al., 1994; Clements et al., 2010), which concentrated on modifiability (including portability, subset possibilities, and variability), and later incorporated analyses of performance, availability, and security (Kazman et al., 2000). Several notable developments and adaptations have emerged from ATAM.

Of particular relevance to this study is the Rapid ArchiTecture Evaluation (RATE) method, developed by Fraunhofer IESE. RATE is described as *"amalgamating best practices from existing methods and being adapted for pragmatic and rapid implementation in industrial contexts"* (Knodel and Naab, 2016). The method comprises five distinct checks: 1) DIC – verification of the integrity of stakeholder requirements, 2) SAC – assessment of the adequacy of the architectural solution, 3) DQC – scrutiny of the quality of architectural documentation, 4) ACC – conformance checks between implementation and architecture, and 5) CQC – general evaluation of code quality (Knodel and Naab, 2016).

The DIC check is critically important for aligning the concerns of various stakeholders and mapping these concerns onto evaluation criteria. Its purpose is to generate clearly structured problem descriptions based on stakeholder concerns, thereby ensuring that the architecture evaluation is both meaningful and effective. The primary aim of the SAC (Solution Adequacy Check) is to determine whether existing architectural solutions effectively address stakeholder concerns and whether there is sufficient confidence in their appropriateness. This assessment relies on a robust set of architectural drivers—typically formulated as scenarios—developed during the DIC process. Due to the abstract nature of architecture, evaluations rarely produce definitive outcomes; thus, it is essential to define the desired level of confidence and its implications early on. SAC supports early decision-making by validating architectural solutions before implementation resources are committed.

RATE was developed based on experiences where RAs lacked sufficient information to be evaluated under the ATAM framework. As a result, RATE incorporates several concessions compared to ATAM and demands fewer resources (Knodel and Naab, 2016). It is therefore well-suited for the evaluation of a RASS developed at the conceptual level.

2.5. Reference Architectures in the Field of Education

There exist not too many research papers that address the reference architectures created for the educational domain of our interest. The most common focus in such papers is the learning analytics or multimodal learning analytics enriched with IoT solutions (Drlik et al., 2018; Smith et al., 2018; Aleksieva-Petrova et al., 2020) or learning analytics in gamified eLearning (Maher et al., 2020). But there are also Assessment Analytics (Nouira et al., 2017), IoT curriculum (Abichandani et al., 2022), Robotics in Education (Kuppusamy and Joseph, 2020), Smart Education (Kuppusamy and Suresh, 2020), Smart Campus (Pandey et al., 2020), Context-aware Learning Environments (Lopes et al., 2019), and Tracking system for Online Laboratories (Zapata-Rivera and Petrie, 2018). These are only a few examples, but unfortunately none of them are suitable for implementation in our Smart Schoolhouse concept.

This underscores the necessity for a customised RA that addresses the unique requirements and objectives of the Smart Schoolhouse. In developing such an architecture, it is essential to consider various technological and pedagogical aspects that support learning and teaching in an innovative and effective manner. For instance, the architecture could integrate elements of IoT, data analytics, and gamification to create a dynamic and engaging learning environment that can respond to individual learners' needs and preferences. Furthermore, this architecture should promote flexibility and adaptability, enabling easy adjustments to align with developments in educational institutions and technology.

In the process of creating the RA, it is vital to involve a diverse array of stakeholders, including teachers, students, educational technologists, and administrators, to ensure that the final product meets the needs and expectations of all parties. Through further research and collaboration, a RA can be developed and implemented that not only meets current demands but is also sufficiently flexible to adapt to future educational and technological innovations.

3. Research Methodology

3.1. Research Aim

This research consists of two complementary parts: a theoretical part aimed at systematically mapping and analysing existing solutions for creating and evaluating reference architectures (RA) through an iterative literature review; and a practical part focused on applying these theoretical insights to develop and evaluate a reference architecture specifically tailored to the Smart Schoolhouse concept.

Over a period of four years, the practical component involved conducting a comprehensive case study across 19 Estonian schools. This included mapping (Kusmin et al., 2018), testing (Kusmin, 2019a, 2019b; Kusmin et al., 2019), and systematising (Kusmin and Laanpere, 2023) suitable IoT solutions for educational purposes, as well as identifying support system requirements (Kusmin and Laanpere, 2020). The findings of this case study contributed to the development and evaluation of a self-assessment model for the Smart Schoolhouse (SAMSS) (Kusmin and Laanpere, 2022; 2024).

Utilising these outcomes, the practical part of the present study aimed to create a robust RA to support the integration of physical and virtual learning environments, thereby facilitating the effective use of IoT-generated data and learning analytics within learner-centred, creative, and collaborative STEM education.

3.2. Research Questions

In this study, we sought to answer the question:

How to develop, validate, and implement RA for the Smart Schoolhouse?

To address the research question, two sub-studies were conducted: 1) a mapping of the literature (N=209), followed by the creation of the RASS, and 2) its evaluation. For the mapping and analysis of the literature, we established the following sub-questions:

RQ1: Which processes and phases constitute the life cycle of a RASS and how are they managed?

RQ2: Which existing reference architectures and their validation methods would be suitable or adaptable for our concept of Smart Schoolhouse?

RQ3: What methods are most commonly employed in the development of an RA?

During the evaluation of the Smart Schoolhouse reference architecture, we sought answers to the following sub-questions:

RQ4: To what extent does the RASS meet the expectations, requirements, and needs of the Smart Schoolhouse concept?

RQ5: Does the RASS meet the general criteria for reference architectures, i.e. is it adequately abstract and all-encompassing while still remaining understandable and executable?

We have already addressed the sub-questions RQ1, RQ2, and RQ3 in our literature review above. In the next chapters, we will describe the application of its results in design and validation of the RASS. To find answers to sub-questions RQ4 and RQ5, we conducted an evaluation of RASS based on the first two checks of the RATE method. At the end of this chapter, based on our findings, we provide guidelines for the implementation of RASS.

3.3. Research Design

We used a Design Science Research (DSR) to develop a RASS. DSR is defined as „*a problem-solving paradigm that seeks to enhance human knowledge via the creation of innovative artifacts*" (vom Brocke et al., 2020). Hevner et al. clarify that an artefact can take the form of a construct, model, method, or instantiation (Hevner et al., 2004). According to Hevner, DSR is a fundamentally pragmatic approach, prioritising relevance and meaningful contributions to the application environment, but he adds that it is crucial to establish a harmonious balance between relevance and rigour in research studies (Hevner, 2007).

Our research design consists of the following steps: (a) conducting a literature mapping, (b) analysing existing architectures, (c) developing a reference architecture proposal based on requirements that were collected, analysed, grouped, and evaluated within the case study (SAMSS), and (d) evaluating the proposed architecture.

3.4. Development of the RASS

The analysis of the literature (in section 2) revealed that, although among the 137 relevant scientific articles examined in depth, including 68 articles that focused on the educational domain, none of these are suitable as the basis for the RASS. Many of them were too abstract, but the main issue was substantive – they were created for entirely different functionalities, such as developing e-learning environments, assessment analytics, curriculum development, etc. Therefore, we tried to find the most optimal solution, taking into account the experiences of others, to create the RASS as efficiently as possible.

Creating, evaluating, and maintaining a RA must be empirically justified to ensure their relevance and practical applicability. Building on Galster's interpretation of Karow et al., it is necessary to ensure: a) empirical foundation - the RA must be based on 1) real-life situations reflecting stakeholders' interests, 2) proven principles validated in practice, and 3) aspects reflected therein must be derived from the problem domain; b) empirical validity - evaluating the RA demonstrates its applicability and validity (Galster and Avgeriou, 2011).

The development of a SOA for the Smart Schoolhouse followed a six-stage framework of "*Empirically Grounded RA*" (EGRA) (Galster and Avgeriou, 2011), utilising a top-down research-driven approach (Angelov et al., 2008). Stakeholders' concerns central to the Smart Schoolhouse concept were mapped out during a four-year project, "*Smart Schoolhouse by means of IoT*", based on patterns of IoT tool selection and usage emerging from the learning process. These patterns were integrated into the Smart Schoolhouse Assessment Model (SAMSS). Subsequently, six personas and six scenarios were developed, utilised for both creating and evaluating the RA. In terms of structural design, we relied on the RAMI 4.0 model (Hankel and Rexroth, 2015).

The personas were as follows: 1) a 28-year-old engineer working as a smart home systems implementer in a technology company and conducting extracurricular activities at school; 2) two 15-year-old 9th-grade students, 3) a 47-year-old physics teacher with extensive professional experience but limited practical knowledge in ICT and IoT, 4) a 26-year-old young art and design teacher with no prior teaching experience but who has participated in two pedagogical internships, 5) a 34-year-old experienced ICT education specialist with experience in ICT who has been working as an educational technologist in schools for over ten years. As the concept of the Smart Schoolhouse is still under development, based on our previous experience in the project, we were able to create scenarios for the life cycle of the IoT devices used in the Smart Schoolhouse and their usage at three hierarchical levels (Disconnected, Online, Connected) (Kusmin and Laanpere, 2023) of IoT technology. Two higher levels of the hierarchy of IoT devices usage (Smart, Integrated) could not be mapped in the project, so they are theoretical and based on the SAMSS (Kusmin and Laanpere, 2022) validated by experts. Therefore, it is crucial to pay greater attention to them when evaluating the RA.

3.5. Evaluation of the RASS

To select a suitable evaluation method, a comprehensive literature analysis was conducted, examining scientific articles. Some of these articles provided brief overviews of RA evaluation, primarily focusing on RA development, while others offered an in-depth examination of evaluation processes.

In total, 72 scientific articles were analysed with the aim of identifying an evaluation method recommended by experts and empirically validated in practice. The objective was to ensure the empirical validity of the RASS evaluation, thereby guaranteeing that the selected method and measurement technique are of high quality and specifically designed to measure the required indicator. RATE consists of five critical checks (Knodel and Naab, 2016); however, only Driver Integrity Check (DIC) and Solution Adequacy Check (SAC) are relevant within the scope of this study. DIC identifies and explains ambiguous architectural drivers through specific scenarios, while SAC assesses the suitability of architectural solutions for these drivers, including confidence in their effectiveness. Thus, we employed two components of the RATE approach: DIC and SAC.

The evaluation of the RASS involved five experts with somewhat varying type of expertise in the fields of education, IoT, and engineering, including 4 males and 1 female as summarised in Table 2 below.

Table 2. Experts involved in the evaluation of the RASS, along with their age, gender, and experience in various fields.

age range	gen-der	experience as a software developer (in years)	experience with IoT devices	teaching experience	teaching areas or subjects
40-49	M	-	developed	more than 10	robotics, microcontroller programming, home automation, operating systems
40-49	M	-	configured	1-6	the use of produced IoT devices (in grades 5-7), assembling IoT devices and solutions on your own (in grade 7), guiding IoT devices UPT (usage, programming, and troubleshooting) (in grade 11)
30-39	M	7-10	configured	-	-
30-39	W	7-10	configured	1-6	software engineering
50-59	M	more than 10	-	more than 10	software development methodology, programming, etc.

Three of them had experience as software developers, with one having 7-10 years of experience and two having over 10 years. One expert had no exposure to IoT devices, while another had been involved in their development. In terms of teaching experience, one had none, while two had over 10 years of pedagogical experience, having taught subjects such as operating systems, software engineering, software development methodology, programming, robotics, microcontroller programming, home automation, the use and configuration of IoT devices, the creation of devices and solutions, and troubleshooting IoT devices.

The RATE approach to evaluation integrates several practices from both the software industry and academic research, focusing on five key checks: (1) evaluating the robustness of the architectural drivers, (2) assessing the adequacy of the architectural solution, (3) examining the quality of the architectural documentation, (4) verifying the alignment between the implementation and the architectural design, and (5) appraising the overall quality of the code (Knodel and Naab, 2016).

When evaluating a reference architecture using the RATE model, architectural drivers (typically formulated as scenarios) are employed. These are developed through the DIC process. Therefore, the DIC check plays a central role in transforming stakeholder concerns into clearly structured evaluation criteria.

In the first phase of the evaluation, we applied the DIC process according to the guidelines provided by Knodel and Naab (2016), creating six scenarios that reflected stakeholder concerns. These concerns had previously been collected, structured, and presented as an integrated whole within the Smart Schoolhouse Self-Assessment Model (Kusmin and Laanpere, 2022), which had been validated by experts using the Nominal Group Technique (Kusmin and Laanpere, 2024).

Through the DIC process, we identified the most critical aspects of the Smart Schoolhouse concept and, based on these, developed six scenarios. The first four scenarios (Life cycle of IoT device adoption, Disconnected, Online, Connected, Disconnected, Online, Connected) are drawn directly from real-world practice. In contrast, the final two scenarios (Smart, Integrated), while still conceptual due to their innovative nature, are grounded in data validated by both stakeholders and experts. Before proceeding to scenario analysis and their application in the second RATE check, the SAC, two domain-specific teachers contributed to evaluating and refining the clarity of the developed scenarios.

The evaluation's second stage, the SAC, took place in a Zoom session with experts. Incorporating external experts into the assessment of architecture adequacy using SAC techniques, as recommended by (Knodel and Naab, 2016), enables the attainment of solution reliability through comparison of detailed scenarios developed in the DIC phase with the RA. The online meeting adhered to the planned two-hour duration. An expert of considerable experience moderated the session, accompanied by an observer who undertook various roles: documenting the proceedings, sharing files (scenarios), presenting and sharing explanatory content in zoom's screen, gaining consent for video recording, managing the video recording process, and later transcribing the video to receive feedback for accuracy feedback from the experts on its accuracy.

The primary objective of the SAC was to assess the suitability of proposed architectural solutions relative to the identified architectural drivers and to ascertain the level of confidence in their appropriateness. The input for the SAC session consisted of six scenarios developed during the previous DIC session along with the three-dimensional and layered RASS.

The SAC encompassed five key steps: 1) an introductory session with Q&A, 2) the RASS evaluation, 3) a discussion, 4) a summary of pivotal observations and suggested amendments, ending with a vote, and 5) closing remarks, allowing experts to voice their final thoughts on the necessity and implementation of RASS.

Introduction aimed to ensure a shared understanding among all experts, facilitating effective collaboration. It covered the Smart Schoolhouse concept, its operational principles, data flow, security issues related to data collection and use with a focus on GDPR compliance, the three-dimensional RA (Figure 3), and its layered structure (Figure 4). With their questions answered, experts proceeded to validate the RASS against the scenarios.

The evaluation started with the scenarios describing the use of IoT devices with the lowest compatibility level (Disconnected), gradually moving towards better connectivity (Online, Connected, Smart, Integrated). Finally, the scenario describing the life cycle of IoT device deployment was evaluated. The evaluation process was conducted similarly across all scenarios. Initially, experts were given time to familiarise themselves individually with the scenario, shared via Google Drive. Subsequently, the moderator then led a discussion, querying the clarity of the scenario, the need for replenishment, and the compliance of the smart schoolhouse's three-dimensional and layered architecture with the described scenario. After collating expert opinions, a summary of key points and amendment recommendations for both the scenario and the RASS was compiled.

After the RASS assessment, which involved six similar evaluations based on scenarios, a feedback session was conducted. During this session, the proposed improvements and modifications for each scenario were discussed and prioritised according to their significance in order to identify all critical changes or potential enhancements. This information was subsequently used to refine the RASS. Subsequently, experts were asked to comment on the abstractness, comprehensiveness, understandability, and feasibility of the RASS. The aim was once again to determine whether the RASS corresponds to the described scenarios and is feasible in its proposed form.

3.6. Empirical Validity of the RASS Evaluation

The final stage involved the empirical validity assessment of the RASS evaluation. The discussion focused on three aspects of empirical validity: (1) construct validity, which examines whether the evaluation accurately measured what it was intended to measure; (2) external validity, which analyses the extent to which the results can be generalised; and (3) internal validity, which assesses the replicability of the experiment.

1) Construct validity assesses the extent to which the evaluation environment reflects its purpose with regard to dependent and independent variables (Galster et al., 2017). Within this framework, we highlight the following aspects that were confirmed during the discussion:

The utilisation of the RATE evaluation method: The RATE method, an advancement of ATAM, is designed to achieve objectives with optimised resources. The discussion confirmed that this evaluation method contributed effectively to fulfilling the assessment's objective.

Created and analysed scenarios: The scenarios employed in the evaluation were developed based on key aspects reflected in the SAMSS, which had previously been validated by experts using the Nominal Group Technique (NGT). The content and phrasing of the scenarios were coordinated with a broader target group prior to the evaluation. Therefore, it can be asserted that the scenarios employed effectively facilitated the evaluation of the specific criteria they were designed to assess. This was also corroborated by experts.

Preparation and management of the process: The evaluation was conducted online, adhering to the principles of the second control (SAC) of the RATE method. Following the pandemic, online meetings—particularly for IT experts—have become customary. Both the online meeting and file-sharing environments functioned flawlessly, providing all experts with the opportunity to offer both oral and written comments. The discussion confirmed that the evaluation process effectively supported the achievement of the objective.

Duration of evaluation: The pace of the RASS evaluation was measured and deliberate. The moderator guided the progression of the discussion in response to the level of expert engagement, introducing new questions or arguments as the feedback began to diminish. It was confirmed during the discussion that the time allocated and spent on the various stages of the evaluation was sufficient for all experts to explore the subject in depth and contribute as objectively as possible.

Interpreting visualised information: To avoid any issues, a thorough introduction to the topic was provided before the evaluation. Specifically, we explained the concept of the Smart Schoolhouse, including the principles of data collection, management, and use; the grouping of IoT devices identified based on usage patterns; their life cycle; and both the three-dimensional and layered RASS. Although the interpretation of visualised information largely depends on an individual's background and experience, experts confirmed that they were provided with a sufficient overview of the context and received answers to their questions before the evaluation.

Expertise of evaluators: It is reasonable to assume that experts with more extensive experience in the analysis of RAs might have offered somewhat different responses, and their involvement could be considered in future evaluations. However, due to resource constraints, a purposive sample was employed, consisting of experts who are recognised and highly experienced in fields relevant to this study. Regarding whether the experts involved in the evaluation met the expectations placed upon them, the thoroughness of their input, along with the quality of their recommendations and proposals, confirms that they fulfilled the expected criteria.

2) Regarding external validity (the generalisability of results: whether the findings are of interest to others), we are confident that our results are generalisable. The mapping of stakeholders’ requirements and concerns (i.e., the critical aspects of the Smart Schoolhouse concept) was conducted through focus group interviews and action research in 19 schools, which varied in size, location, and language of communication. This process was followed by a thorough analysis of the literature to corroborate the conclusions with scientific research. Although the experts stated during the evaluation that, following the implementation of their improvements and recommendations, the RASS is suitable for the next phase of the RA life cycle, namely, implementation, it is nonetheless advisable to conduct a new evaluation that also takes into account the specific requirements and concerns of the target group (whether at the school, municipal, or national level). This indicates that further evaluation will be necessary.

3) To ensure internal validity, we employed a reliable evaluation method for assessing the RASS and are confident in the results (particularly regarding how evaluation outcomes may depend on the experts’ experience) because we adhered to the guidelines of the chosen method (RATE). The key assessment components of RATE, namely the first (DIC) and second (SAC) checks, are expert-driven activities which, due to the significant human factor involved, can be classified as qualitative in nature. As such, they are not considered the most reliable in the sense that identical results may not be replicated in a different context. Nevertheless, major discrepancies are unlikely to arise, as the participating experts were highly experienced and impartial. Furthermore, the RA evaluation was conducted using predefined metrics, specifically, scenarios developed in line with stakeholder requirements, which ensured that the experts assessed the RA from consistent and comparable perspectives.

The insights gathered from this SAC session with experts will be discussed in the next section.

3.7. Results of the RASS Evaluation

During the two-hour SAC session, a RASS evaluation took place. Immediately after the introductory part, numerous questions were posed to gain a better understanding of the developed RASS, and its three-dimensional and layered nature. Subsequently, during the presentation of the scenarios and the analysis of the resulting RASS, two major proposals were made, and seven recommendations were provided. In addition to these, the questions raised during the discussion about the Smart Schoolhouse concept provided food for thought and need consideration in the future implementation of the concept. The downside of implementing the SAC is that it is largely a manual task, requiring considerable effort, and primarily yields qualitative results (Knodel and Naab, 2016).

Suggestions and Discussion:

a) One expert suggested placing the presentation and business layers side by side rather than overlapping since they utilise the same data and services, but other experts did not consider it essential. Therefore, to gain a visually clearer overview, we postponed this suggestion for the time being.

b) Considering the Smart Schoolhouse concept, which involves data from the Smart House system, sensors inside and outside classrooms, learners' digital footprints, and, with learners' requests and parental permission, also from their personal wearable devices, it results in a large volume of diverse data that can be utilised in the learning process and learning analytics. In the initial RASS, the collected data was divided into four categories 1) raw, 2) processed, 3) pseudonymised, 4) Learning Record Store (LRS) data. During evaluation, a recommendation was proposed to include three additional groups in the data layer: 1) essential or objective data (such as fire or security data that should not be manipulated by students), 2) manipulative or experimental data (gathered/generated by students), and 3) simulation-based data (exclusively for modelling or educational purposes).

c) The third, and perhaps the most significant, supplement proposal was to add an integration layer or create integration capabilities for the data layer. It is crucial that devices which will need to be added or introduced to the created software system in the future can understand each other. These integration activities may be added to the documentation of the RASS, intended for the replacement and upgrade of existing IoT devices, or for acquiring entirely new functionality-providing IoT solutions. The idea was to add a recommendation that, in case the data layer does not support the standard of the offered IoT devices or solutions, manufacturers or providers should ensure integration capabilities by supplementing the IoT devices with adapter software.

d) Additionally, other smaller-scale suggestions and recommendations were made, such as the information that IoT devices suitable for home solutions may not always yield the best results when used in schools, but these are not reflected in the RASS.

In summary, it can be highlighted that the experts reached a consensus on two important additions: 1) additional grouping of data used in the learning process and 2) adding integration capabilities.

The development of the RASS was informed by the six-stage framework "Empirically Grounded RAs," (EGRA) (Galster and Avgeriou, 2011) and the design of RASS adhered to the principles of SOA. The stakeholders' concerns, pivotal to the Smart Schoolhouse concept, provided essential input. In terms of structural design, we relied on the RAMI 4.0 model (Hankel and Rexroth, 2015). The architecture (Figure 3) manifests in three dimensions: 1) Life cycle of IoT devices or solutions adopted in the Smart Schoolhouse; 2) Hierarchy levels of IoT device usage, categorised as Disconnected, Online, Connected, Smart, and Integrated; and 3) an architectural framework comprising eight layers (shown in Figure 4): Devices, Data, Integration, Application, Business, Presentation, Support, Governance, and Security.

For evaluation purposes, we employed the first two checks of the RATE method, conducted with the expertise of five specialists. Regarding the validity of conclusions and recommendations, which are further explained in the discussion section, we must rely solely on trust in the expertise and contributions of experts, since, as Angelov et al. claim, "the progress and shortcomings of the RA can only be measured in a temporal perspective" (Angelov et al., 2012).

We do not assert that the developed RASS represents the best solution; however, it signifies an initial step within the context of the Smart Schoolhouse.

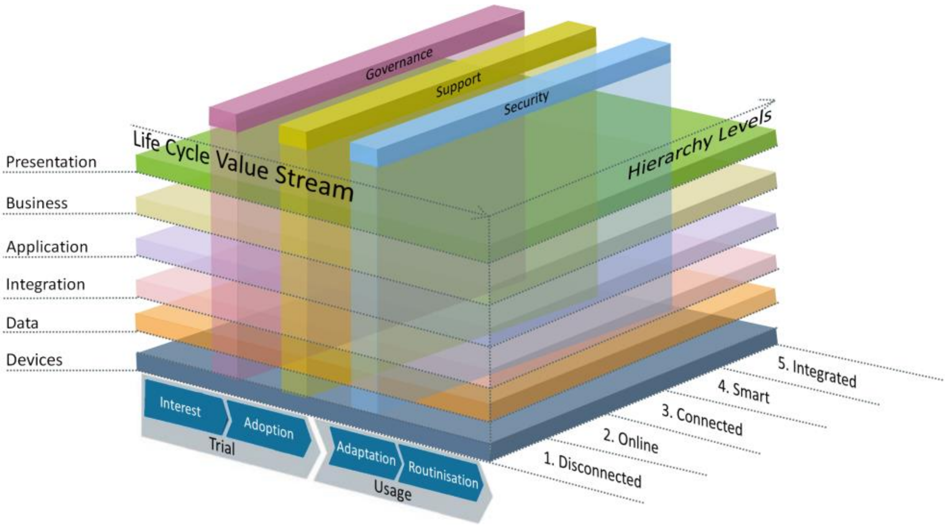

Figure 3. Three-Dimensional Reference Architecture of Smart Schoolhouse

3.8. Evaluated Reference Architecture of the Smart Schoolhouse

The Smart Schoolhouse reference architecture (RASS) is presented as a three-dimensional model in Figure 3, illustrating three distinct dimensions: 1) The lifecycle of IoT technology within the Smart Schoolhouse; 2) The hierarchical levels of IoT device usage, categorised based on usage patterns; 3) The layered architecture of RASS.

To enhance clarity, the service-oriented layered architecture is presented separately in Figure 4.

The presentation layer is responsible for providing essential technical and technological capabilities to modern learners. This includes applications, portals, and internal system user rights management. It also refers to the integration of diverse technologies into the learning process.

The primary function of the business layer is to manage various functionalities, such as user management, activities, tasks, communication, learning analytics etc., to establish a comprehensive overview of the learning experience and related activities. Although RASS is pedagogically neutral, the business layer outlines learning strategies and methods that must be considered at the next stage of RASS implementation.

The purpose of the application layer is to orchestrate data services, facilitating the collection, integration, and processing of data from various sources.

The integration layer was introduced during the evaluation process to enable the integration of IoT devices from different providers within the Smart Schoolhouse system, accommodating various standards and protocols.

The data layer is responsible for data management. Initially, it included raw data collected from various sources, processed data, and pseudonymised data to enable their use in the learning process. During the evaluation, three data categories were added: 1) Objective Data (e.g., safety or fire protection data), which should not be accessible for manipulation by students; 2) Manipulable Data, which students collect, create, and process; 3) Simulation-Based Data, intended solely for modelling or educational purposes.

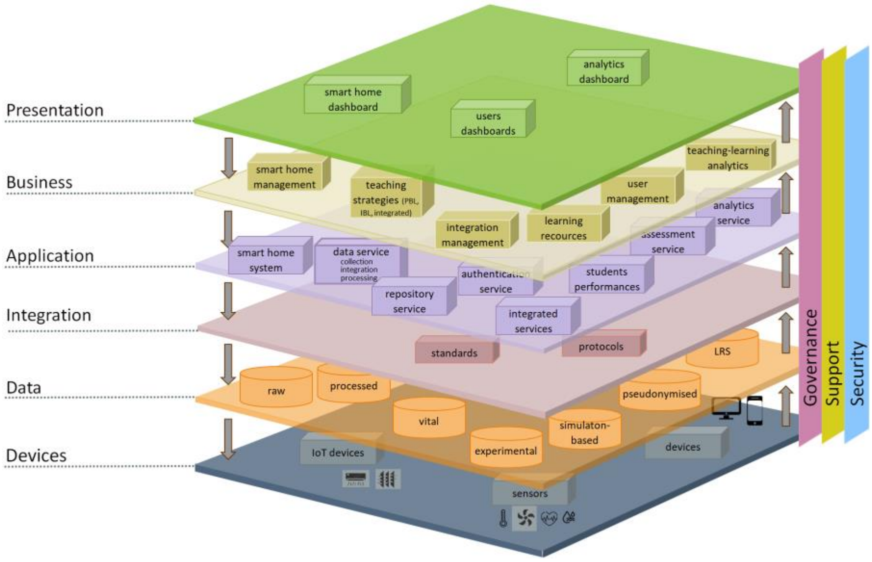

Figure 4. Layered Reference Architecture of Smart Schoolhouse

The device layer must facilitate the rapid and convenient addition and utilisation of IoT solutions, taking into account the hierarchical levels of IoT technology. To ensure technological neutrality, no specific standards are defined within RASS.

The support layer reflects the services required for education, including training programmes, guidelines, and the dissemination of knowledge.

The management layer ensures the identification, management, and dissemination of various standards, legal requirements, and regulatory obligations throughout the organisation.

The security layer must prioritise the accessibility and secure transmission of learners' personal data and data used within the learning process. Additionally, it is essential to ensure the system's reliability, confidentiality, integrity, and privacy.

3.9. Recommendations for the Implementation of the RASS

RASS can be applied in various future scenarios, such as: 1) formulating requirements for the development of a nationally commissioned learning environment that facilitates the rapid and convenient implementation of IoT technology; 2) integrating an IoT-enabled solution with an educational platform; 3) providing recommendations for the procurement of sustainable IoT technology, etc.

To effectively implement the concept of a Smart Schoolhouse within a specific purpose, the following recommendations are proposed to map the concerns of stakeholders. Based on the RASS:

R1: Identify the Components: Ascertain the key components and systems that constitute the smart schoolhouse architecture, tailored to the specific context. This may include sensors, devices, infrastructure, networks, databases, and learning analytics tools.

R2: Map the Data Flow: Visualise the flow of data within the architecture, commencing with the physical learning environment (data is collected via IoT sensors and smart devices from various sources) and concluding in sophisticated e-learning environments equipped with monitoring systems. It is essential to demonstrate how this data is transmitted and processed within the school infrastructure.

R3: Incorporate Digital Footprints: Integrate the digital footprints of learners, which may include data from personal devices (e.g. smartphones and tablets) and online platforms (including learning management systems, educational applications, and social media). Identify the connection points where this data is collected and synchronised with the smart schoolhouse architecture.

R4: Consider STEM Education Focus: Highlight any specific components or functionalities within the architecture that are pertinent to STEM education, such as integration with STEM-specific tools, virtual laboratories, or interactive learning resources.

R5: Design Data Integration: Analyse how data from both the physical learning environment and learners' digital footprints are integrated. This integration may involve processes of data harmonisation, aggregation, and transformation to ensure compatibility and consistency for learning analytics purposes.

R6: Include Learning Analytics: Demonstrate the components or tools responsible for conducting learning analytics. This may involve the use of algorithms, machine learning models, or dedicated analytics platforms that process the integrated data to generate insights and metrics related to learners' performance, behaviour, or engagement.

R7: Address Privacy Concerns: Emphasise the measures implemented to protect the privacy of students and teachers while utilising the data. This may include techniques such as data anonymisation and pseudonymisation, encryption, access controls, and adherence to relevant privacy regulations and policies.

R8: Provide a Visual Legend and Explanations: Construct a legend or key that elucidates the symbols, labels, and connections used in the RA. Include explanatory notes or descriptions to clarify the purpose and functionality of each component.

R9: Engage with Relevant Stakeholders: Consult with relevant stakeholders, including educators, IT specialists, and privacy experts, throughout the process to ensure that the RA meets their concerns and adheres to best practices in data collection, integration, and privacy within the context of STEM education and Learning Analytics.

In light of the collected data and based on the RASS a concrete architecture (Gidey et al., 2017) can be developed by adhering to the steps delineated in the chosen framework (Cloutier, et al., 2010) for its construction. Concrete architecture is fashioned within a particular context, reflecting specific objectives (Angelov et al., 2012) and encompassing required functionalities (Angelov et al., 2009), domain knowledge (Saay and Norta, 2016), extant technologies (Kuppusamy and Suresh, 2020), pertinent standards, protocols, and other essential elements to ensure compatibility with existing software. Following the creation of a concrete architecture, it is imperative to assess its alignment with the expectations and concerns of stakeholders. Additionally, it is crucial to evaluate its quality requirements prior to the development of applications based upon it.

4. Research Results

The study comprises two complementary parts: a theoretical component, which focused on an iterative literature analysis to map and examine the possibilities for developing and evaluating a reference architecture (RA) for the Smart Schoolhouse (RASS); and a practical component, in which the knowledge derived from the theoretical part was applied to the development and evaluation of the RASS.

A total of 137 scientific articles were analysed in depth, including 68 directly related to reference architectures in the field of education. This analysis identified the key stages of the RA life cycle, provided recommendations for selecting an appropriate architectural style and approach, and offered essential input for defining quality indicators, selecting an evaluation method, and conducting the evaluation itself.

The insights gained from the theoretical component were applied to the creation of the RASS. The result is a three-dimensional, layered reference architecture, developed using a top-down approach grounded in service-oriented architecture (SOA) principles. Its substantive foundation derives from data collected over four years through case studies conducted in 19 Estonian schools. These data are represented in the form of the Smart Schoolhouse Self-Assessment Model (SAMSS) and may be characterised as stakeholder concerns. Using SAMSS as input and drawing on the first check (DIC) of the RATE model, six personas and scenarios were developed. These personas and scenarios were subsequently used in the evaluation of the RASS, corresponding to the second check (SAC) of the RATE model.

Given the abstract nature of architecture, SAC facilitates early, forward-looking decision-making by validating architectural solutions during the design phase, prior to significant implementation investments. Its primary purpose is to assess whether the current architectural solutions adequately address stakeholder concerns and instil sufficient confidence in their suitability.

The evaluation confirmed that the RASS broadly meets stakeholder expectations and is sufficiently flexible and applicable to support the integration of IoT solutions and the use of learning analytics data in STEM education. During the evaluation, experts highlighted the need to enhance the architecture with additional data categories and integration capabilities, which were incorporated into the final refinement of the RASS.

In conclusion, the study demonstrated that the developed RASS provides a strong foundation for the development of practical solutions, supporting the effective integration of learning environments and data-driven education.

5. Conclusion

The changed expectations for today's students, i.e. the members of tomorrow's society, have created a situation where schools have to be innovative to provide the education that society expects from them, despite lacking the necessary resources to do so.

To support schools in engaging learners with real-world problem-solving through various teaching methods, enabling the application of innovative technology and the analysis of collected data, we proposed the Smart Schoolhouse concept. To clarify this concept for stakeholders and to facilitate the development of an appropriate software solution for software developers, we introduced a reference architecture (RA) based on the Smart Schoolhouse concept in this article. To ensure that the developed RA would be both relevant and applicable, we grounded its development in empirically justified prior practice, drawing evidence from a comprehensive literature review. We aimed to answer the following research question: How can we develop, validate, and implement a reference architecture (RA) for the Smart Schoolhouse?

In the first part of the scientific literature analysis, we identified the various processes and stages of the RA life cycle, along with recommendations for their management. Additionally, we mapped out different methods that have already been applied in the creation of RAs. The development of RASS was based on the empirically grounded reference architecture framework (EGRA), utilising a top-down, evidence-based approach.

The created RASS is, similarly to RAMI 4.0, three-dimensional service-oriented architecture: 1) Life cycle of IoT devices or solutions to be adopted in the Smart Schoolhouse, 2) Hierarchy levels of IoT devices usage (Disconnected, Online, Connected, Smart, Integrated) and 3) architecture, comprising eight layers: Device Layer, Data Layer, Integration Layer, Application Layer, Business Layer, Presentation Layer, Support Layer, Governance Layer, and Security Layer. Since it is currently uncertain when the resources and readiness of schools will emerge for the implementation of the Smart Schoolhouse idea, we tried to create the RA abstract enough to ensure its longer life-cycle.

In the second part of the scientific literature analysis, we focused on RA evaluation methods to identify the most suitable one for RASS. To ensure the empirical validity of the assessment, confirming that the chosen method and measurement technique are of high quality and targeted towards what we intend to measure, we selected the RATE method, which is recommended by experts and validated in practice. The first two checks from the RATE method – DIC and SAC – were employed. The study included five experts in their respective fields, each possessing in-depth knowledge in at least two of the following fields: education, the Internet of Things (IoT), or software engineering. Six personas and six scenarios were utilised. This article presents the enhanced and refined RASS, which has been improved based on recommendations and suggestions from the evaluation process, in order to prevent the spread of misinformation.

Due to the constrained resources available during the evaluation of the RASS, this study is subject to several limitations, which present opportunities for improvement in future research and development endeavours. Among the most notable constraints, one may underscore 1) the geographical location of this study, 2) the novelty of the Smart Schoolhouse concept 3) the small size of the sample, 4) the experience of experts engaged in the RASS evaluation, 5) the level of abstraction of the RASS devised for its presentation and evaluation, and additionally, 6) the complexity of evaluating an abstract RA, 7) the restricted quantity of personas and scenarios fashioned for its evaluation.

1. Geographical limitation - The study encompassed a range of specialists; however, they all originated from the IT sector and hailed from a markedly homogeneous background with respect to both educational and living conditions. The inclusion of external experts would undeniably have furnished additional viewpoints and enhanced the evaluative procedure. The incorporation of international experts would necessitate broadening the linguistic spectrum, yet this may be contemplated in subsequent investigations.

2. The novelty of the concept of Smart Schoolhouse – The evaluation process may be biased due to the novelty of the concept of the Smart Schoolhouse. Since it is unknown when schools will have the necessary resources to implement Smart Schoolhouse concept, the idea was introduced and evaluated solely based on a RA. No additional resources were allocated for the development of a specific architecture or prototype, though this could be considered in future studies.

3. Small sample – As the current stage of development prioritised obtaining feedback on the alignment of the RA with stakeholder requirements and concerns, as well as its suitability for subsequent stages, minor flaws in the RA were of lesser importance. Therefore, a smaller sample sufficed for this study. In the future, as the Smart Schoolhouse concept is implemented, it is imperative to conduct a new mapping of stakeholder requirements. Based on the results, updating the RA is necessary, along with a comprehensive evaluation that should involve a larger number of experts.

4. Experts' Experiences – The efficacy of RASS assessment was significantly contingent upon the expertise and experience of the professionals engaged in the evaluation process. Although numerous software developers exist, software development frequently does not depend on RA, rendering it difficult to locate experts who possess simultaneous expertise across multiple domains (education, software development, the Internet of Things) with experience in software creation predicated on RA. In preparing for the following studies, it would be prudent to consider allocating resources in the budget to involve an expert with RA evaluation experience.

5. Abstraction of RA – Identifying the optimal level of abstraction frequently presents a considerable challenge. The RA requires a degree of abstraction that is sufficient to mitigate the risk of rapid obsolescence attributable to technological advancements, to facilitate alternative decision-making processes, and to guarantee its applicability for broad usage. Concurrently, it necessitates sufficient detail to offer a comprehensive overview of crucial elements, whilst efficiently securing the fulfilment of stakeholder objectives. In the assessment of the RASS, feedback from experts indicated that our selected approach is satisfactory.

6. The complexity of evaluating an abstract RA – Owing to its abstract nature, evaluating RA presents a considerable challenge, no universally applicable methods exist for undertaking such an evaluation. Consequently, it is advisable to customise an architecture evaluation framework. For the evaluation of RASS, the initial two checks of the RATE method were employed. The first check facilitated the development of scenarios rooted in stakeholder concerns, whilst the second aided in determining whether the solutions are satisfactory and meet the requirements. Since the second check predominantly relies on expert judgement, requiring substantial effort while producing only qualitative data, the outcomes are significantly influenced by the knowledge and experience of the experts.

7. The scope of use-case scenarios is restricted – In our evaluation of the RASS, a limited array of scenarios was employed. Our emphasis was placed on the technology innovation area pertinent to the self-assessment model, enriched by facets of change management and pedagogical innovation to enhance comprehension of the context. Our objective was to encompass the majority of descriptions outlined in the criteria. Subsequent research might gain from an expanded collection of succinct scenarios.

Our study undoubtedly has several limitations at different levels and related to various fields, but the ones mentioned above are those of which we are aware and recommend to be considered in future research.

In conclusion, a thorough literature review and input gathered from previous studies enabled the development of a reference architecture that supports the Smart Schoolhouse concept. This architecture was further refined through an evaluation involving five experts. This process confirms that the research question was effectively addressed and that, through the evaluation, the resulting RASS was validated as meeting the expectations of relevant stakeholders.

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