Enhancing Software Engineering Education in Africa through a Metaversity

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***Abstract*—Software engineering education requires a new boost in African higher education, because of the high demand for professionals, caused by the fast increasing internet connections calling for meaningful applications and governmental initiatives like Fourth Industrial Revolution (4IR), and the current situation where universities graduate software engineers that cannot serve in the job markets. Inspired by the Conceive, Design, Implement and Operate (CDIO) model for engineering education and the CATI model for curriculum reform focusing on contextually relevant education in the Global South, we introduce how a complementary model for a conventional university, i.e. metaversity, can enhance software engineering education in Africa. Metaversity uses the full potential of the metaverse, requiring fast internet, and is a balance between access to the globally best expertise for technical problems and design of solutions to contextually relevant problems on site. It combines the global and the local contexts in software engineering education.**

Keywords—Metaversity, Software Engineering, Africa, Fifth generation (5G), Metaverse

I. Introduction

Software engineering (SE) is a key competence that African economies need to develop beyond the stages of industrial and information societies. While software engineering is taught in a range of educational institutions in certain developing countries, the Software Engineering (SE) discipline has evolved to be an independent discipline from the other computing disciplines. Little or no distinction is however made between graduates from computing-related disciplines. There are still universities that assume that graduates from any computing discipline can be employed as software engineers, especially in the computing industry in developing countries. Graduates from the computing disciplines are treated equally with little or no distinction, employing these graduates as software engineers. Computing bodies such as IEEE/ACM however distinguish between the different computing disciplines and spend considerable time working on the computing curriculum for adaptation in universities, involving industry from developed countries and focusing on the needs of developed countries [1]. The aim of every university is to have a curriculum that ensures that the knowledge conveyed is appropriate and necessary to a specific society and the time [2]. Universities, therefore, adopt the IEEE and ACM curriculum although the curriculum was developed with the focus on infrastructures from developed countries in mind. The SE discipline is believed to consist of practical courses that are mostly offered on a full-time basis, and in a face-to-face mode. African countries however have their own challenges, which need to be considered.

African countries as well as other developing countries face challenges of missing or limited infrastructure, that is, power systems with access to electricity, and internet access, leaving people living in rural areas without having access in an unequal position, thus fostering the digital divide. To get these existing resources fully utilized and delivered to rural and underserved communities, new, fast, and light-weight systematic solutions, such as 5G Mökki [12], a platform and base introducing the digital infrastructure for all, are needed to connect these communities to the global value chains. Africa can be a unique laboratory for transforming Software Engineering (SE) education, learning in a natively digital metaverse that is integrated into real-life environments from the outset.

In this paper, we propose how a new scheme for universities, called metaversity, can enhance software engineering education in Africa. [3] defines a metaversity as a university that connects staff, students, and other interested parties using metaverse technology. A metaversity goes beyond the usual and provides students, especially software engineers with a new opportunity to learn and interact with their fellow international associates and peers. Accordingly, students could get in contact with universities and industries and have the opportunity to do hands-on projects quicker, and accordingly by applying problem-based learning (PBL) methods.

Through metaversity, SE students could identify problems to improve a given community, set up a 5G base, and begin to collaborate internationally to produce solutions by using metaverse technology. This type of learning might challenge learners to not just provide "Textbook solutions" but also to understand problems, identify an opportunity, and work together with a diverse and international team to implement new solutions and develop innovations through collaborative processes of co-design and co-creation. Moreover, this would foster learning and knowledge sharing leading up to faster and more practical transdisciplinary collaborations around the world. Introducing a metaversity will bring novel structures to replace those of traditional universities, such as mobile universities. For SE education, metaversity extends a given local setting beyond íts fixed limits toward a universal scene.

This paper will add to the general concept of the metaversity defined in [3], emphasizing how this concept could enhance software engineering education in Africa. It is structured as follows. Section 2 presents related work, followed by research design in Section 3. Results are presented in Section 4. Section 5 discusses the results of the paper, and Section 6 concludes and presents future work.

II. RELATED LITERATURE

A. Metaversity

Metaversity is a concept first described in [3]. It is the result of combining a mobile university model with metaverse technologies such as Virtual Reality (VR), Augmented Reality (AR), Extended Reality (XR), Mixed Reality (MR), and Remote Presence (RP). A metaversity extends the current fixed university model by adding modular university bases in multiple locations interconnected using metaverse technology including communications. The metaversity allows for collaboration not just between the university bases but the world at large. The metaversity was designed with the intention to improve the way universities function, it challenges the traditional university design by introducing aspects such as:

- *Extended Reality* - Metaverse technology allows for the use of digital tools to interact with virtual realities and create digital artifacts that can be interacted with using VR, AR, XR, MR and RP.
- *Serendipity* - The metaversity allows students to be free and make discoveries as they explore concepts without time restrictions of when and how long the metaversity can be accessed.
- *Freedom to explore using unconventional methods* - students can safely explore concepts digitally with few restrictions.
- *Loose structures* - metaversity is not set up with fixed structures such as set modules, faculties, and practices. Students have the opportunity to be as creative as possible to learn and solve problems.
- *Learning by doing and by being* - learning inside a metaversity is student-driven and done by solving real problems while being a part of a learning community, instead of using an individualistic teacher-learner pedagogy.
- *Imaginative inspiration* - students are encouraged to not only follow industry standards but to imagine freely and, consequently, do things differently. Creative solutions may arise when imagination is not constricted in favour of traditional tried and tested methods.
- *Bottom-Up approach* - metaversity is driven by the community, important decisions are not made by a select few, but everyone can vote on matters.
- *Multiple locations* - physical metaversity bases can be distributed in strategic locations following the mobile university model while allowing students to virtually access the metaverse from their own location(s).

In order to support metaversity technology, reliable, high-speed communications with internet access are required, which 4G, 5G standalone (SA) technology and in near future 6G can provide. But these can only provide local connectivity, the backhaul connectivity implemented with a fiber-optic network, micro links, or satellite connectivity is needed as well.

B. 5G Technology

5th generation (5G) of mobile data communication is the current and newest standardized wireless mobile network technology [4], [5]. The predecessor of 5G, 4G also known as Long-Term Evolution (LTE) was the previous mobile generation technology that revolutionized data communication and connectivity and brought wireless broadband internet to people's mobile devices. 4G and its predecessors are built by relaying all the data through or storing data in the cloud, which has brought the questions of how sustainable or energy-efficient this architecture is, especially today when sustainability and climate change are the biggest challenges of our lives and the future of our planet [6]. According to [7], the Internet will use a fifth of all the world's electricity by 2025, and this requires a huge amount of energy, which due to and for the sake of climate change needs to be produced sustainably with renewable energy sources. 5G with its edge computing features [8]– [10], has already been introduced and brought as features into 4G LTE Advanced technology and private LTE networks [11].

One of the key features of 5G is energy consumption and energy efficiency, which are addressed in data processing and transfer. There are built-in distributed artificial intelligence (AI) enabled analysis tools that monitor these aspects and together with edge computing are making 5G more efficient than previous technologies [8].

In 5G wireless mobile radio network technologies data speeds are further increased as well as latencies are decreased compared to 4G. Data speed and latencies are the key performance indicators (KPI) and advantages as there are a variety of IoT as well as commercial multimedia applications calling for these. This will be a fruitful playground and setting for the universities and the proposed metaversity concept, as the need for new developers increases. Current developers especially in the African continent are already lacking and need to be taught and educated to become developers of the future to design and implement new applications for 5G and SE.

One example of a 5G platform is 5G Mökki, a concept designed for demonstration, testing, and introduction showcasing new technologies, such as 5G and different forms of virtual reality (VR) technologies [12]. 5G Mökki is not just about the technological base, but the key thing and innovation are in that the universities and companies and other entities, each having the Mökki, are in the same network and immersively connected to one another and each other forming a 5G Mökki network. All the data, design, implementations, proof of concepts, etc. contents are shared and broadcasted through and via the 5G Mökki network, and thus the information and knowledge are shared within the network. This forms a fruitful baseline for the further development of concepts, ideas, etc. The 5G Mökki design could be used as the base for the metaversity.

III. Research Design

Research problem: Delivering quality education in Software engineering in Africa is a complex problem because of multiple factors such as the high cost of the courses, the legacy of theory-based education which has been reduced to memorization, limited access to technology and resources to learn with, and learning in a vacuum without the necessary integration to stakeholders, such as industry. Due to these factors, software engineers in Africa lack the skills to be internationally competitive, limiting the scope of their work to a local context, and forcing clients requiring specialized software to import skills beyond the African continent. It seems that the conventional and mostly Western design of a university adapted or just transferred to an African environment needs to be rethought. Developing software engineering education that is relevant in Africa can transform an African higher education institution into a pioneer on the global stage.

A. Research questions and goals

We reduced the extensive research problem above as follows. We explored how the metaversity model can provide software engineering students in Africa at the same time with both access to international collaboration and software engineering technology and elaborate relevant solutions in a given context and hence enhance the quality of software engineering education in Africa. We concretized the agenda as three research questions:

- RQ1: What is the state of or expectations for software engineering education in Africa?
- RQ2: How can current models meet the requirements of or enhance software engineering education in Africa?
- RQ3: How can metaversity technologies be used to enhance software engineering education in Africa?

B. Research Method

Since both the long-term and general research problem as well as its reduction call for a design task, we applied Hevner's design science research method [13] to answer the research questions. It is a three thread or cycle model that focuses on relevance, rigor, and design, to make sure that the artifact to be designed in the design cycle - in our case an adaptation of metaversity for software engineering education in Africa - matches with the relevant requirements of the context, elicited in the relevance cycle, in a way that takes into account the appropriate state-of-the-art knowledge base, provided by the rigor cycle.

In other words, in the relevance cycle, the task of the design science research exercise in software engineering education relevant in the African context is discovered answering RQ1. The rigor cycle links existing literature in current software engineering educational models to the discoveries of the relevance cycle answering RQ2. Finally, the design cycle creates a model of how software engineering education can be enhanced using information uncovered during the relevance and rigor cycles, answering RQ3.

IV. Results

A. Relevance cycle

Software engineers are in high demand in Africa which is facing an internet boom; more users are being connected to the internet. The internet economy in Africa is expected to grow to $180 billion by 2025 and $712 Billion by 2050, almost a 300% increase over the period of 25 years [12]. Internet technology is also evolving with social innovations such as 5G Mökki setting up 5G bases in some African countries [24,25]. Software engineers are also in high demand because of the 4th industrial revolution which is fusing the digital and physical world together. Africa which is already lagging behind in terms of internet technology and infrastructure cannot afford to be left out of the revolution because of a lack of skilled talent to develop and implement new digital technologies. As demand for software engineers increases so does the need for quality education. There is unfortunately a problem that exists with the way software engineering is taught. In many countries, industry and academia are disconnected from each other, and as a result academia educates students with skills irrelevant or insufficient for the industry needs. It is important for academia to collaborate closely with industry for efficient national and global innovation systems [13]. Reasons for the disconnect were identified in [14] and [15] as follows::

- Lack of faculty awareness. Faculty training objectives are not linked to current industry requirements because of little to no collaboration between the two.
- *Fake projects*. Student projects are usually "Fake", they have no stakeholders and usually do not solve a current or real existing practical problem.

- *Resource limitations*. Some universities lack important resources such as powerful computers to enable students to effectively develop software.
- *Lack of career planning.* Career planning is usually not part of the curriculum so students themselves do not understand industry needs and are also otherwise ignorant about the software engineering profession.
- *Lack of university-enterprise cooperation*. Universities hardly engage the industry to help them with tasks such as updating their curriculum to fit current industry needs.

This disconnect leads to problems in:

- *professional issues*, exemplified by insufficient understanding of future careers, employment positions, and business needs by students.
- *soft skills*, for example when students lack environmental cognition, engineering practice ability, innovation consciousness, and teamwork spirit.

Heeks' design-reality gap [16], although originally aimed at identifying, analyzing and interpreting the problems and shortcomings of information systems in the developing countries, is helpful also for doing the same for software engineering education in Africa. When adapted to software engineering education, the scheme emphasizes the importance of designing education in such a way that it takes reality seriously. Figure 1 is used to illustrate the design reality gap showing a gap between intended design and reality; in a well adapted model the smaller the gap the better.

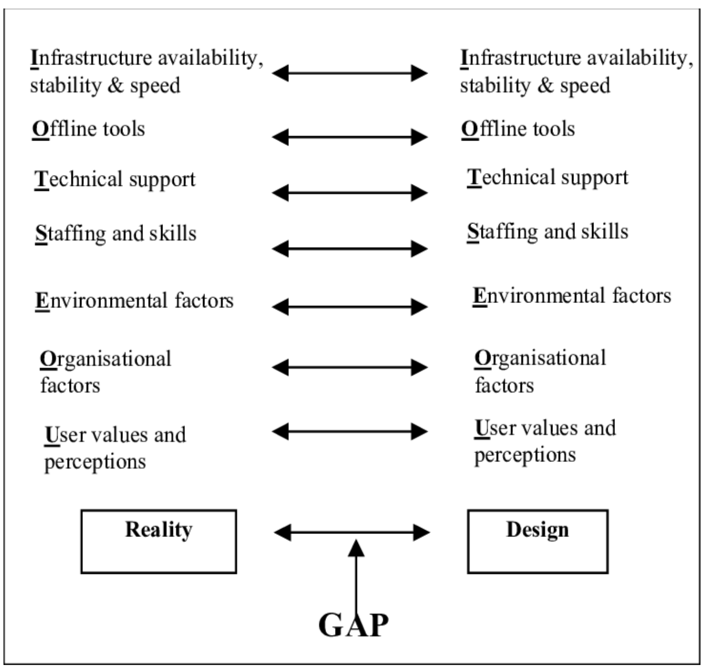

Fig. 1. HEEKS DESIGN REALITY GAP [16].

B. *Rigor cycle*

The Conceive, Design, Implement and Operate (CDIO) model is a contextual educational framework that aims to solve some of the problems with the way engineering, including SE, is taught by providing a learning environment where students actively link formal knowledge with real-life experiences reducing the design-reality gap. It was developed in the late 1990s by MIT and three Swedish universities, and today there are over 160 university institutions following the framework. The CDIO framework follows the learning by doing principle and emphasizes project-based education and learning [19]. The framework focuses on "cultivating students with certain technical knowledge and reasoning ability, professional skills and quality, interpersonal communication and teamwork ability, and completing the conception, design, implementation, and operation of products in the enterprise and social environment" [17].

The framework has four working stages, Conceiving, Designing, Implementing, and Operating, defined as follows:

- *Conceiving stage*: Customer and societal needs are identified and defined.
- *Designing Stage*: A solution is designed to address the need.
- *Implementing Stage*: The design is turned into a usable solution.
- *Operating stage*: The implemented solution is used in the intended environment.

The model works by introducing learners to a problem and then learning to solve that problem through a practical design of the system. During the design stage, the learner accumulates theoretical knowledge that is directly linked to the need they are addressing. They then acquire practical knowledge through experience by building the solution in the implementation stage and finally learn to deploy and maintain a solution in a working environment in the operating stage. This model teaches learners in an industry like setting with real stakeholders so they are prepared for what to expect in the industry. In order to enhance industry-university collaboration during the Conceiving stage members from the industry usually give the students the customer and societal needs so the students solve real problems. There is constant communication with the members of the industry throughout the rest of the process so the industry members act as mentors to the students in addition to their lecturers. This is especially important in SE as the industry member introduces the students to the state- of-the-art development technologies and best practices while being supported by their lecturer.

The CDIO model bridges the industry-university disconnect and fosters academia-industry partnerships and collaboration. The industry-university disconnect is depicted in Table 1.

TABLE I. INDUSTRY-UNIVERSITY DISCONNECT.

Disconnect Caused by	connect Solved By CDIO
Lack of faculty awareness	Conversations between lecturer and industry member before the start of the course.
Fake projects	Projects given by the industry members
Resource limitations	Access to industry resources through industry collaboration
Lack of career planning	ry member acts as a mentor to the students
Lack of university enterprise cooperation	Industry members present throughout the entire project

The CATI model is another development framework, especially for evaluation and supporting the applicability of technology transfer and educational development. It is also deeply linked to the contextualized curriculum design approach. The model has four stages, namely import, transfer, apply and contextualize. The import level refers to something that is available but not used. Transfer ensures that the imported knowledge or technology works but in a very limited sense. Application-level is the first one where you actually use the technology and knowledge and the action benefits the surrounding society. The contextualization level is the innovative level in which (totally) new approaches are developed and applied [20], [21]. This level supports the development actions. Authors in [22] analyzed the stages and relevance for developing a totally new type of programming course in a Tanzanian university using the model. In fact, the key finding of their work was to turn around the conventional order import →transfer→apply→contextualize towards its opposite of contextualize→apply→transfer→import. In software engineering education, the traditional one reminds of importing a given curriculum from the Global North to the Global South, as so-called education export. The transposed one named CATI starts from the context (Conceive & Design in the CDIO), then continues to application (Design & Implement), which possibly requires some transferred or even imported knowledge or technologies for Implementation. Thus, the models talk the same language, even if the individual stages overlap. As Figure. 2 shows, the CATI model uses most of the resources in the Contextualize stage, to be reduced by each following stage. To summarize, the CATI model can be seen as an application of the CDIO model in the Global South.

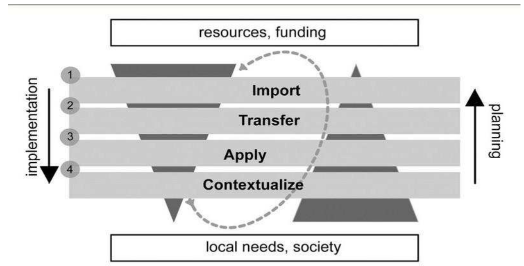

Fig. 2. CATI MODEL FOR CONTEXTUALIZED DEVELOPMENT [20].

C. Design cycle

A metaversity can further enhance the widely used CDIO framework for SE education in the context of Africa, because of its particular challenges identified in the Relevance cycle. Collaboration with the current CDIO framework is usually through local industry members. This has its merits such as possible access to physical industry resources like computers. However, local collaboration can also be limiting as local African companies may not be internationally competitive so the skills students are learning and taught will not hold up when compared to the world at large. Integrating metaversity with the CDIO model would solve this problem as it would give universities and companies more ways to collaborate using metaversity technology and the expertise it gives access to. This technology can be used throughout most phases of the CDIO model. The table below shows which metaversity aspects can be applied to the various CDIO stages and their varying impacts during the different CDIO stages. The levels of impact are divided into Low, Medium, and High.

Table 2. INDUSTRY-UNIVERSITY DISCONNECT.

CDIO Stage	Extended Reality	Serendipity	Freedom to explore	Loose structures	Learning by doing and by being	Imaginative inspiration	Bottom-Up approach	Multiple locations
Conceiving	H	H	H	L	H	H	L	H
Design	H	H	H	L	H	H	M	H
Implement	H	H	H	M	H	M	M	H
Operation	L	L	M	L	L	L	L	H

The extended reality aspect of Metaversity is important in the first three stages of the CDIO framework as it gives the students, lecturers, and industry stakeholders access to more ways to collaborate and communicate with each other using VR, AR, MR, XR, and RP technologies. *Serendipity* is also important in the first three stages of the framework as it enables the students to experiment and come up with various solutions without time restrictions on access to the metaversity. This is an important factor as students will be able to access their metaverse projects at any time. Metaversity encourages *Learning by doing and by being*, which is an important aspect of SE as it gives students real practical experience compared to a theoretical approach. Students are encouraged to follow an *Imaginative inspiration* in the metaversity, the artifacts designed are virtual and can be changed which gives a learning software engineer the freedom to Conceive and Design a product using non-standard techniques. Because the metaversity is set up with *multiple access locations*, SE students can access it in the comfort of their homes or at a physical university base near them, making it highly accessible.

Meetings between industry and university personnel can be done using metaversity technology: RP can be used to virtually transport the students to the environment where the problem to be solved is, giving them a better understanding of the working context. After requirements have been gathered, designs and the final product can be done within the metaversity environment and shown in the physical world using XR/AR, the designs can be put through extensive scrutiny as the scrutinizer will be able to visualize the product better and drill down on the designs while interacting with it in a 3-dimensional manner.

Example scenario: A company X in the Global North has a problem with its current inventory tracking system. The system does not clearly track the path an inventory item moves through the company's various sections. The system requires a redesign. Company X works closely with a university in Africa following the metaversity model and wants the SE students to redesign the inventory tracker. The students accept the task and visit company X virtually using remote presence so they have a better feel of the way inventory moves around the company. They then use a virtual reality environment to Co-Design the system with students from multiple separate campuses. Company X stakeholders are invited into the VR environment to view the proposed designs of the system and give their opinions. They can clearly see the flow of the project and observe the designs intensely in the VR. The students physically working together can present the designs to each other using AR, and when done can present the solution to the client.

V. Discussion

Software engineering is one of the fastest-growing industries in Africa, it is a billion-dollar industry with the potential to positively impact a country's GDP. With the way SE is currently being taught in most institutions in Africa, SE graduates lack the competencies to capitalize on the growth of the sector, because there is a disconnect between their skills and the industry standard and requirements of the users. This was a problem not just in Africa but worldwide. MIT developed the CDIO model to bridge the disconnect. However, African institutions are resistant to adopting contemporary teaching models. In fact, only two African universities, the University of Johannesburg and the University of Pretoria follow the CDIO model, while the rest of the universities in Africa still follow an outdated theoretical approach.

We have designed a modern approach whereby software engineering education can be based on a novel model of a university, called metaversity, based on the metaverse. The model is a cross of a top-down approach where the universal state-of-the-art knowledge and technologies are available by extended reality and remote presence requiring 5G connections and a bottom-up approach where the students learn by solving real-life problems at the grassroots. The model allows a higher education unit for software engineering education to be located anywhere and thus bring the expertise onto the ground.

Sustainability factors. The model is sustainable, as defined by the Brundtland report [23] by dimensions of economy, environment, and socio-cultural setting. First, while it consumes mobile resources, it does not require the investments in and facility management of massive buildings serving only a limited set of purposes. It also can make use of not only dedicated faculty but shared human resources, startups, and industry. Secondly, it can be made environmentally friendly and sustainable when designed carefully, especially along the lines of green computing. Thirdly, when engineering education is taking place in a given context, the graduates learn to think and act in a way that is socio-culturally meaningful. Fourthly, even if not part of the original scheme of sustainability dimensions, the model is ethically sound because it can use modern approaches, such as blockchain, for a fair share of every stakeholder's contribution.

Design-reality gap. Heeks' design-reality gap also clarifies the strengths of the revised model for software engineering education. Rather than following the usual path of importing a given curriculum from another context, very different from the target environment of the intended education, our metaversity model designs and delivers education in the given real-life, or target, context, thus avoiding the gap between the separate contexts of design and delivery. For example to reduce the Design Reality Gap in organizational factors the Metaversity is governed by a Bottom-Up approach meaning students are involved in decision making instead of a top down approach where students opinions are sometmes not heard. The Gap in staffing and skills is also limited by following the CDIO model to ensure that there is constant collaboration between industry and academia.

Limitations to the study. This was a theoretical and conceptual study, no primary data was gathered in the form of surveys or tests to confirm the model. However, the used secondary sources are based on empirical data gathered for mapping the realities in Africa.

Future research. Designing an initial prototype of the metaversity in an African setting using Bauhouse designs inspiration.

Recommendations to practitioners. While software engineering educators might prefer to make use of universal curricula and related learning resources, the metaversity approach requires a bold pedagogical soul that wants to explore and, in fact, make use of advanced technology to co- create learning resources with the students. University administrationis required to be accommodating, flexible, and service-oriented in order to impliment the Metaversity. The approach also requires adaptation from students that need to be aware of the pedagogical approach followed.

Generalization to engineering education. While software engineering forms a part of the engineering that does not require huge laboratories or massive equipment, some of the ideas of our model can probably be applied also in other engineering disciplines, like electrical and mechanical engineering or engineering the built environment. Our model can make advanced use of modelling and simulations which would even attract ordinary people at the grassroots to co-design solutions with the students and experts.

VI. CONCLUSIONS

We have proposed how the modernized and updated concept of university – that we call metaversity – can enhance software engineering education, especially in Africa. A bold shift to the metaversity as the academic platform for software engineering education will make Africa a global pioneer in training engineers that get inspiration from local challenges and learn to solve them by using the best expertise available.

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