CREATION AND ACCEPTANCE OF LOW-THRESHOLD MOBILE TRAINING ON SUSTAINABILITY IN CONSTRUCTION

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ABSTRACT: *Many recent developments in mixed reality applications are exploited for research on improving training in the construction industry. While immersive technologies offer indisputable advantages over classic paper- or multi-media-based training material, access to this kind of technology is still very limited in the academic world and even less widespread in industry. In this paper, the authors follow the current trend of creating low-threshold micro-learning nuggets, which are easily consumable on mobile devices but can be accessed in every web browser. This is essential to reach the construction trade workforces, which for the most part will own a smart or mobile device, but neither specialized equipment, nor will there be time or patience for a lengthy setup phase before learning content consumption. The learning content aims to give construction workers a clear vision of what some of the fundamental components of a sustainable construction site should look like and what role they play in achieving the said vision. The learning content revolves around the initial idea of DGNB certification (German: German Sustainable Building Council), waste management, certification of construction wood, handling of harmful substances and chemicals and some general health and safety regulations that impact the emission of dust, noise and vibration. The paper describes the general approach of the planning, orchestration of learning material, development of the learning nugget, and deployment, as well as a study for acceptance and user experience.*

KEYWORDS: *DGNB, continuous education and training, micro-learning nuggets, responsible consumption and production, smart and mobile devices, sustainable construction, ubiquitous learning, workforce.*

1. INTRODUCTION

The construction industry plays an important part of the European economy, employing over 13 million people (6.6% of the EU employment) (CEDEFOP, 2023). The sector's related effects in other industries are known, for decades, to be extensive as the entire value chain from sourcing over to fabrication and final installation, maintenance and operation, and reuse of products consume enormous amounts of raw materials and energy. As such, 13.5 million other jobs in supplier industries are directly impacted by construction in Europe. In brief, the entire life-cycle chain in the built environment involves, to name a few resources, substantial plant environments, complex products, purposed machinery, and specialized trades with skilled personnel across industry sectors.

While construction is generally seen as a catalyst for stability in economies around the world, it is also viewed in the public perception as one of the most important areas for the green transition, as it is responsible in large amounts for energy consumption contributing to waste and emissions (Teizer and Wandahl, 2022). Yet, in Denmark, the Renovation Wave and the New European Bauhaus, supporting building and infrastructure facilities in the entire of the Europe Union (EU) in becoming smarter and greener, construction significantly contributes to the green transition through large-scale installations of wind farms (EU 2020b). However, Denmark and other countries have realized that sustainable construction plays a significant role in achieving the 30% emission-reduction goal by 2030 and becoming climate neutral by 2050 (DEA, 2023).

While construction remains one of the least digitalized sectors in the EU, new digital technologies will shape it with increasing intensity. Demand for highly qualified workers is growing steadily, as will the skill needs for medium- to low-skilled occupations to learn and practice sustainable goals (UN 2023b). Job surveys, conducted for example by CEDFOP (2023), highlighted substantial training needs for construction workers. Many workers' skills are not well-utilized, which is especially true of construction's significant migrant workforce. Yet, new and far more complex rules and regulations in the built environment demanding ever stricter compliance of construction materials or products, or their integration into installation and maintenance processes, make it even more challenging for the workforce to keep up with state-of-the-art knowledge and practices. All reasons above call for additional learning tools that can create or attract and retain skilled and tech-savvy personnel.

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The following research questions indicate the objectives of this paper:

- While policy makers often force change through top-down approaches, what bottom-up initiatives can be taken to stimulate change by sustainable behavior?
- Who are the suitable recipients and what are the key focus areas of learning sustainable goals?
- How can awareness among the construction and real estate sector's workforce be created with a tool that is simply to use and still actively engaging them in a learning exercise?

2. BACKGROUND

2.1 Policies on climate forcers

The construction and real estate sector is one of the main sources of emissions globally. Typical new construction and renovation processes use various types of equipment, numerous sophisticated raw material or product resources, and a workforce that is highly specialized in their trade discipline. Yet, combined use in inefficient and wasteful building or operation processes, contributes significantly to different forms of waste and pollution, and irreversible consumption of quite significant amounts of energy (Andrade and Teizer, 2023). In the European Union (EU) alone, the sector is responsible for over 35% of the EU's total waste generation and an estimated 5-12% of total Greenhouse Gas emissions (EC, 2022). On a global mission, according to DGNB (2023), a German non-for-profit organization named "Deutsche Gesellschaft für Nachhaltiges Bauen e.V." (English: German Sustainable Building Council), there is further potential for action in the construction and real estate sector as it is also responsible for:

- 30% of worldwide resources consumption,
- 40% of worldwide energy consumption, and
- More than 30% of worldwide carbon emissions.

Consequently, the urgent need for greener construction is being addressed by several world climate agendas such as the European Green Deal, which aims for climate neutrality by 2050 through the green and digital transformation of EU sectors (EC, 2020a).

2.2 Practices in the construction and real estate sector

Three selected examples from Europe, Germany and Denmark point to the significance of the problem and show that the potential impact of bottom-up approaches, for instance, e-learning tools, can be high.

Example from Europe: According to official reports, only 11% of the existing building stock in European Union undergoes some level of renovation each year (EC, 2020b). However, very rarely (1%, weighted annual energy renovation rate) do building renovation works address the energy performance of buildings, and worse, only 0.2% of building renovation projects reduce their energy consumption by 60%. At this pace, the report concludes that "cutting carbon emissions from the building sector to net-zero would require centuries." It is time to act.

Example from Denmark: Avoiding wasteful and energy-consuming construction, less than 3% of the Danish building stock is built newly on an annual basis. The vast majority of Danish projects in the built environment are already renovation efforts to make its buildings more sustainable. Moreover, most of its existing building stock has reached the age for renovation: Over 80% was built before 1990 and over 75% of the total floor area can be attributed to residential buildings (Statisics Denmark, 2019; Wittchen and Kragh, 2016). Additionally, Danish society, and presumably societies around the world, is becoming more and more aware of the negative environmental impact of our living environments. Almost 50% of the annual energy consumption (Nordic Energy Research, 2023) and nearly 12% of annual CO2-emissions can be attributed to households (Statistics Denmark, 2023). By far, the majority of energy usage in a building takes place during its operational lifetime. In this combination lies a vast challenge how can we improve the performance of our building stock on a scale that meets the now urgent and strict energy requirements?

Example from Germany: Construction and demolition in Germany in 2017 caused 220 million tons of waste, 53% of all industry sectors' combined waste (SB, 2023). A fraction of the waste, while its raw material components are valued highly, is typically recycled (Circle Economy, 2022). Note, while this number includes the demolition of bulk material in road infrastructure, the principles of circularity in the construction and real estate sector yet have to arrive in full swing. Subsequently, as part of the Sustainable Development Goals (SDG 12) (UN, 2023), the sector can benefit from responsible consumption and production. The proposed learning tool addresses some of

these goals, see italic text:

- *Sustainable management of natural resources, recycling and reuse*
- *Waste reduction*
- *Avoidance of hazardous substances to air, water and soil*
- *Reuse of components*
- Design for disassembly
- Use of natural resources
- *Awareness for sustainable development*

2.3 Sustainability certificates and target group

While the World Green Building Council has many initiatives around the world, for example, LEED and Green Star, DGNB was founded in 2007 and is Europe's biggest network for achieving sustainable buildings. It is a non-profit organization (NGO) that aims to identify and promote solutions for the planning, execution and use of buildings and communities in order to achieve a sustainable future (DGNB, 2020). Pooling and sharing knowledge, translating sustainability into practice, and sensitizing the general public are its key objectives. As of February 26, 2020, DGNB has more than 2100 members that are comprised of 20% architects/planners, 16% engineers, 21% manufacturers, 17% others, 10% project managers/consultants, 9% investors/developers, and 7% building contractors (DGNB, 2020). DGNB, like the other initiatives mentioned, offers expensive certification courses for a wide range of users, incl. practitioners, consultants, and even students.

The representation of the building contractors in DGNB, and moreover, the large number of personnel it employs, including but not limited to laborers and site superintendents, and supposed to be more than any of DGNB's membership, would be the ideal and predominant use group of the proposed learning tool. In Europe, the construction sector as a share of total employment in the European Economic Area varies by country between 4-10% (Statista, 2023).

2.4 E-learning-content creation in construction and engineering pedagogy

The previous sections have shown, policy and practice differ widely. While behavioral change is one approach to create awareness, yet, hardly any learning tools exist that actively engage the personnel at the workplace. While many methods exist to engage the construction workforce with learning (Wolf et al., 2022), *E-learning (EL),* defined as conducting learning via electronic media, typically on the Internet, depends on the self-motivation of individuals to study effectively.

In the context to construction applications, the effectiveness of EL has been widely studied in safety training and construction management (Lee et al., 2014). Ho and Dzeng (2010) reported a positive impact on Taiwanese labor. Bokor and Hajdu (2014) focused in creating interactive content, incl. use of videos, to facilitate better understanding. Likewise, Lu et al. (2023) investigated the learning curves of participants in modular construction. Kim and Santiago (2005) focused on the instructional development process through the impact of educational technology. Clevenger and Ozbek (2013) and El-Adaway et al. (2014) both addressed service-learning concerning evaluating sustainability competences in the engineering curricula. However, their work made not much use of EL. Similarly did Love et al. (2015), while examining collective learning by coaching, not focus on sophisticated technical aids.

A few other teaching methods are reviewed rather in brief to let readers understand the differences what they offer:

- *Game-based learning (GBL)* is where game characteristics and principles are embedded within learning activities that reward and motivate the participant to think critically. In construction, Oo et al. (2016) focused a game on cost estimation and bidding and Sacks et al. (2007) on reducing waste in construction by applying lean principles. Teizer et al. (2020) utilized Internet of Things (IoT) technology in a serious game for the purpose of identifying and eliminating waste during the construction operations. Jacobsen et al. (2021) extended their work to multi-user GBL-experience in Virtual Reality (VR). Few studies exist to GBL with regards to sustainable design and LEED or equivalent concepts; Dib et al. (2012) is one of these. However, Dib et al. (2013), Ayer et al. (2016), Castronova et al.'s study (2017), Dancz et al. (2017), Clark et al. (2021), most of the studies use university students for evaluation. A late criticism, practitioners should be used instead, was raised by Adami et al. (2023).
- *Problem-based learning (PBL)* uses complex real-world problems as a vehicle to promote student learning of concepts and principles as opposed to direct presentation of facts and concepts. It stimulates

finding and evaluating research materials, critical thinking skills, problem-solving abilities, and communication skills. PBL is often practiced in the format of groups, as seen in architectural studios and construction management courses at universities (Williams and Pender, 2002), and life-long learning workshop exercises or seminar series in industry (Duch et al, 2001).

- *Mobile learning (ML)* is education or training conducted by means of portable computing devices such as smartphones or tablet computers. Among studies investigating m-learning technology acceptance (Al-Rahmi et al., 2021), Wolf et al. (2023) investigated construction product quality by utilizing mobile Augmented Reality (AR) technology.
- *Life-long learning (LLL)* is a formal or informal approach to personal or professional learning that is continuous and self-motivated. Froehle et al. (2022) studied civil engineering skills development in LL using semi-structured interviews. Gao et al. (2022) explored the drivers and barriers of LL in construction, Salajan and Roumell (2021) outlined a holistic view of LL for European learning opportunities and promoted clearer links across educational pathways and sectors, incl.
- *Micro-learning and Nuggets (MLN)* focus on learning by creating concise and bite-sized chunks of information. Nugget learning is a subset of micro-learning that focuses on the development of personal nuggets or mini-lessons at the end of each unit (Ploder et al., 2021). While recent research focuses on the emergence of technology for MLN and how it can perfectly address the next-generation workforce's learning needs (Nanjappa et al., 2022), delivery of MLN in the context of construction applications, including sustainability, has yet to be explored in greater detail.

Several other studies in the architecture and civil engineering domain focused on the effectiveness of education, for example, Vorster (2010) and Mostafavi et al. (2013). Yet, they fall short in explaining the role of advanced technology in education and training. These limitations indicate a vast, and still unexplored, opportunity for leveraging technology in learning, as recently shown by Wang et al. (2020) and Wolf et al. (2022).

3. METHODOLOGY

Based on the concepts and related work mentioned in the background section, the methodology section introduces the exact goals and requirements for the training application, was well as the theory behind both the learning and gamification content. Figure 1 shows the general approach, which is derived from the common SCRUM practice in software or product development.

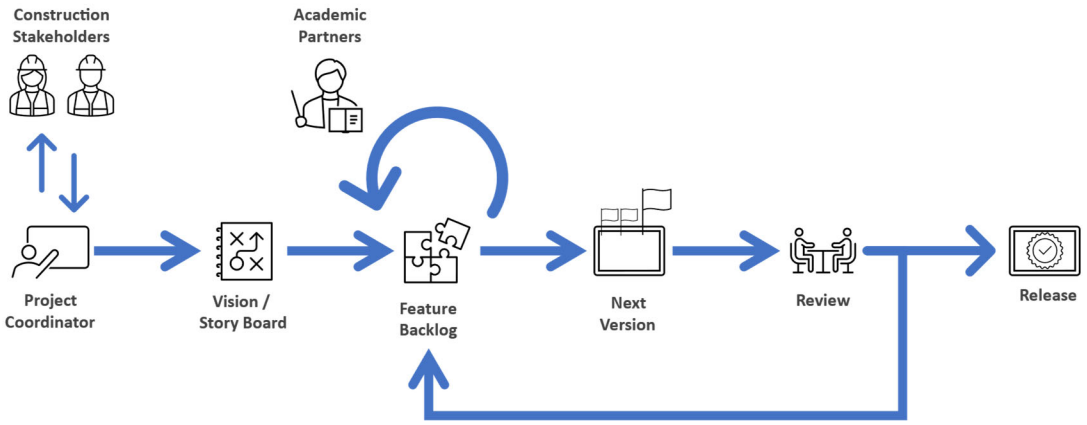


Fig. 1: Development approach for the training application.

The motivation for the training application is based on the needs of stakeholders from the Danish construction sector. A central project coordinator assures the alignment of goals and requirements, as well as providing the solution to the stakeholders after the development. The vision and storyboard are developed with the academic partners after which the iterative development itself starts. A feature backlog is derived from the story board, with each feature being developed as a singular entity. Once enough features are finished, the next version of the training application is released for review with the project coordinator, who keeps contact with the construction sector stakeholders. This loop is repeated until the feature backlog is empty so that every feature from the vision is implemented to sufficient standards. After that, die release version of the application is compiled and provided to the project coordinator.

3.1 Goals and requirements

The goal is to create a learning application that is easily consumable on mobile devices but can be accessed in every web browser if need be. Due to the ubiquitous availability of smart mobile devices and the ease of use of scanning i.e. QR codes, the mobile view is the favorable focus. The target audience is construction workers with basic training and at least prior experience regarding waste sorting on a construction site.

The requirements were to create a fun training, uses gamification elements and transports some core rules for sustainable construction. The five main talking points are: Waste sorting on the construction site, certified wood use, handling of hazardous substances, health and safety regarding dust, noise and vibration exposure and the reduction of energy consumption. The story-board for the training was developed in a virtual whiteboard by both construction experts and academic staff in an evolutionary manner, iterating ideation, creation and feedback for each section after the initial story development. There is no integration into an existing Learning Management System, no user management or login required to use the training, no persistent data storage, especially not on personal information and the final product should be hosted on any regular webserver without special setup.

3.2 Content and structure

The learning content itself is very limited in this context, as the target audience should have prior knowledge in most fields touched upon in this training. It is assumed that the training acts more like a refresher of that long-term knowledge and a reminder of the importance of the acts of each individual.

To minimize the time needed to read texts on the smart device, each section is introduced by an animated character video-narrated by a voice actor. The following take-away messages and key points were chosen for the training.

3.2.1 Introduction

Awareness for the impact of the way most industrialized nations work is one of the main goals of this training application. The introduction therefore lays the foundation by stating that, if scaling Denmark’s energy and resource consumption up to the world population, the world’s yearly available raw resources would be consumed 420%, or within weeks instead of a full year. Therefore, the goal is to become generally better at reusing, recycling, and recovering, in order to reduce the consumption of raw materials, in this case in the construction sector specifically. As stated earlier, the DGNB certification is a comprehensive tool that creates guidelines for a building's environmental, economic, social, and technical quality. Many clients are demanding DGNB-certificated buildings and it is therefore important that craftsmen not only follow those guidelines but understand their impact. Therefore, the introduction offers a perspective of what can be done in everyday life on the construction site.

3.2.2 Waste sorting

Denmark’s goal for 2030 is to re-use, recycle and/or recover a minimum of 70% (weight percent) of raw waste materials. In order to reach this goal, there is a need to ensure efficient and correct material sorting on the construction site. With efficient sorting and reuse, the reduction of the currently excessive consumption is more easily achieved. While providing some background with the animated character videos, the waste sorting section should offer an active exercise in waste sorting as depicted in Figure 2. While most sorting tasks of raw materials seem obvious (metal into the metal container, wood into the wood container, etc.), the edge cases are the important ones to reduce waste and/or problems further down the recycling path. For example, metal buckets with leftover paint belong in the correct waste bin for harmful chemicals, wet sheetrock can not be recycled easily and should be separated from dry sheetrock and reinforced concrete belongs to regular concrete and not to general metal.

3.2.3 Certified wood

For valid certification of a building, every raw material has to be certified too. It is up to the craftsmen to validate those certifications on the material that arrives at the construction site. For the wood sector, Denmark generally uses two internationally recognized systems for FCK and PS3 from forests with Skovbo for the benefit of present and future generations. This quiz offered in this section should put the user into the perspective of a worker tasked with receiving a batch of wood. Before signing the delivery note, the user must identify the correct certification marks or decline the delivery completely. This step in particular is quite harsh in reality and awareness of the importance of correct certification needs to be established as the “higher goal” instead of “just keep working, it’s just wood”.

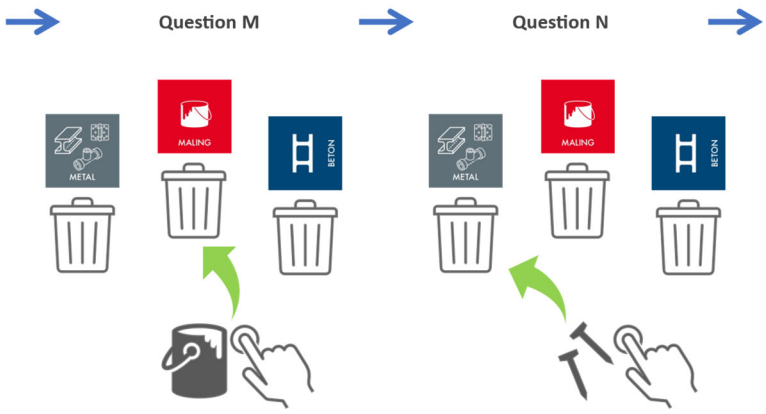


Fig. 2: Sktech of a dragg and drop quiz for waste sorting.

3.2.4 Hazardous substances

While there is great value in being able to reuse materials, if the materials used on the construction site contain chemicals, they usually cannot be used in other contexts where health factors play a greater role. Awareness of the most common harmful substances is essential, as well as which substances are suitable for use on the sustainable construction site. There is a considerable number of valid certifications that can be found on the chemical's containers and, once again, need to be recognized by the skilled craftsmen. The quiz in this section demands the user to judge the sustainability of certain chemicals, like paint for example, based on the packaging and once again to decide whether to accept or decline its use on the construction site.

3.2.5 Dust, noise and vibration

Health and safety play a major role on the construction site. Sustainability also encompasses a safe working environment and the awareness for dangers is one of the most crucial factors in preventing accidents. Especially the awareness of the accumulating severity of seemingly minor hazards like exposure to dust, noise, and vibration are put into focus in this section. Not only is the protection relevant for the workers conducting the operations but also for their coworkers and the surrounding neighborhood. The importance of reducing the noise, dust, and vibration at the source as much as possible and the awareness of restrictions regarding how much and when workers are allowed to apply the mentioned procedures are mediated with easy-to-follow videos and examples.

3.2.6 Energy consumption

Energy consumption is a key metric in every sustainability initiative. In the future, the EU taxonomy will include technical audit criteria for a wide range of activities related to energy supply and consumption on- and off-site construction. It is therefore important that craftsmen prepare for their future tasks, especially since more equipment and machines, incl. hand-held power tools become electric and battery-powered. Likewise, fossil fuel consumption is to be reduced, for example, idling vehicles present a significant waste and contribute to poor productivity. Moreover, excessive energy use to heat temporary office containers plays a critical role during late fall, entire winter, and early spring times, and as such, does cooling during summer times. Lighting of the construction site to ensure sufficiently safe walking pathways and workplaces, or providing a pleasant work desk atmosphere also contribute to energy consumption. While the implementation of Light Emitting Diodes (LED) have substantially reduced the energy needs, yet not all construction sites make use of it, and those who do, can either optimize their use and may at least need to become familiar with the appropriate recycling guidelines.

4. IMPLEMENTATION

In the following paragraph, the tools used to create the low-threshold training are presented, followed by the detailed description of the created content. The main editor for the created training is Microsoft PowerPoint 365, which is enhanced by the use of an E-Learning content management addon called iSpring Max. The latter allows the creation of interactive content and the compilation of the final product into HTML5 plus JavaScript, to be consumed with both mobile devices and PCs. The training could also be compiled into a so-called SCORM (Sharable Content Object Reference Model) package, so that it may be imported into regular learning management systems (LMS) as a separate activity in a more extensive learning path or e-learning course. When deployed as

HTML5, the hosting is identical to any static website, meaning a regular webserver will suffice for hosting and displaying the training.

For media creation, the assortment of applications of the Adobe Creative Cloud were used, most notably the Adobe Character Animator, which allowed the creation of the animated avatar and the voice acting to be conducted separately. The created avatar is depicted in Figure 3, showing some of the animations and the active lip sync.

Fig. 3: The created avatar as used in the Character Animator.

The avatar was chosen based on the stakeholders wishes, but can be switched out very easily if need be, while keeping the animations, triggers and the eye- and body-movement. When switching out the graphical representation, usually, the audio changes too. In that case, the lip-synchronization can be recalculated to match the graphic and audio representations.

Figure 4 gives an overview of the structure and the logic implemented in the training application.

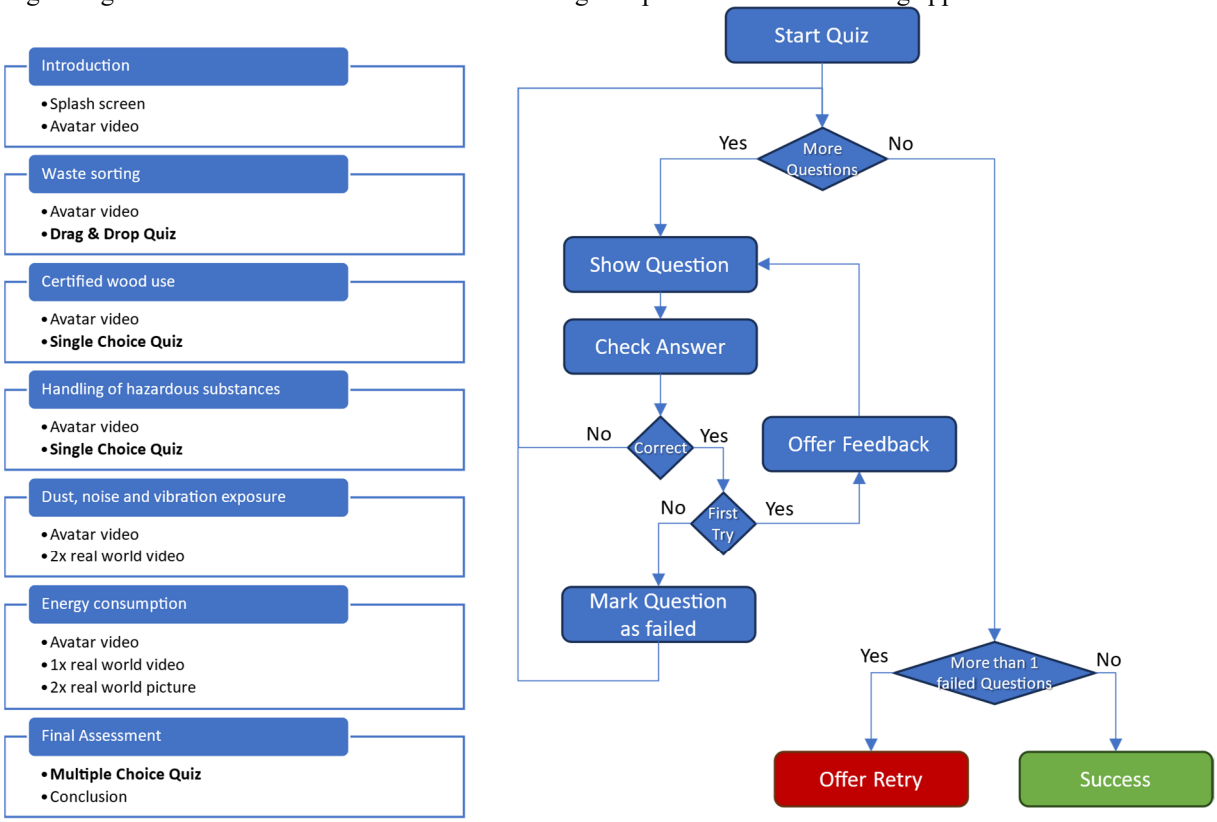
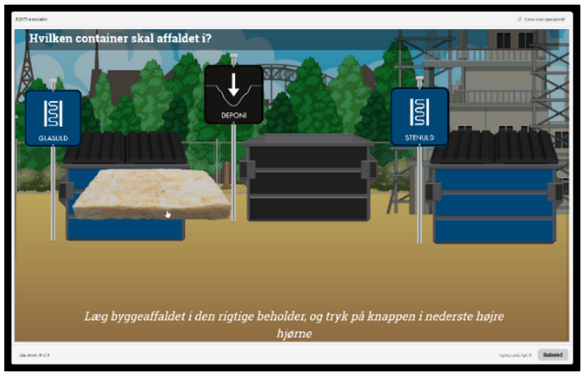


Fig. 4: Structure of the training and implemented quiz logic.

The initial introduction is done with a splash screen, followed by an avatar video. A splash screen is omitted in the sections, as an avatar video represents both the switch to another section, as well as providing background information and an introduction to the topic. Quizzes in the following description are all uniform in their way of providing feedback and explanation right after confirming in the answer and offering a second try, in case the given answer was wrong. After a second wrong answer, the question is marked as not successful. Each quiz only allows a single question to be answered not successfully, with unlimited attempts for each quiz. When finishing a quiz successfully, the next section is unlocked.



(a) Waste.

(b) Certification.

(c) Environment.

(d) Health and safety.

(e) Emissions.

Fig. 5: Training challenges: (a) waste sorting, (b) certified wood, (c) hazardous substances, (d) dust, noise and vibration, and (e) energy consumption.

4.1 Waste sorting

After the avatar video, the trainees are presented with the first quiz (Figure 5a). The quiz focuses the correct assignment of material to recycling bins or containers, with narration at the start of the quiz to clarify task and functionality. There are eight questions in the quiz, which are simply solved by dragging and dropping the waste to the correct bin.

4.2 Certified wood

After the avatar video, the trainees are presented with a real-world video, showing a truck delivering construction wood (Figure 5b). The quiz then revolves around the identification of relevant certifications. Several life-like delivery documents are presented and the trainees must choose to either accept or decline the delivery, based on the provided certification.

4.3 Hazardous substances

After the avatar video, the trainees are presented with the third quiz (Figure 5c). There are six different typical chemicals, which are regularly used on construction sites, and the task is to check for the correct certification.

4.4 Dust, noise and vibration

After the avatar video, the trainees are presented with two real-world videos and instructions with narration regarding health and safety regulations (Figure 5d). As Health and Safety Trainings are regularly conducted, there is no quiz in this section.

4.5 Energy consumption

After the avatar video, the trainees are presented with two real-world videos and instructions with narration regarding health and safety regulations (Figure 5e). As health and safety trainings are regularly conducted, there is no quiz in this section.

4.6 Final

The final of the training is a quiz of four questions with a summary of the training at the end.

5. STUDY AND PRELIMINARY RESULTS

According to studies of Wolf et al. (2022) and Adami et al. (2023) practitioners as participants that evaluate the application matter. While the evaluation of the testing with an initial group of dozen practitioners is pending, preliminary comments that both workers and construction site staff left with the authors indicate that the developed application is technically sound to communicate the relevant content to the participants. The participants claimed to have known most, but not all of the content, thus receiving some value from using the application. While neither personal data about the participants nor IP-addresses of their smart devices accessing the application were collected, completion rate and time spent when navigating within application was recorded. Preliminary data indicates that participants stay within the envisioned time span of less than 15 minutes to complete the application. Abortions before ending the application were very low, probably due to the application still being novel. Yet, few participants mentioned that additional or variations of the examples within each module could help make it more attractive or revisit in the future or as part of continuous training short courses that they also recommended. One participant expects that repetitive use of it “makes some of us [workers] change thoughtless behavior”. Yet, the authors recommend the application for extensive testing with structured evaluation methods, utilizing, for example, anonymized pre- and exit surveys and/or interviews, and, perhaps, accompanied by behavioral observations of workers on the construction site. In addition, a verbal review meeting with site management staff who also acted as participants, revealed that demographic developments in the construction industry need to consider as well. While smart and mobile devices offers a communication style that attracts younger workforce and subsequently increases the chance that workers accept to participate, offering multiple international languages prevalent in the target country might be required, especially for migrating workforces that are not familiar with the local language. Likewise, the dependence on a voice actor while listen to the application may require a quiet space or headphones to operate it. Overall, preliminary results demonstrate technical feasibility and the workforce seems to accept the delivery method.

6. CONCLUSION

The tools mentioned in the implementation section allowed for a rather quick implementation of the desired training. While the technical and content goals were met, several quality-of-life requirements, which came up during the implementation process, could not be implemented due to restrictions in the frameworks, applications or time constraints. Most revolved around the exact depiction of feedback in the different quizzes or certain behavior regarding user interaction. Some of the preliminary results to a study showed that technology to create an effective learning nugget for achieving sustainability goals in construction exists. This can be used to counter the general trends in the construction workforce that can be named: significant labor shortage in certain trades, often replenished by migrant personnel, joining construction initially with limited skills or awareness. Future work will encompass the creation of multilingual trainings in the now focused field, as well as the creation of a larger scope training, based on multiple micro-learning nuggets, which will allow more room for learning content, media and assessment of learning outcomes.

7. ACKNOWLEDGEMENT

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