



# A snapshot review of future-oriented standards for cement, admixtures, and concrete: How Africa can spearhead the implementation of green urban construction materials

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Received: 11 January 2023 / Accepted: 31 March 2023 / Published online: 17 April 2023  
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## Abstract

The existing cement and concrete standards are not capable of making full use of the current technology capacity due to strong focus on conventional concrete and thus they are not fit for the current and future challenges of construction industry. The paper highlights shortcomings with regard to the implementation of the existing standards. It can be seen that future-oriented standards are generally required to contribute to a lower-carbon footprint of the industry. These changes are significantly more relevant in sub-Saharan Africa, due to the rapidly increasing urbanisation challenge and the enormous potentials to develop lower-carbon technologies than elsewhere in the world.

## Introduction

Concrete has become an integral part of construction technology, due to its outstanding structural properties, versatile applicability, and global availability. It is a mixture of coarse aggregates that are bound by a mineral cement paste, typically Ordinary Portland cement (OPC) mixed with water. OPC is composed mainly of lime (CaO), silica (SiO<sub>2</sub>), and alumina (Al<sub>2</sub>O<sub>3</sub>). After sintering at approximately 1450 °C, the so-called clinker is formed, which has to be ground and blended with calcium sulphate as a set retarder to form OPC.

Since the invention of OPC, concrete has been considered as a system of cement, water, and coarse aggregates, where the strength providing phases are calcium silicate hydrates (C–S–H). In this simple 3-phase system, the workability, strength, and durability depend upon the cement content and the water to cement ratio (w/c), with a lower w/c yielding higher strength but reduced workability. This context has

been fundamental to most standards and mixture proportioning recommendations today [1].

However, in the past decades concrete technology has evolved and the material has changed towards a multi-phase system, which contains supplementary reactive or inert mineral fillers (such as fly ash (FA), ground granulated blast-furnace slag (GGBS), or limestone filler (LSF)) [2–6] and organic admixtures that can manipulate a variety of fresh and hardened concrete properties [7–10]. The most important group of admixtures are superplasticizers (SP), which adsorb on particles' and hydrates' surfaces for better dispersion. This enables the use of a lower w/c to achieve higher strength values without compromising the flow properties [11–13]. These components that interact with the cement hydration on the micro- and nanoscopic scale, respectively, have significantly advanced and widened the range of technology potentials. Today, concrete engineers can choose between strength values ranging from 15 to 200 MPa and consistencies that can vary between earth moist and self-levelling. In return, the higher number of interacting constituents has increased the complexity and reduced the application robustness [14, 15]. Modern concrete, therefore, fundamentally distinguishes from past concrete, but current standard systems build up on concrete knowledge that was developed several decades ago.

In addition, concerns of the sustainability and environmental aspects of cement and concrete industries have come to the forefront [16–18]. Cement production is responsible for 8% of the global carbon emissions and cement makes out

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about 80% of the carbon footprint of concrete. In return, concrete is nearly half of the total anthropogenic mass [19], so that the carbon emissions are owed to the enormous global production volumes. To minimise the carbon emissions, OPC has to be partially replaced by supplementary cementitious materials (SCMs) and fillers that can reduce the overall clinker in concrete, and SP has to be used to enhance the binder performance. SCMs can have three fundamental reactions. Inert materials such as LSF do not actively interfere with the cement hydration, but they improve the packing density and become reaction seeds. Latent hydraulic materials contain CaO and can be binder, but they require the limewater of the cement hydration to spark the reaction. Pozzolanic materials do not contain significant amounts of CaO and therefore require  $\text{Ca}(\text{OH})_2$  to form C–S–H. Any of the three SCM types can help to reduce the OPC content significantly, but still require a small amount of 20–50%.

In response to these developments, the variety of different OPC-based binders has grown. The European EN 197–1 and 197–5 distinguish between 39 different cement types, each having its own strengths and weaknesses, but every type is calibrated to the performance of traditional OPC. Hence, the current standard system significantly limits the variability of materials that reduce the carbon footprint. Although modern concrete types require a vast variety of performance specifications depending upon application technology and structural demands, the standards are not flexible to use binders that significantly deviate from OPC in their performance. In addition, standards struggle with the apparent incongruence between the traditional standard focus on high safety, where more material or binder is better, and the novel demands for sustainability, where often less material or binder are required to minimise the carbon footprint.

From foregoing, the currently applied cement and concrete standards are not capable of making full use of the current technology capacity and they are not fit for the current challenges and yet unknown technology developments in the future [20]. Future-oriented, performance-based standards are generally required to contribute to a lower-carbon footprint of the industry [21]. They are significantly more relevant in sub-Saharan Africa (SSA), due to the pressing urbanisation challenge and the enormous potentials to use locally abundantly available resources for lower-carbon emissions [22, 23]. The biggest cities in the world by population will grow on the African continent. 80% of the urban construction that will have taken place by 2050 has not yet been built, leaving no time to waste to build these structures in a more sustainable manner [24].

The unnecessary use of concrete in general must be avoided. This can happen by avoiding architectural visions that are wasteful [25], and by more reasonable structural design [26]. This also requires to re-think the established safety concepts for structural design by balancing today's

safety demands and the demands of future generations. In addition, greener construction materials have to become integral part of construction technology. This comprises

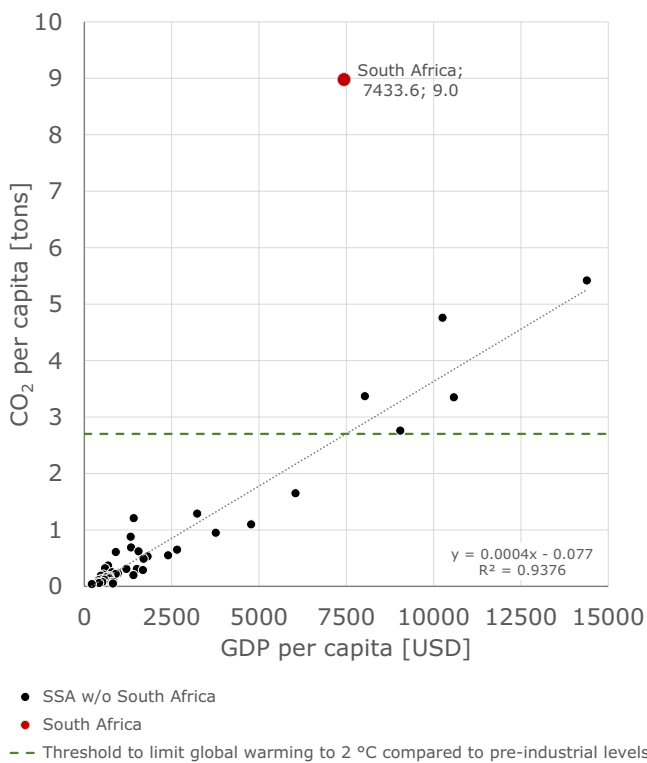
→Construction materials based on renewable materials, such as timber, bamboo, or straw. Here particularly fast regrowing biomass is of interest, due to their potential to become carbon neutral. Timber should be seen as critical in this context, since timber takes several decades to regrow and the resources on a global scale are limited. Due to the vast availability of biomass in SSA, these technologies need attention [27].

→Processed construction elements that are fully or partly composed of biomass, such as plaster, mortar, boards, or tiles, that include mineral binders with bio-based aggregates, such as hemp shivs, rice husks, or straw. These materials help to replace primary resources with carbon-neutral components, but have to be used with care, since alternative use of the biomass needs to be considered, e.g. if it can become animal feeding or serves to improved agricultural yield.

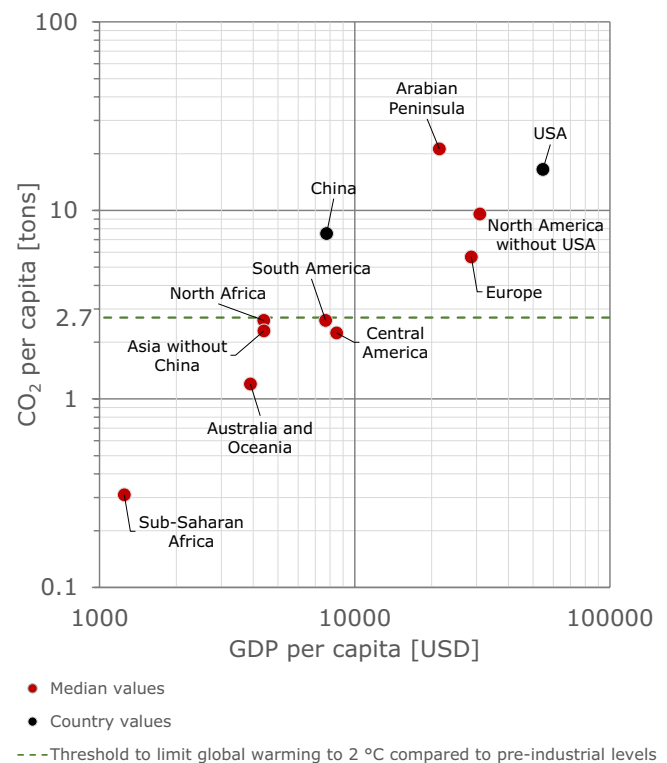
→Earth-based and vernacular technologies which have been derived over the course of centuries and today point out to be climate-friendly and greener than established technologies. However, for the tremendous construction demand, these technologies need to be better understood using modern analytical methods, made scalable, and enhanced with state-of-the art constituents (Vernacular 2.0 [22]).

These materials can significantly help in de-carbonising construction, provided they are derived from sustainable sources that have no negative impact on the biodiversity. They can help replace the significant fraction of concrete, where today it is used as commodity just due to its easy accessibility. However, these materials cannot replace structural concrete. For infrastructure and urban habitat, concrete remains inevitable. Such concrete can be made less carbon intensive most efficiently by replacing OPC with SCMs. Most SCMs are less carbon intensive but not inherently green, since they are also derived from industrial processes. However, particularly, agricultural by-products that are abundantly available in sub-Saharan Africa converted to high-performance concrete constituents have potentials to become literally green construction innovation that helps to develop innovative construction businesses whilst maintaining a low-carbon footprint.

In comparison to the rest of the world, sub-Saharan Africa (SSA) has a significantly lower per capita carbon emission (Fig. 1). It is therefore in the best position to master the construction challenges in a more climate-friendly approach, but technology drivers and regulations have to become enablers for the change and facilitate Africa's capacity to become a



(a)



(b)

**Fig. 1** Per capita carbon emissions vs. per capita gross domestic product **a** in SSA countries and **b** expressed in median values for different regions in the world in comparison to the threshold that needs to be achieved to limit the global warming by 2 °C compared to pre-industrial levels according to [28–31]. (Source of carbon emission data: Carbon Dioxide Information Analysis Center, Environmen-

tal Sciences Division, Oak Ridge National Laboratory, Tennessee, United States; source of population data: United Nations Population Division, National statistical offices, Eurostat, and United Nations Statistical Division; source of GDP data: World Bank national accounts data, and OECD National Accounts data files

global green construction technology leader. Therefore, in this study, a critical review of existing standards and design codes is conducted, and necessary solutions are developed to unleash Africa’s leapfrog potentials.

### History of cement and concrete standards

The history of cement as a binding agent for concrete has always been marked by developments in the northern hemisphere [1]. The more than 2000-year-old predecessor of today’s concrete, the “Opus Caementitium” was a Roman invention. Significantly later the term Portland cement was patented for a product invented by Joseph Aspdin in 1824, but the binder that resembles today’s Portland cement was invented by his son William Aspdin in 1843 [32]. Since then, the technology has been further developed mostly in the UK, Germany, and France and then spread out to the USA, Russia, and Japan in the 1870s, followed by Canada and China [1].

The first countries to start up cement production in the Southern hemisphere all around 1890 were Australia, Brazil, and South Africa. Most of the African cement production remained at low levels and increased with the demand of the colonial occupying forces. Bigger production facilities were built shortly before the disreputable European colonial history in Africa started to come to an end. Today, due to an increasing demand for construction, more and more cement plants have been built, but for reasons of regionally limited availability of limestone and global economic market forces, the majority of African countries import clinker and cement. As a historic result, most African countries implemented the standards that were established by the colonial occupiers, even though many of these with time have been converted to harmonised EN standards that were developed with a focus on European climate conditions, resources, supply chains, industry stakeholders, prices, and technology levels, which are not per se compatible with the African frameworks.

## Shortcomings of existing standards

Existing standards for cement, concrete, and chemical admixtures exhibit a variety of shortcomings, so critical of which need are mentioned below.

i. Many standards regulations are very Europe centred.

Laboratories all over the world are often forced to use calibration or reference materials from European sources (e.g. standard sand), and many methods are overly sophisticated and expensive in relation to their relevance.

ii. Strong focus on OPC as reference binder.

The technical specifications for cementitious binders must adhere to the performance of OPC. Mechanical and durability properties of cement and concrete are assessed based on the performance at 28 days, after which historically it was assumed that OPC has approximately reached its final strength. However, for fast-paced production, concrete producers today are interested in the materials performance after 2 days. For sustainable structural design with SCMs, which typically slow down the reaction, significant amounts of materials could be saved when 90-day values were chosen.

iii. Limited use of available sources of mineral oxides for cementitious binders.

Existing standards are limited to the materials from industries that are historically linked to European industrial history such as FA or GGBS derived from energy and steel industries, respectively. However, since these resources have become scarce, alternative SCMs are urgently required, such as calcined clays [33–36], agricultural waste ashes [37–41], mining wastes [42, 43], and even municipal wastes [44]. Particularly, agricultural by-products can become a viable option in Africa, where up to 5% of the OPC production capacity can be replaced already today with a future growth potential of 1600% [23].

iv. Inflexibility to minimise OPC content over the course of the entire process.

Existing cement and concrete standards are heavily focused on OPC as major binder (Fig. 2a) without looking at technology and carbon reduction potentials of alternative cementitious binders that inherently provide different performance specifications. The OPC

reduction can take place either in the cement plant, which requires large, steady, and homogeneous supply chains (Fig. 2b) or during the concrete production using generally less OPC and blending it with available SCMs/fillers locally, which can also be sourced from smaller and multiple supply streams (Fig. 2c). In order to produce greener cement, a combination of both is necessary and blends of multiple SCMs need to be homogenised to provide reliable supply chains (Fig. 2d). Then, performance-based standards become mandatory.

v. Lack of capacity to unfold the full capacity of mineral microparticles and organic polymers.

Microfillers and organic admixtures can help minimise the cement content or reduce the water demand by half, which would approximately also allow to reduce the cement content in concrete equally by half without compromising the safety and durability of the material.

vi. Historic focus on safety only.

Important parameters of resource saving and circularity have never been a pivotal part of the current regulations. The existing prescriptive standards concepts limit the implementation of recent requirements with respect to sustainability in an adequate way, and the concepts limit the application of yet unknown technologies that will be developed in the near future [20].

vii. Complex quality infrastructure (QI).

Standards have been evolving steadily building up on existing concepts. The regular addition of new specifications without seriously screening for synergies and filtering for outdated rules caused complex QI systems that have difficulties in rapidly adapting to changes, which however evolve with increasing velocity today. Structural concrete, for example, in Germany would require consideration of 128 standards comprising more than 4000 pages and cost of more than 10,000 EUR. Future standard developments, hence, need to become more flexible and reduced to the very fundamental aspects to ensure that industry activities are boosted rather than hindered.

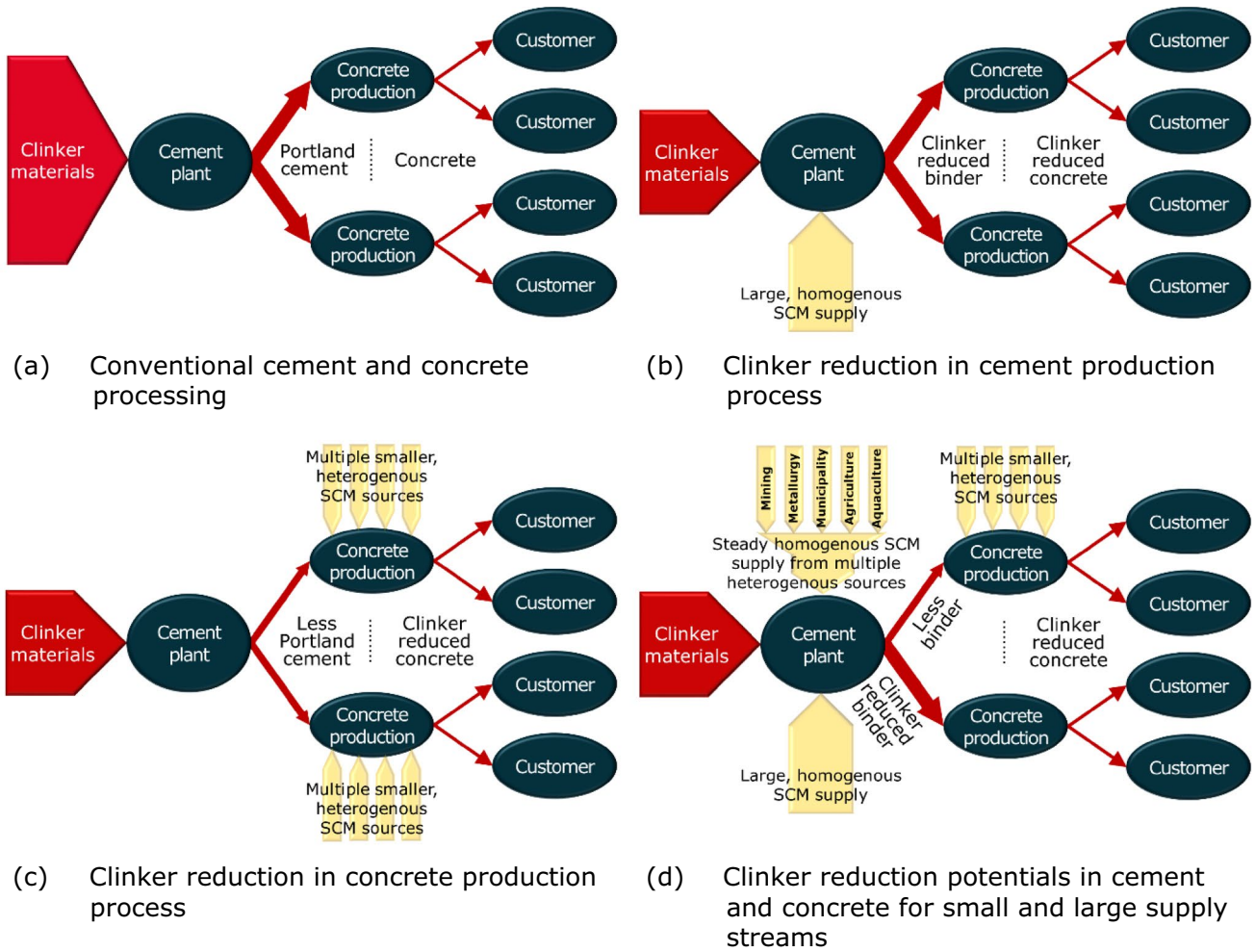
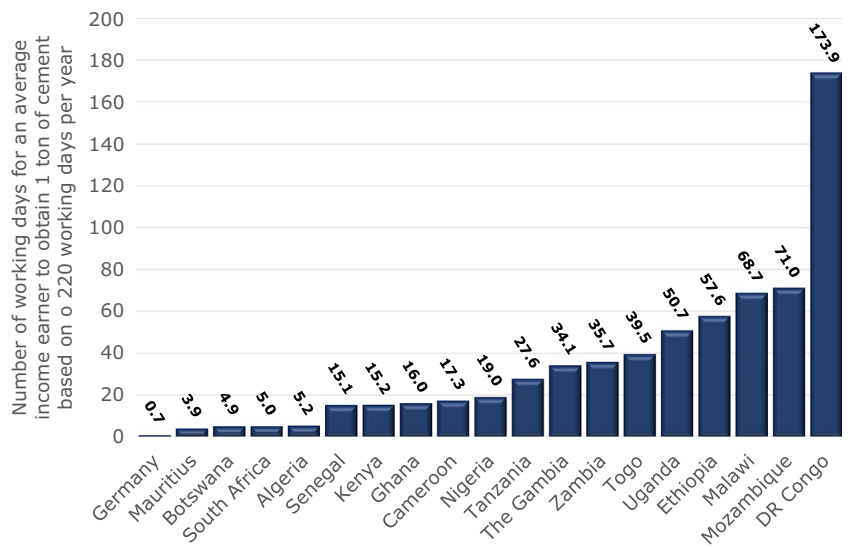


Fig. 2 Methods to minimise the OPC content in concrete

Fig. 3 Cement prices expressed to purchasing power referred to the number of working days required to obtain 1 ton of cement (data sourced by the authors)





**Table 1** EU vs. SSA framework and challenges and potentials for SSA

Focus	Criteria	EU	SSA	Challenges and potentials for SSA
Cement/ binder	Number of plants	High density approx. 300/4.2 Mio km <sup>2</sup>	Low density approx. 300/30 Mio km <sup>2</sup>	Lack of clinker and long-distance transportation favours clinker reduction during concrete production
	Cement factories	Integrated and grinding plants, according to supply and demand	More grinding plants than integrated plants	
	Clinker	Local supply	Largely imported	
	Most relevant SCMs in use	Fly ash, GGBS, Limestone filler	Limestone filler, natural pozzolana	Increasing demands accelerate the market implementation of sustainable novel binders
Chemical admixtures	SCM potentials	Calcined clays	Calcined clay, agricultural waste ash, mining waste, municipal waste	
	Cement market	Stagnating	Increasing	
	Availability	Commonly used	Mostly only used in special applications	Polysaccharides are adequate and sustainable solution to reduce prices and create markets
	Cost	Low	High	
	Supply	East Asia and Europe	From outside Africa	
	Basis	Petrol chemistry		
	Potentials	Polysaccharides		
	Production technology	Dominantly pre-cast and ready mixed		Education about good practice is required at all levels
	Efficiency	Highly industrialised	Individual	
	Market participants	Highly formalised	High percentage of informal business	
Cement and concrete market	Driving forces for construction	Maintenance and retrofitting	Rapid urbanisation and infrastructure	Different cost allocation makes the application of EN standards in SSA economically unviable
	Cement delivery	Silos	50-kg bags	
	Distances to customers	High population density	Low population density	
	Cement costs	Relatively low	Relatively high	
	Labour costs	High	Low	
	Temperatures	Temperatures ranging between - 30 and + 30 degrees	Mostly higher than 20 degrees	Narrower, yet more challenging climate framework, requires deletion of useless regulations and adaption to local conditions
	Humidity	Wide range from dry to medium humidity	Mostly humid	
	Damaging potentials	Relatively lower than in SSA due to generally lower temperatures and humidities	Greater, since many large cities are located close to the sea	
	Standards	EN	EN, ASTM, others	Lack of over-regulation gives degrees of freedom to evolve, but knowledge base needs to be developed
	Standards relevance	Over-regulated	Under-regulated	
Quality infrastructure	Highly specialised laboratories and market surveillance	Lack of staff, equipment, and less monitoring		

## Critical discussion of European concrete standards in the African framework and boundary conditions

Many intrinsic and extrinsic parameters vary between Europe and SSA, one obvious example is the differences in the climatic frameworks. Generally, high temperatures and mostly more humid conditions in SSA are more challenging for the casting, curing, and the durability.

In addition, the supply chains and local resource supplies differ greatly. In Europe, there are hardly scalable SCM alternatives for FA and GGBS. Africa provides a vast variety of SCM potentials from natural pozzolana to calcined clays to agricultural by-product ashes [37, 41, 45, 46]. In addition, it has been shown that for chemical admixtures, the African continent provides bio-based alternatives for established crude oil-based materials [47–50].

Furthermore, the economic frameworks differ. Expressed in purchasing power, cement is extremely expensive in SSA (Fig. 3), whilst at the same time, labour cost is relatively low. In contrast, EN standards are focused on minimising labour costs, which is the highest cost driver in Europe, whilst materials costs are not given specific considerations. Hence, from an economic perspective, the application of EN standards in SSA cannot be considered as sensible.

A detailed discussion of all differences goes beyond the scope of this paper, but Table 1 provides an overview of various aspects. It can be seen that many challenges occur, but adaption to local frameworks also creates potentials to improve the technology.

## Conclusions and recommendations

Existing standards do not account for the evolving developments in cement and concrete industry and need critical revision. Most standards applied in Africa have been historically developed in Europe without considering aspects of relevance outside Europe. After the critical discussion in this paper, the following conclusions can be drawn:

- European bodies need to increase awareness of their global role and take serious responsibility.
- Standardisation bodies need to understand that adaptability to rapidly changing demands and technologies requires reduction and simplification of existing regulatory frameworks rather than additional complexity.
- Europe is over-standardised, making implementation of innovation difficult, costly, and time intensive. In contrast, SSA is rather under-standardised, which opens innovation potentials.

→African institutions are typically equipped with greater implementation power than their European counterparts, which makes rapid changes faster and easier to implement so that they can be multipliers of innovation.

→African standardisation bodies need increased awareness of the relevant parameters affecting safety and sustainability and subsequent standards must be tailored for specific African parameters.

→The typical process for standards development requires a mandate from the industry. Considering the significant impact of cement and concrete on the global climate, this concept might need revision.

→Standardisation bodies have to take responsibility without waiting for the industry. They need a political mandate to work on required changes on behalf of the society, because

- o Demand for infrastructure in Africa is rising rapidly and
- o there is no time to wait for better standards to evolve outside Africa.
- o Africa has more degrees of freedom to implement better, climate-friendly, future-oriented innovation than the rest of the world, and
- o resources are abundantly available.

Standards create markets and local livelihoods, which are urgently required and fully align with the Agenda 2063. In the challenging framework of the African cement and concrete market, where rapid changes take place and international market forces create a lot of detrimental impact to structural and environmental safety, further international and pan-African collaboration is urgently required. This helps to overcome the limitations African standardisation bodies face with regard to often lacking funding, staff, equipment, and capacities to fulfil their task in the QI ecosystem. Then SSA can unleash the tremendous potential to become global green concrete pioneer.

**Funding** Open Access funding enabled and organized by Projekt DEAL.

**Data availability** All data can be made available upon request by any person or party. The data sources for Fig. 1 are mentioned below the figure, and the data collection as well as the data conversion process can be made available upon request. Figure 2 does not contain data. Figure 3 shows that all data were collected by the authors through their network and converted by common economic country data available in the public domain. The collected data and the conversion method can be made available upon request. Table 1 does not make use of data. Information provided is based on observations of the authors.

## Declarations

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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