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Five recommendations to accelerate sustainable solutions in cement and concrete through partnership

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Abstract

Though the technical knowledge to make cement and concrete more sustainable already exists, implementation of solutions lags behind the rate needed to mitigate climate change and meet the targets set by the Sustainable Development Goals. Whilst most of the focus around the built environment is on embodied carbon, we stress an important but neglected dimension: partnership (SDG17). Effective partnerships can be powerful enablers to accelerate sustainable solutions in cement and concrete, and let such solutions transfer from academia to the market. This can be achieved through knowledge generation, solution implementation, and policy development, among other routes. In this article, we share five recommendations for how partnerships can address neglected research questions and practical needs: 1) reform Science, Technology, Engineering and Mathematics (STEM) education to train "circular citizens"; 2) map out routes by which cementitious materials can contribute to a "localization" agenda; 3) generate open-access maps for the geographical distribution of primary and secondary raw materials; 4) predict the long-term environmental performance of different solutions for low-CO_2 cements in different geographical areas; 5) overhaul standards to be technically and regionally fit for purpose. These approaches have the potential to make a unique and substantial contribution towards achieving collective sustainability goals.

Keywords: Partnership; Sustainable Development Goals; Education; Raw materials; Standards

1 Introduction

The Sustainable Development Goals (SDGs) are a milestone of global consensus in the short-term targets for sustainable development [1]. Construction materials play an important part in attaining many of these goals [2]; at the same time, their environmental impacts are under serious scrutiny, and present a threat to achieving some of these goals. The largest and most impactful construction material sector is cement and concrete [3]. In response to this, a vast and ever-growing body of research is developed around how to make cement and concrete more sustainable. Most of this research is techno-centric, measuring or devising improvements at the material or product level to reduce environmental impact [4]. Technical research remains critical, but the underlying processes and enablers needed to successfully implement these solutions have received relatively little attention. Maximizing the efficacy of such enablers will be key to achieving the desired sustainability outcomes, and increasing the rate at which they can be achieved.

Partnerships are enshrined in the SDGs within Goal 17, "Partnerships for the goals", and are recognized as a key enabler for achieving a diverse range of sustainability outcomes [1]. Within Goal 17, the most relevant individual targets are: Target 17.6 "*Enhance North-South, South-South and triangular cooperation on and access to science, technology and innovation and enhance knowledge sharing…*", Target 17.16 "*…multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology, and financial resources, to support the achievement of the Sustainable Development Goals in all countries…*", and 17.17 "*Encourage and promote effective public, public-private and civil society partnerships…*". This raises the question – what is considered a partnership? The definition of partnerships can be highly ambiguous – for the purposes of this articles, the definition by Pattberg and Widerberg [5], is used: "*institutionalized transboundary interactions between public and private actors, which aim at the provision of collective goods*". Whilst broad, this definition is useful in drawing the boundaries around what partnerships are not – in particular,

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contractual relationships motivated only by profit (and hence neglecting the provision of collective goods).

With respect to the built environment, stakeholders in construction need to network and devise strategies that may enable the achievement of the Paris Agreement goal of keeping global temperature rise well below 2°C above pre-industrial levels [6]. Pineo and Moore [7] suggested that the built environment stakeholders should not be limited to governmental institutions, but also include other players such as contractors, researchers, entrepreneurs, climate change activists, logistics practitioners among others. The networking should have a global perspective, where regional, continental and international trade blocs need to collaborate for more effective supply chain management in the building industry, considering that the great economic divide between the Global North and South may worsen an already dire situation. A priority in emerging economies is addressing housing and infrastructural needs associated with the fast pace of population growth and urbanisation. It is estimated that the world population will increase by 1.7 billion by 2050 [8], and that the number of people living in urban areas will increase by 2.5 billion by 2030 [9]. Ninety percent of these new city dwellers will be concentrated in Africa and Asia and will need access to adequate shelter and infrastructure, considering that today one billion people in the world are living in informal settlements [8]. In the Sub-Saharan African (SSA) scenario, rapid urbanization and poor urban planning have generated a dramatic housing deficit, with the current backlog accounting for over 50 million missing units [10]. The cost of building materials represents the main barrier to affordable housing plans. For instance, materials account for over 40% of housing costs in Kenya [10] and 60-70% in Ghana [11]. This scenario represents both a challenge and an opportunity in terms of economic growth and job creation, as well as research and implementation of best practices into sustainable construction materials.

Beyond achieving sustainability outcomes specifically associated with the SDGs, there is also the potential for partnerships to improve outcomes in the cement and concrete sector in more generic ways; for example, improving the resilience of supply chains to shocks such as pandemics [12,13] and geopolitical instability [14].

Whilst the role of partnerships is a vast subject, in this article we put forward recommendations on five particular topics: education, definitions and concepts, resource information, environmental performance, and standards. For each one, we firstly state what each unmet need is, and then explain why and how partnership can help address each need.

2 Reform STEM education to train “circular citizens”

2.1 Circular citizenship approaches to reduce materials demand for housing

Materials consumption has to be reduced at a global scale, to avoid depletion and environmental impact [15,16]. However, construction remains inevitable globally, with driving forces and solution strategies varying regionally. In many countries of the Global North with a well-developed building stock and a stagnating or decreasing population, the current driving force for construction is maintenance and adaptation to demographic changes [17]. In this case, policies that incentivize reduced consumption, re-use and recycling can significantly contribute to resource saving. In addition, concepts of “circular citizenship” have been recently discussed, wherein circularity becomes part of daily living [18]. In the context of housing this can include: designing adaptable domestic premises; house sharing; changing dwellings to fulfil the specific demands of different phases in life. An intended effect of these strategies is to fulfil societal needs around housing, whilst minimizing floor area per person and hence reducing the volume of material stocks in service. In the Global South, the driving force is represented by developing urban environments and the need of infrastructure and housing for a fast-growing population, while at the same time there is a need for uplift of the standard of living. “Circular citizenship” is nothing novel for many societies of the Global South, as daily living practices such as house sharing are culturally often firmly rooted. Partnerships between Global South and Global North could help transfer social “circular citizenship” practices around housing, and hence reduce net consumption of construction materials for housing in the Global North.

2.2 The role of education in promoting a circular transition

Delivering sustainable and resource-efficient construction requires skilled professionals. The topic of education and training therefore underpins all technical discussions around cementitious materials [19]. Alongside improving technical knowledge about developments in cement and concrete, there is a need for a greater awareness of Circular Economy principles in construction [20]. Whilst certain Circular Economy strategies for cement and concrete will require large infrastructure investments (e.g. for concrete recycling) that are not widely available in all countries, many other strategies (e.g. re-use and refurbishment of buildings) can already be widely achieved throughout the world. Broadening practitioners’ understanding that Circular Economy is more than just recycling will help them to deliver impactful strategies that do not necessarily depend on large investments. The Carbon Literacy Project offers a precedent for how this could be used for education and accreditation at an individual and organizational level [21]. Beyond awareness, there is also a need to challenge underlying cultural assumptions amongst practitioners that put a low priority on material efficiency [22].

Numerous reports have recommended the importance of partnerships to various aspects of Science, Technology, Engineering and Mathematics (STEM) education: between industry and academia, to ensure university curricula are relevant to employers’ needs [23-25]; between national engineering institutions to establish robust, internationally-recognized accreditation programs [22]; and, collaborations between academic institutions within the same region [27,28]. Such partnerships will be crucial to sharing knowledge and best practice to support the sustainable use of concrete in construction [29].

Besides a vision and deep understanding of the global construction framework, this requires interaction, adjustment, and compromises between a wide range of players in the construction sector. To date, this sector is heavily fragmented and the communication between the stakeholders of a construction project is unidirectional (Figure 1). Each stakeholder has their specific agenda that may or may not align to sustainable construction processes. Facilitating interdisciplinary communication with mutual understanding of the other disciplines between all stakeholders will contribute to setting common goals and implementing policies that incentivize best practice solutions. Hence, the effectiveness of partnerships in STEM disciplines will be essential, and education is a prime tool to achieve this.

3 Map out routes by which cementitious materials can contribute to a "localization" agenda

3.1 Local construction materials and the "localization agenda"

The Sustainable Development Goals' (SDGs) Indicator 11.c promotes the use of local materials in construction: "Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials" [1]. Prior to the SDGs, UN-HABITAT [30] endorsed the potential benefits that local materials can provide for developing countries, considering that construction of new housing units will be mainly concentrated in Africa and Southeast Asia [31], where carbon emissions associated with rapid urbanization are projected to rise sharply [32]. Beyond this institutional focus on developing countries, there is interest in the "localization" of construction materials in the Global North, too [33]. This can be broadly framed as a "localization agenda" for construction materials.

However, a specific definition for local materials is not provided in SDG Indicator 11.c. More widely, there is a lack of consensus around what the term "local materials" actually means [33]. Because local contexts can vary dramatically, agreeing on a working definition for local materials would require partnership from actors from a range of different places, and disciplinary perspectives.

How this aim of promoting local materials ought to be interpreted and applied to concrete, as the world's most-used material, is an outstanding question.

3.2 Potential benefits from local sourcing of raw materials for cement and concrete production

Amongst the sustainability aspects of local materials referred to by UN-HABITAT, the environmental and economic aspects are the most well-explored for concrete. Cementitious materials are typically used in high volumes in construction, and have a low "value density" (i.e. ratio of economic value to mass) [4]. Local sourcing is therefore advantageous for cementitious materials, in terms of reducing the embodied carbon and associated cost of transportation. This aspect has been explored for supplementary cementitious materials (SCMs) [34-36] and aggregates [37].

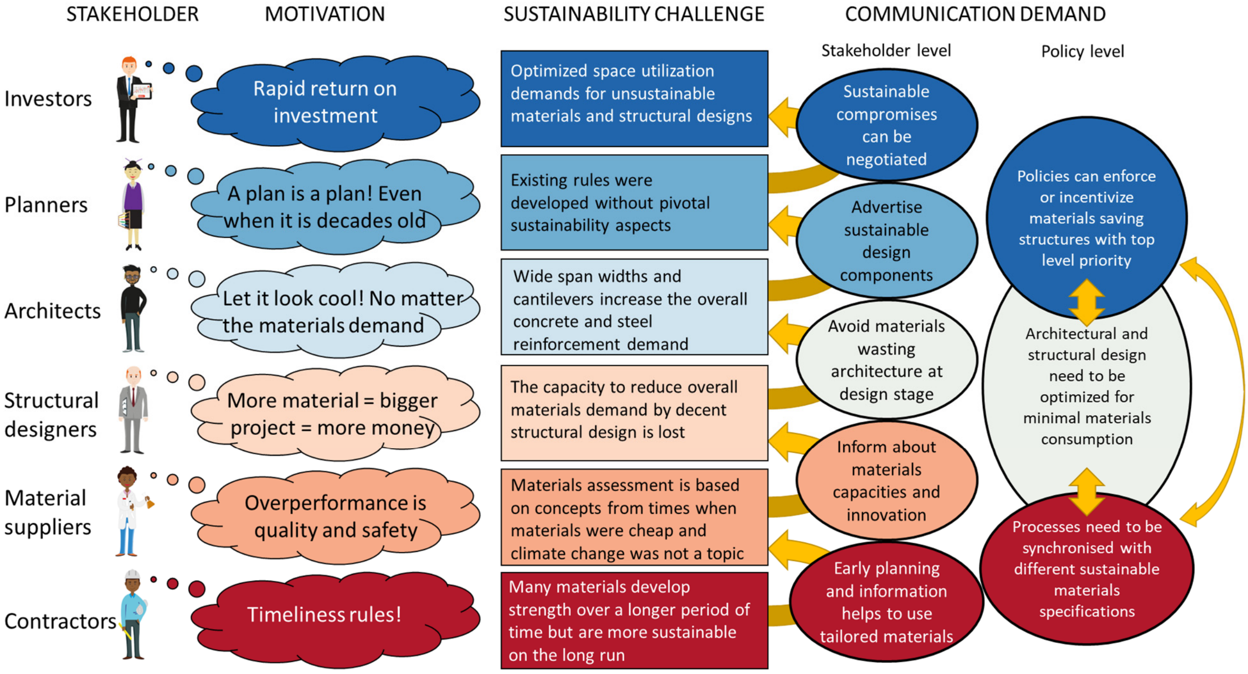

Figure 1. Sketch with overview of how differences in motivations between construction stakeholders can present challenges around sustainability; and how communication and policy can help overcome those challenges.

The localization of cementitious materials production has the potential for positive impacts beyond just carbon and cost. For example, valorizing locally available resources could help countries that are heavily dependent on cement imports to reduce their reliance on external supply chains and to promote the creation of local jobs. From this point of view, clays are regarded as optimal raw materials for use in construction in emerging economies, given the large availability of kaolinictic clay soils in Sub-Saharan Africa, South America and South-East Asia [38]. Such clay soils can be exploited for affordable housing, both as raw clays in earthen construction [39-41] and as SCMs in low-CO_2 cement, after calcination, for example in masonry units and building blocks [42]. The use of locally sourced raw materials for construction, such as lateritic and other Fe-rich clays, may also offer a more coherent visual integration with vernacular architecture, as compared to the ubiquitous grey of concrete made with Ordinary Portland cement. When calcined in an oxidizing atmosphere, Fe-rich clays largely retain the color imparted by their iron oxide impurities [43], which provides an aesthetic argument to the use of cements incorporating such locally sourced materials.

3.3 Overcoming barriers and implementing best practice approaches in local sourcing

A localization agenda could also result in negative impacts, since the non-responsible extraction of primary resources (e.g. clays) can incur negative impact or disruption of ecosystems, and potential knock-on impacts for health and livelihoods. For example, in health impacts - poorly managed or unplanned localized extraction of clay can result in malarial breeding ponds [44]. In social impacts, conflict with the local population is more likely if the reward trade-off of extraction activities is not deemed fair [45]. Where governance is weak, unregulated extraction activities can also foment crime and violence, such as observed in the case of sand [46, 47]. A drive towards greater localization can be a means to more sustainable construction and greater resource efficiency, but if followed blindly, there is a risk of achieving neither. Therefore, a localization agenda for cementitious materials needs deep scrutiny of both resource value-chains and societal economies generated around it. This debate will be strongly shaped by the evolving technical understanding of valorization pathways for a range of primary and secondary resources in cementitious materials, for both binders and aggregates. The potential to use wastes and by-products to ensure a responsible extraction of resources offers greater flexibility for use of locally available raw materials in a range of geographic contexts. Examples include: in urban areas - material streams from concrete recycling [48] and from food supply wastes [49]; in industrial and post-industrial settings - slags [50], mining tailings [51] and stone-cutting slurries [52], and in rural settings - bioashes [53]. Another techno-economic aspect shaping the localization agenda will be around which manufacturing pathways are suitable for smaller-scale, localized production. For example, it would make little sense to produce clinker locally at a small scale, but a small-scale clay calcination plant [54] or concrete recycling plant may be feasible in a wider range of scenarios. Certain reactive materials, e.g. bio-based ashes that qualify as SCM may not be available in sufficient supply for cement producers, but can be used by local concrete producers.

Providing a clear vision for how cement and concrete can provide effective local solutions in a range of contexts will be a complex task, but has a high potential for benefits. Global partnerships can play an important role in shaping and informing the localization agenda for cementitious materials. Firstly, identifying appropriate indicators beyond transportation distance and embodied carbon, to encompass environmental, economic, social and cultural dimensions, aligned with the SDG agenda. Such indicators could then be used to assess how 'locally beneficial' a given route for cementitious materials production is. Secondly, gathering the broad evidence base to inform our understanding of how concrete can be best utilized as a 'local material', with lower embodied carbon. This evidence will have to be used to inform policymakers and local stakeholders about appropriate interventions to support the localization of cementitious materials.

4 Create open-access maps of the geographical distribution of primary and secondary raw materials for construction

4.1 Opportunities to produce low-carbon cements from geological resources in SSA

Global cement production is currently dominated by China and has reached a plateau in OECD countries. It is predicted that in the next decades, demand for cement in China will stabilize, and it will dramatically increase in other emerging economies such as the BRICS (except China) and countries of SSA [55,56]. SSA currently has an average annual urban growth of 4.13%, which is the fastest urbanization rate worldwide [57]. While the local demand for cement in SSA is soaring, this is largely satisfied by imports from outside the region. Apart from a limited number of countries, most of the SSA countries are net cement importers (Figure 2). This partly arises from the limited availability of high purity limestone resources. Because of the old geological age of the continent, the continental crust is largely exposed as a consequence of the erosion of sedimentary covers (including carbonate rocks such as limestone). Remnants of geologically old sedimentary covers occur in the orogenic areas such as the Lufilian arc [58], in between Zambia and RD Congo, where significantly large limestone deposits occur.

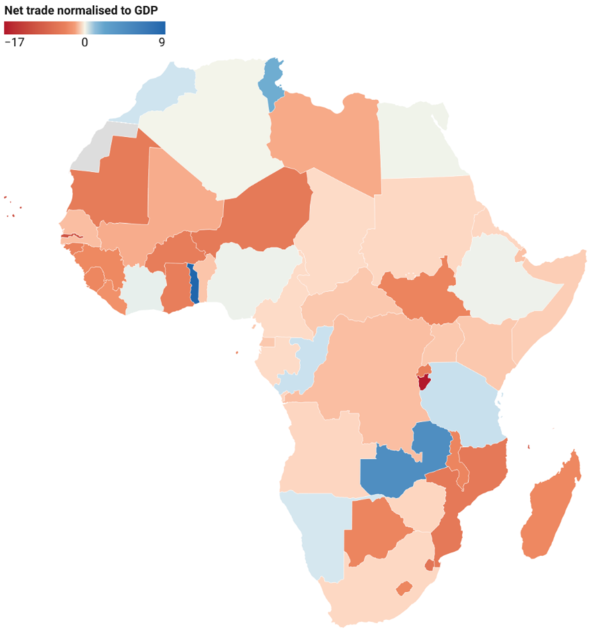

Figure 2. Net trade expressed as aggregated cement and clinker import/export flows in Africa, normalized to real GDP (2018 data). The numbers are expressed as 10^{-3} USD. Data retrieved from wits.worldbank.org and oec.world. An interactive map, with downloadable data, is available at https://datawrapper.dwcdn.net/L2679.

4.2 Open-access resource mapping as a systematic enabler for low-carbon cements

Appropriate mapping of available resources can accelerate the production of alternative cements, based on locally available primary and secondary raw materials. An open-access inventory will enable an optimized approach to the supply of resources. This applies not only for current construction, but more specifically for sustainable low carbon cement production. Table 1 reports a number of available online resources, which can potentially be used as raw data for such an open inventory and to create open-access maps (Figure 2).

Although the databases presented in Table 1 are useful for the supply of the raw materials needed for sustainable construction, these databases may not be formalized on a local level. Therefore, the databases may not necessarily be an indication of availability or reliability of a local supply chain for a given mineral resource. Furthermore, as highlighted by Nteta and Mushonga [59], there are many barriers and drivers related to the supply chain of sustainable construction and to the demand of sustainable products from construction material manufacturers. In this case, partnerships can play a key role – both in gathering additional data where needed, and curating data which are already available to be in a format which is accessible and useful. Beyond the data itself, partnerships could also have a beneficial role in developing policy. If well-designed and effectively implemented, government policy could maximize the benefits of local resource use, whilst avoiding exploitation of vulnerable populations.

5 Predict the long-term environmental performance of different solutions for low-CO2 cements in different geographical areas

5.1 Regional approaches for using SCMs to reduce the CO2 footprint of cement

The environmental burden associated with cement and concrete manufacture is on the forefront of discussions by industry, government, academia and policymakers. This is reflected by the plethora of strategic plans and roadmaps aimed at reducing CO_2 emissions [60-69]. The target year in the surveyed documents ranges from 2040 to 2060, and is most typically 2050. At the same time, global projections of cement production, through to 2050, are on the rise and it is well recognized that sustainable approaches along the value chain are imperative [69]. Recognizing this global observation, all strategic plans include lower clinker-to-cement ratios using supplementary cementing materials (SCMs). Synthesis from ten strategy/road mapping documents reveals that the reference clinker-to-cement ratio ranges from 0.65 to 0.90 (corresponding to reference years 2011-2019), and propose a clinker-to-cement ratio target being as low as 0.52 to 0.71 by 2040 to 2060. One key approach to reduce the clinker ratio involves a continued and expanding inclusion of SCMs. Drawn from international published roadmap documents, Figure 3 summarizes sixteen target materials identified as potential SCMs. Ground granulated blast furnace slag, limestone, and fly ash additions, are most prominent in the strategic plans. Natural pozzolans, artificial pozzolans, steel slag, rice husk ash (and other agricultural waste) are also envisaged to be used, albeit markedly less widespread. However, the abundance and availability of industrial by-products and agricultural waste are geographically dependent and can also change due to policy decisions and regional climate.

5.2 Predicting regional variations in the durability and service life of low carbon concretes

Testing the environmental performance of different low-CO_2 cements in different environments is necessary to evaluate cement-based materials and concrete structures from a life-cycle perspective. Quantification of environmental impacts is partly motivated by government commitments to national/international agreements and policies intended to achieve targets for greenhouse gas emissions reductions. Tools such as Life Cycle Analysis (LCA) (as regulated by ISO 140040:2006 [70]) can facilitate such estimates through the provision of principles and a framework. However, an understanding of modelling choices and variability associated with spatio-temporal uncertainty is also warranted [71,72].

Table 1. Available online geographical databases for resource mapping. Abbreviations: DE = domestic extraction; DMC = domestic material consumption; EXP = export; IMP = import; PTB = physical trade balance; RME = raw material equivalent.

Database	Material Flow Indicators	Commodity Categories	Accessibility
Resource Watch (resourcewatch.org)	DE; DMC;	Non-metallic minerals	Free
International Resource Panel (resourcepanel.org/global-material-flows-database)	DE; DMC; EXP; IMP; PTB	Non-metallic minerals for construction; Products from non-metallic minerals	Free (fee requested for disaggregated data)
Materialflows.net (materialflows.net)	DE; DMC; DMI; EXP; IMP ; RME	Non-metallic minerals for construction; Products from non-metallic minerals	Free
Observatory of Economic Complexity (oec.world)	EXP; IMP	Various (aggregates, cement, clay, limestone etc.)	Free (PRO version requires a subscription)
Raw Materials Information Systems (rmis.jrc.ec.europa.eu)	DMC; EXP	Various (only most relevant commodities to each country are displayed. Data available only for Europe and Africa)	Free
World Integrated Trade Solutions (wits.worldbank.org)	EXP; IMP	Various (aggregates, cement, clay, limestone etc.)	Free
Cemnet (www.cemnet.com)	DMC; EXP; IMP	Cement, clinker	On subscription
Extractives Industries Transparency Initiative (eiti.org)	DE; EXP	Various (only most relevant commodities to each country are displayed. Data available for 50 countries)	Free

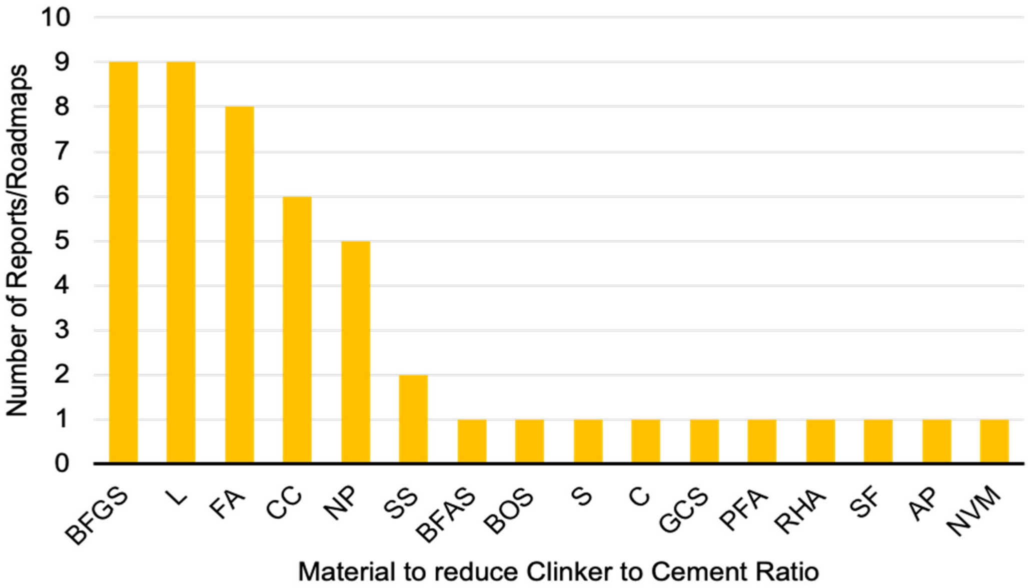

Figure 3. Proposed replacement materials in blended cements for reduction of the clinker-to-cement ratio [50-59]. Note: Blast Furnace Granulated Slag (BFGS), Fly Ash (FA), Calcined Clay (CC), Limestone (L), Blast Furnace Acid Slag (BFAS), Steel Slag (SS), Natural Pozzolans (NP), Burnt Oil Shale (BOS), Silica (S), Chalk (C), Ground Crushing Sand (GCS), Pulverized Fuel Ash (PFA), Rice Husk Ash (RHA), Silica Fume (SF), Artificial Pozzolanas (AP), Natural Volcanic Materials (NVM).

Climate change is a global phenomenon, but implications at a local scale can vary from country-to-country, region-to-region, and city-to-city [73,74]. Concrete durability is largely controlled by environmental exposure conditions, and therefore, concrete degradation has potential to also be impacted in a heterogeneous manner. Therefore, addressing and understanding climate impact on concrete durability is a complex task, due to geographical variability. Partnerships are key to meet this challenge. Collaboration between climate physicists, materials scientists, structural engineers, and owners of infrastructures can facilitate the understanding of the interaction between the environment and concrete structures, and the prediction of performance on regional projections of climate variables for the next 50 to 100 years.

Additionally, the extent to which existing approaches to the implementation of low-CO_2 cementitious materials are reliable for different concrete mix designs requires particular attention, since some of the commonly used SCMs are only relevant for some countries or regions, depending on local availability. Uncertainty in the quantification of life cycle assessment and carbon accounting pertaining to material processes, construction processes and projects is complex. There are uncertainties around several factors, such as: functional unit, reference flow, geography, scale, recurring embodied energy [71,72]. Resolving such uncertainties can partly be achieved through standardization of approaches for life cycle assessment and carbon accounting [72]. Effective partnerships within and feeding into these standards committees will be key to ensuring that these tools are fit for purpose.

6 Overhaul standards to be technically and regionally fit for purpose

6.1 The role of standards in enabling the adoption of sustainable cements and concretes

Regardless of the regionally required demands and the specific solution strategies, a global mindset change in the materials supply market for the built environment is urgently required. The mostly centralized decision-making and pricing processes have to be converted towards more local solutions. Purely technical and economic considerations have to be outweighed by sustainability aspects in policies and standards in order to foster affordable, innovative and environmentally friendly materials solutions. Standards are the transmission belt between technology and society. Today’s standards were developed in a framework where mechanical performance and durability were pivotal. Today, this needs to be changed and climate aspects have to be considered at least at equal level to strength and durability (see Globe Consensus: www.rilem.net/globe).

Ensuring safety, durability and reasonable service life has been implemented through a conservative risk assessment, dimensioning and materials design; yet implementing sustainable construction requires reduced cross-sections, adapted safety parameters, and minimization of climate-intensive materials components, such as cement in concrete. Each regulatory body will have to balance the needs in terms of safety of construction and environmental sustainability [75].

6.2 The need for standards to respond to regional contexts

For standards to enable the adoption of sustainable cements and concretes, urgent revision of current standards is required, particularly in a regional framework [76]. To date, European standards are widely applied in many parts of the world outside Europe, where the framework significantly diverges from the conditions assumed in the EN standards. National annexes can address the gap left on adopting and using conventional building materials, especially cement originating from the Global North [77], but they cannot cope with the historic framework of the fundamental standard concept [78] This situation consciously or unconsciously often even implies a colonial legacy to be maintained in the Global South [79]. The ideal type and chemistry of cement is dependent on the area of application. This is outlined from the history of European concrete and cement standards EN 206-1 and EN 197-1 as non-harmonized documents [80].

Many of the cementitious precursors [81] specified for cement production, such as fly ash and ground granulated blast furnace slag, are not available in many developing countries. Alternative materials with similar oxide composition exist, but cannot be used due to lack of inclusion in the applied standards. Furthermore, cement and concrete standardization has been heavily influenced from Europe where the climatic conditions are advantageous for the standardized materials and technologies. This is not the case for example in tropical climates. Beyond technical factors, even the cost parameters can vary greatly. In Europe and North America, for example, materials are reasonably cost efficient, but labor costs are the major budget provision; whereas in many other parts of the world, this is exactly inverted. Such differences are exemplified in Figure 4, which displays cement prices for different countries in the world. When the nominal cost is normalized to the purchase power, the economic efficiency varies greatly, and for example the normalized cost becomes 400 higher for an average income household in the Democratic Republic of Congo, when compared with the USA.

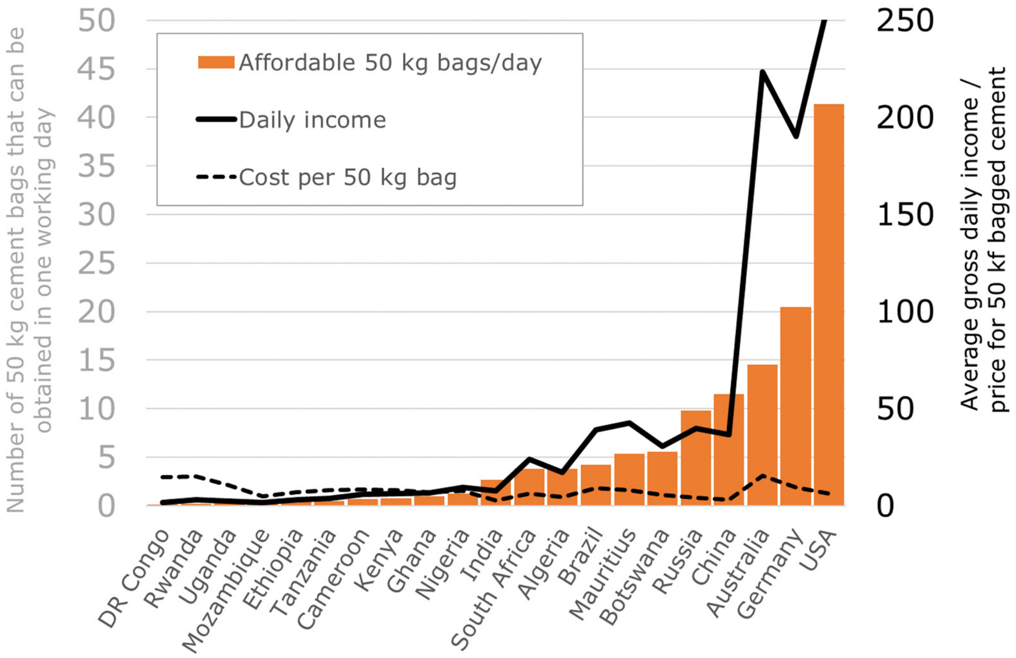

Figure 4. Number of 50 kg bags of cement that can be bought from one day's wages in different countries, based on the per capita GDP. The dataset is based on average values collected from urban and rural areas in the respective regions in 2017, related to economic and demographic values based on UN data from the same year [82].

Finally, the existing standards require expensive test methods and reference materials, which makes the adoption of standards expensive and exclusive. Due to lack of capacity to develop a new framework, standards are typically adopted with little adaptation. However, the growing economies of the Global South would require a standardization framework that allows rapid implementation of innovation, which is no longer possible in the over-standardized normative framework of the Global North [83].

The societies of the Global South, in return, are often in an under-standardized stage and this may cause challenges, but also provides the degrees of freedom to develop a more contemporary and future-oriented standards framework. For example, by implementing performance-based cement and concrete standards. Whilst standards committees do classify as partnerships (given their composition of a range of private and public sector actors), such an overhaul of standards argued for here will require a wider range of evidence and voices.

7 Conclusions

Partnerships offer much promise for accelerating sustainable transitions in cement and concrete, however they can also be exposed to risks. A challenge for all voluntary partnerships is securing the human and financial resources to deliver their mission. This will be more straightforward when aims align with profitable opportunities, but which may carry the risk of bias. The requirement for resources can also risk the input of such partnerships being biased towards those partners who have greater resources. Future work to evaluate the efficacy of current and past partnerships towards their goals would be valuable for maximizing the success of future partnerships.

The potential for partnerships to achieve progress on the five issues previously described is immense and can be summarized through the following recommendations:

1. Revise educational programmes to train "circular citizens" to reduce material demand for housing through sustainable lifestyles, and, to equip practitioners with broader ways of thinking, to design more sustainable concrete structures.
2. Develop a practically useful definition of "local material", and understand the spectrum of potential local benefits, and harms, that can arise from using a wider range of local resources for cement and concrete production.
3. Make global, open-access maps of primary and secondary raw materials available that can help enable sustainable resource solutions at a local scale for producing low-carbon cement and concrete.
4. Develop interdisciplinary global partnerships to assess the impact-mitigation potential of alternative cement and concrete formulations in different geographic locations and environmental conditions.
5. Develop global partnerships to revise existing codes and standards for cement and concrete, to incorporate parameters that account for environmental performance and sustainability.

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