Bilateral collaboration in built heritage material research and resource maintenance supportive to smart and sustainable cities

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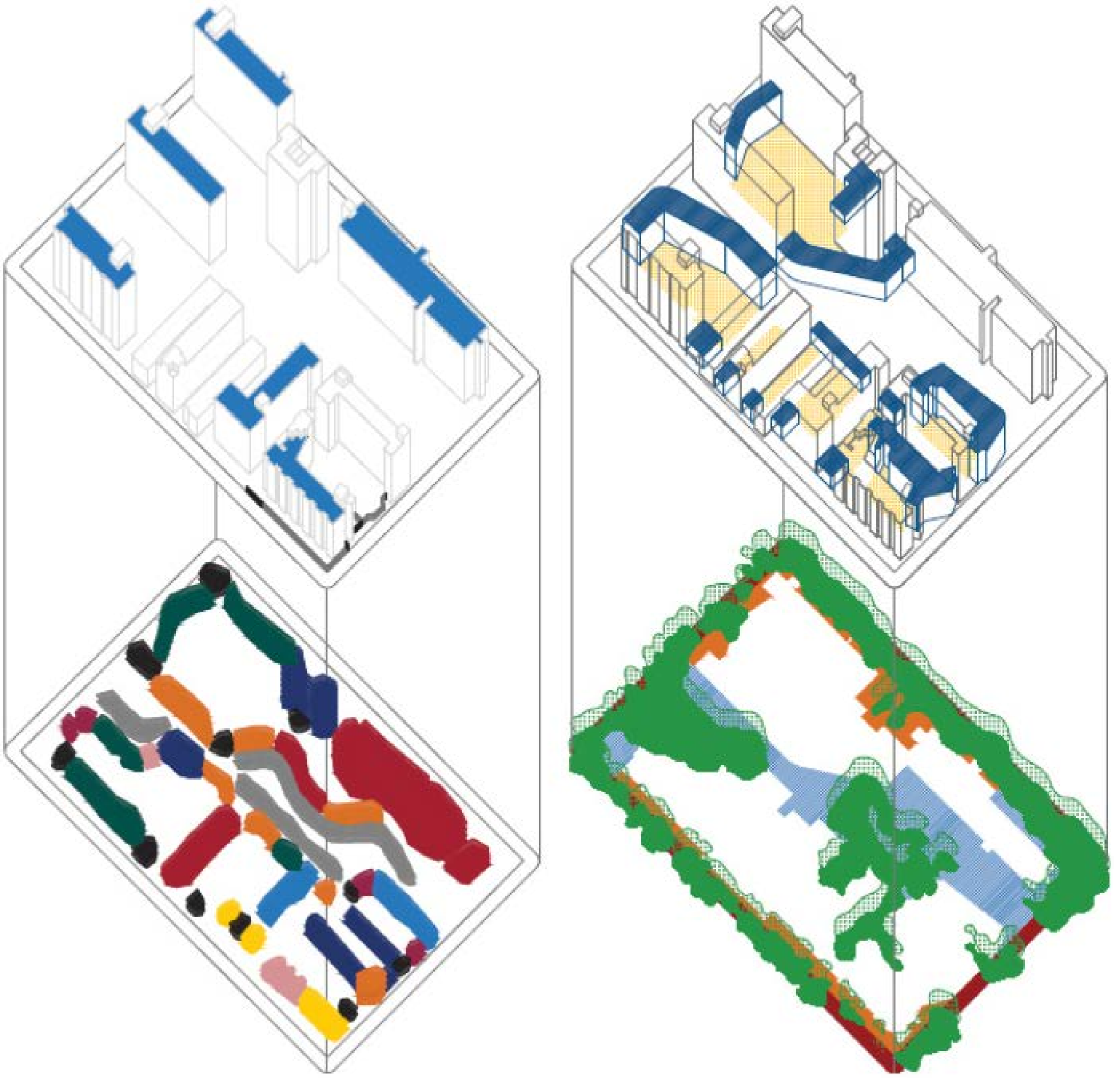

Smart & Sustainable Cities and Transport

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12 – 14 July 2017
CSIR, Pretoria, South Africa

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PEER REVIEW PROCESS

A full double peer-review process was followed for the conference. This included a double peer review process for all abstracts. A double peer review of all full papers was also undertaken. All papers were reviewed by reviewers from outside their institution. Reviews were undertaken by Delft University of Technology, University of Pretoria and CSIR. The organizing committee communicated the results of these reviews to paper authors. Full papers also received final editing and quality checks before being included in the proceedings. Of the initial 19 abstracts received, 11 full papers were accepted for publication in this proceedings.

ABOUT THE CONFERENCE

The *Smart Sustainable Cities and Transport Semina*r is the result of recent formal cooperation agreements between Delft University of Technology, the University of Pretoria and CSIR. The target audience of the conference is built environment researchers and professionals, as well as government, business and non-government organisations that have an interest in smart and sustainable built environments. The main purpose of this seminar is to present original research findings and research in progress to further boost the collaboration between South African and Dutch parties working on similar themes of sustainable (re)development of cities. In particular, the aim of this seminar is to help the cities of Tshwane and Amsterdam and their respective knowledge institutes, to collaborate and learn from each other in their endeavours to become smart, resilient and sustainable.

ORGANIZING COMMITTEE

PREFACE

We are living in a rapidly changing world. The effects of climate change and the weakening of critical ecosystem services are beginning to impact on every aspect of our lives; big data, the Internet of Things and artificial intelligence are creating both new opportunities for more effective management of cities, as well as new challenges and threats; and a range of new economic and governance models are emerging that make use of distributed networks for effective stakeholder engagement. All of these changes come together in our cities, which themselves are rapidly changing in form, nature and extent.

Given this situation, it is not only valuable to understand these changes and their impact on the physical and cultural heritage of our cities and the standard practices of producing our built environment. It is equally, if not more, important that high impact, positive change also occurs. Positive change must be informed by rigorous and targeted collaborative research that can be readily and rapidly applied to counter climate change and develop more sustainable built environments.

The papers at this seminar characterise this positive approach from different spheres of interest and perspectives. The papers cover a wide range of subjects reflecting the various research interests and pressing topics of the day. We welcome you to this seminar and look forward to sharing, discussing and developing ideas, tools and plans needed for smarter and more resilient and regenerative urban environments.

DCU Conradie

Dr DCU Conradie	Prof. C du Plessis	Prof. AAJF van den Dobbelsteen

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[SSC07] BILATERAL COLLABORATION IN BUILT HERITAGE MATERIAL RESEARCH AND RESOURCE MAINTENANCE SUPPORTIVE TO SMART AND SUSTAINABLE CITIES

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Keywords: Maintenance, material resources, repair, shared built heritage, the Netherlands-South Africa.

Abstract

Built heritage contains value on many scales. On the most basic level it represents the investment of building materials following a constructional logic. As the use of once-predominant materials goes out of fashion due to changing technological regimes and architectural styles, knowledge about them is lost. Yet retaining and maintaining their embodied energies in place is an important aspect of resource efficiency. Waste management, circularity and in situ retention of built fabric as useful resource is a sustainability ambition for built environment systems in general and for heritage conservation in particular.

The Netherlands and South Africa have a long historic association. Therefore commonality is to be found in the constructional logic of the shared built heritage of both countries. This historic association brought the transfer of construction components through material streams as well as the transfer of knowledge from the Netherlands to climatically different South Africa. It is expected that the historic transfer of knowledge and materials from the Netherlands to South Africa has led to climate adaptive and practical alterations of Dutch principles. These hold potential to shed valuable new light on retaining built fabric in the Netherlands average temperatures are increasing. Dutch knowledge on maintenance and repair can augment the rather scant South African body of knowledge on material maintenance and repair.

This paper will explore the possibilities for collaborative research on material maintenance and repair from the perspective of Smart and Sustainable Cities, identifying opportunities for collaboration in the commonalities that exists between the Netherlands and South Africa.

1. Introduction

The re-use of building materials and components is an age-old tradition, not only because they can be useful, or are close at hand, but because of the artistry with which they have been manufactured or their histories and associations. As such building components lead secret lives. Take for instance the rood screen of the Church of St. Michael and All Angels, in the English town Penkridge. It started its life as a driveway gate. Dutch settler at the Cape of Good Hope, Willem Boers originally ordered its manufacture when constructing his house Rust-en-Vreugd in c.1778. He ordered the gates from an unknown smith in Amsterdam and had the date of manufacture the name of the house incorporated in their design. One hundred years later, the British governor of the Cape, Sir Bartle Frere, gifted the gates to his aid-de-camp, William Littleton who shipped them to England. Littleton donated the gates to his parish church in memory of his forebears lying buried there (Picton-Seymour, 1989), no doubt inspired by the inscription on the gates, which translates as ‘rest and joy’.

This historic anecdote – which is interesting but not exceptional – reveals that building components can be more than just useful elements of a larger building and illustrates how matter and meaning are connected through the layered concept of heritage value. It also tells of a longer history of international exchange of materials and technologies of the built environment, which has left its own residue. This residue forms a notable part of the South African built environment and its built heritage. It also informed South African material use and construction methodologies.

This cross-national residue potentially holds opportunity for researching a number of themes aligned with Smart and Sustainable Cities (SSC) exploration and implementation. These, include understanding the role of construction materials in resource efficiency, waste streams and circularity, appropriateness of material use and green construction. Aligned themes such as climate adaptation, maintenance and management cycles and regimes can also be informed by a comparative study of similar physical residue in different environments. But if such research is to be undertaken, a first step will need to be an assessment of past contacts and the bilateral results of these interferences.

A recently instituted bilateral Memorandum of Cooperation (Faculty of Engineering Built Environment and Information Technology, University of Pretoria and Faculty of Architecture and the Built Environment Delft University of Technology, 2015) now offers the means to study how to most efficiently maintain these material resources, both precious and prosaic, invested by previous generations in our built environment and learn from climate and contextual adaptations in diverse contexts.

This paper presents first attempts at exploring research opportunities based in this history of bilateral material and knowledge exchange, within the framework of the smart and sustainable city. To do so it will briefly unpack the role of material maintenance, preservation and restoration as an integral part of resource management. It will identify those aspects based in a shared building technology and materials located in differing climatic and cultural environments that hold potential lessons for sustainability in general and the smart sustainable city in particular.

2. Built Fabric and the Smart Sustainable City

2.1 Maintenance and Re-use as Sustainable Practice

Re-use is smart and sustainable. That was already the standpoint on which the chair of Renovation & Building Maintenance was established at the TU Delft in 1988 (Van Stigt, 1988), more recently analysed in more detail. The Preservation Green Lab of the National Trust for Historic Preservation (USA) has calculated that it takes between 10 and 80 years of efficient operations of new constructions that are 30% more efficient than the average performing buildings they replace, before the climate change impacts of their construction are recuperated (Preservation Green Lab at the National Trust for Historic Preservation, 2011). It should be noted that this calculation does not take into account possible societal benefits of retrofit of extant infrastructure.

The Preservation Green Lab also cautions that 'materials matter: the quantity and type of materials used in a building renovation can reduce, or even negate, the benefits of reuse.' They conclude that where renovation projects require many new materials and components or large-scale structural interventions, they offer significantly fewer environmental (climate change, human health, ecosystem quality and resource depletion) benefits than renovations that require fewer interventions. The conversion of warehouses to dwellings – a process that requires high material investment – was found to not offer a climate change impact savings compared to new construction with 30% more efficiency. The Preservation Green Lab also concluded that for residential buildings, rehabilitation creates 50% more and better-paying jobs than new construction (Preservation Green Lab at the National Trust for Historic Preservation, 2011), supporting the similar calculations of Rypkema (2005). These are important considerations to take into general consideration when conceptualising and implementing Smart and Sustainable City programmes.

The Preservation Green Lab conclusion that the '…reuse and retrofit are particularly impactful in areas in which coal is the dominant energy source and more extreme climate variations drive higher energy use' has specific relevance in South Africa where 92,6% of all electricity produced in 2015 was coal-based (Modise *et al., s.a.*).

2.2 Built Fabric: Investment or Resource?

'Sustainability is implicit in a smart city' (Kondepudi & Kondepudi, 2015). It is estimated that 40% of all resources extracted from our planet are used and stored in our built infrastructure (Van Bueren, 2012; Young, 2015). This is a large investment and potentially is also a latent resource. On example of such a latent resource approach the Prospecting the Urban Mine of Amsterdam (PUMA) research project of the Amsterdam Institute for Advanced Metropolitan Solutions, set out to map those material resources that are locked up in the built fabric of the city of Amsterdam. Their focus was limited to metal stocks in buildings for practical reasons. The project located these resources geographically and attempted to understand the conditions under which these resources could be exploited as part of a circular economy. (Van Der Voet *et al.*, *s.a.* [2016]). According to the authors of the PUMA end report the '…aim is to keep resources in use in society in some way, to prevent creating waste and to reduce the need for virgin materials.' The stocks of materials contained by buildings that are in use are, of course, not directly available for mining as is acknowledged in the PUMA report. Peoples attachment or policy will dictate that categories of buildings – be they in use or not – cannot be mined, because they represent more value than only as embodied 'raw' materials. They may also present historical, cultural and other values.

The re-use of buildings has even been called the 'ultimate' form of recycling (Young, 2014); their in-situ curation a priority (Young, 2015). The World Bank has found that: '…the key economic reason for the cultural patrimony case is that a vast body of valuable assets, for which sunk costs have already been paid by prior generations, is available. It is a waste to overlook such assets, yet much of the existing patrimony is insufficiently activated and lies dormant' (World Bank, 2001).

This provides a clear argument for the need to investigate maintenance regimes as means to ensure that the state of conservation of materials and components will allow for their longevity: a precondition for the longevity-of-use of the buildings they form part of.

3. A Common Technical Heritage in Contextually Dissimilar Environments

The history of permanent settlement and construction in South Africa has a strong Dutch connection (Bakker *et al.*, 2014, Greig, 1971). The historiography has mostly been written from a historic and art-stylistic perspective. Bierman (1955) was a notable exception. He describes how Dutch building technologies fused with other traditions to suit local conditions at the Cape of Good Hope. Early attempts at brick making by early settlers failed, but they brought with them some knowledge of lime and rubble construction, assimilated from Portuguese and Spanish colonialists in other parts of the world. This became the mainstay of construction of what is today regarded as the Cape-Dutch legacy. This legacy is arguably the best-known built heritage typology in South Africa and important for the identity of the Cape, its success as tourism destination and it serves as drawing card for highly educated inhabitants and the creative industry.

Dutch-South African bilateral relationships have spanned 400 years. As the Dutch and other settlers expanded northwards more extreme and varying climatic conditions than those encountered on the Peninsula were encountered. These differed greatly from the Netherlands and Flanders with its rather uniform climate, now identified as a single Köppen-Geiger climate zone coded Cfb: warm temperate, fully humid, warm summer (Kottek *et al.* 2006). South Africa has a much more varying climate with 13 Köppen-Geiger zones identified by Conradie (2007), based on 20 years of data collected by the South African Weather Services. These range from arid to warm temperate zones. This means that many climate-based adaptations to early traditional construction methodologies can be expected, but also that industrially informed construction processes had to be modulated to suit climate and context during more recent times.

From a construction-technical perspective three periods of Dutch-South African exchange can be identified: the pre-industrial; the early industrial and the mature industrial.

3.1 Pre-industrial

The Pre-industrial is characterised by the central role of the craftsman and a simple limited pallet of materials: earth, timber, stone and lime (Figure 1). Brick and tiles were imported from the Netherlands to South Africa as ballast in ships during the seventeenth and eighteenth centuries. Climate adaptations led to unique vernaculars such as stone-constructed corbel houses and turf-roof construction in hot and arid areas. However at the same time large structures were also constructed, as were infrastructure and water works, as well as military structures all of which called for specialist expertise. The various vernaculars slowly developed and held sway for over 200 years in parallel to other indigenous vernaculars until industrialisation brought about a revolution in constructional methodologies.

Figure 1: Failure of an uninformed repair project in the historic mission town Wupperthal, South Africa. Soft mud brick construction with later Portland cement plaster leads to façade failure (N. Clarke, 2013).

3.2 Early Industrial

The gold fields of the Witwatersrand discovered in 1886 became the motor for the industrial revolution in South Africa: a period that saw the introduction of new building typologies, mass-produced components and closer service-systems integration into the architectural realm than encountered before. This integration of system services has already been explored for the European and North-American context by Reyner Banham as far back as 1962 (Banham, 1962) but remains to be explored for the South African context. The new-found mineral resources drew fortune-seekers from all over the planet, but of specific interest to South Africa, also stimulated the emigration of architects and engineers to the then South African Republic or Transvaal, where the Department of Public Works (DPW) was staffed predominantly with Dutch staff (Bakker, 2014). During a short period of thirteen years, this department not only transformed the cities of the Transvaal, they installed a much-needed modern road infrastructure and developed waterworks. For this they looked initially to Europe to source their materials and components. They soon stimulated local industry, building on their own extensive body of cutting-edge construction knowledge. It is inevitable that the changed context they found themselves in would influence their constructional thinking. Soon their buildings presented climate responsive thinking with, for instance, the inclusion of the South African ‘stoep’ as a near stock-standard device into their architectural quiver.

This period of influence is not only limited to the northern provinces of South Africa. Dutch architects were also active in, for instance Cape Town where the first skeleton-frame steel high-rise building, the Chubb and Maxwell Building, was completed to the design of Dutch born and trained architect, Anthony de Witt (Louw, 2014).

Typical for this period is the transition, and therefore fusion, of traditional craftsmanship and local small scale and imported mass-production. This produced both an eclectic expression of style, as well as a rich and eclectic use of materials and components often following a – often experimental – construction logic. The use of natural stone, especially local iron rich sandstone, became part of the architectural vocabulary. In so doing, local natural stone use supplanted the use of expensive imported natural stone from Belgium (De Jong *et al.,* 1988) or artificial stone elements for which the Dutch Nederlandsche Cementsteenfabriek was a main supplier. Throughout this period, the foundry of F.W. Braat of Delft supplied cast- and wrought iron components on a large scale for DPW deigned projects (Hoorn, 2003).

The same period saw the development of rail infrastructure in the former Transvaal, undertaken by the Nederlandsche Zuid-Afrikaansche Spoorweg-Maatschappij (NZASM). This Dutch company was active in South Africa for a short thirteen years but had a large and lasting impact. The engineers employed in the construction of the line were almost all educated at the Delft Polytechnic, the precursor to the Delft University of Technology. At this institution’s ‘Indische instelling’ (transl. Dutch East-Indian institutions), young engineers were prepared for a professional career in the tropics of the then Dutch Indies, today Indonesia. This education however was equally useful in the sub-tropical South African Lowveld. Besides their specific training in architecture, engineering or even mining, all Delft engineers – whether being trained for the tropics or not – were intensively trained in building materials by prof. J.A. van der Kloes (Quist, 2015).

Figure 2: Climate adaptive designed staff housing at Kaapmuiden Station on the NZASM Eastern Line dating to c.1898. The double roof and large overhangs were a response to the hot and humid conditions of the Mpumalanga Lowveld (N. Clarke, 2016).

The NZASM sourced a number of Delft-trained engineers from the island of Semarang in the Indonesian archipelago to plan and design the line and its ancillary structures between Pretoria and Komatipoort. They brought Delft-based knowledge, augmented by their tropical experience and know-how with them (Bouten, 1941). The NZASM also stimulated construction innovation, implemented new construction materials and techniques and adapting Dutch technologies to local conditions from a purely pragmatic perspective (Jong *et al.*, 1988; Barker, 2014). Contractors of Dutch decent also started to make their mark.

Today buildings with climate specific adaptations built by the NZASM, including double-ventilated roofs and wrap-around verandas (Figure 2), still exist (Clarke *et al.*, 2016). Much of this valuable transport infrastructure is still in daily use today (Clarke *et al.*, 2016) and its sustainable maintenance an issue of national economic importance (Doke, 2015; Bulbulia, 2017). The period we have chosen to define as the Early Industrial came to a close with the Anglo-Boer War (1899–1901).

3.3 Mature Industrial

After the afore-mentioned war, the stream of mass-produced building components destined for the northern provinces of South Africa was diverted from the Netherlands to Great Britain. Yet, the familiar relationship between the Netherlands and South Africa persevered. Geo-political conflicts and economic depression in Europe stimulated emigration from the Netherlands to South Africa, where gold mining averted the effects of the global economic downturn for a while. On-going research indicates that among these émigrés were many Dutch architects and tradesmen who took with them their technical skills and knowledge of building materials (Clarke et al., [ongoing]).

Concrete was the subject of much experimentation in the Netherlands during the inter-war years (Heinemann, 2013). In South Africa this subsequently found application not only in architectural designs but also in for instance the construction of cooling towers for power stations of the type developed by Frederik van Iterson. Relations between the Netherlands and South Africa cooled down substantially during the Apartheid years, but the influence remained resilient.

The Mature Industrial has strong associations with the use of concrete, be this for infrastructure, industrial projects, residential, civic or other construction typologies (Figure 3).

Figure 3: A lamppost at the Sea Point Swimming Baths, Cape Town, attributed to Dutch architect, Jaap Jongens. Spaling, cracking and exposed corroded reinforcement of concrete in a marine environment. This column also exhibits the effect of uninformed maintenance work, especially evidenced by the new pointing (N. Clarke, 2015).

4. A South African Dilemma

South African construction industry has historically focussed on new-build and subsequently the country does not have a well-developed material conservation sector. A small hand-full of architects have in the past delivered exceptional conservation projects, but most of them are not in active practice anymore and they have little influence on contemporary conservation practice today. This manifests clearly in conservation of heritage buildings, where well-meaning attempts at material conservation lead to further damage (Figure 4).

The 2004 restoration of the Garrison Church on Robben Island, a World Heritage property, is a well-documented, but not exceptional, case. This church was constructed by inmates of the Robben Island prison in 1841 to the design of Sir John Bell utilising soft-burnt brick, covered by a lime-based plaster layer. It had been restored at least three times during its lifetime: during the Second World War, 1964 and the 1970's during which occasions, areas of lime plaster were replaced with a Portland cement plaster. Because of poor monitoring and maintenance, many components - including the main doors of the building - had to be replaced with replicas (Viney, 2014/2016a). During the 2004 project, a new Portland Cement-based plaster layer was provided to the exterior, because, the argument went, of the predominance of similar plasterwork on the rest of the structure, ignoring the nature of the substrate and the possible long-term implications of such a decision. This new plaster layer started to fail within one year of application; one reason postulated for this is that seawater had been used to mix the render applied to the soft-fired brick and lime mortar walls instead of fresh water. Since the 2004 restoration, which included the application of the new plaster layer, the walls of the building have also started to exhibit damp problems on the interior (Viney, 2014/2016b).

The lack of materials conservation knowledge extends to the general maintenance of constructions, for instance concrete, where reactive repair is the norm because pro-active maintenance regimes have not been sufficiently developed. This effectively places the investment in built fabric at risk and undermines potentials of this investment – which is concentrated in cities – as resource. This lack of knowledge adversely affects the life cycle expectation of structures.

Specific lacuna already identified (Clarke *et al.*, 2015) include the identification, maintenance, diagnosis and repair of:

- sandstone building components;
- lime mortar-based constructions;
- maintenance and repair of soft brick, especially when used as face brick;
- façade cleaning and maintenance;
- historic concrete.

A further problem that requires urgent investigation in South Africa is the damage caused by salt migration in historic materials.

Figure 4: The Old Government Printing Works in Tshwane (1898), constructed of soft brick. The parapets were replaced with an incompatible harder brick in the late 1990s leading to salt efflorescence and disintegration of the softer brick. The line indicating the transition from original to later material is indicated (N. Clarke, 2014, adapted).

5. Future Collaboration

'A smart sustainable city is an innovative city that uses information and communication technologies (ICTs [Information and Communication Technology]) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects' (International Telecommunication Union Focus Group on Smart Sustainable Cities, 2014). A sustainable city or living environment in general should be our aim and ICT can bring us there, but to be really smart and innovative, people need to connect to and understand the developments that are required. It's our belief that (built) heritage can present such a connection, because everyone is able to physically and mentally connect to the continuity in the built environment.

Historic materials have been shown to exhibit surprising qualities, such as the self-healing nature of lime-pozzolana renders, discovered at the Delft University of Technology and TNO (Nijland *et al.*, 2007). Historic systems are also receiving renewed interest. The principles of buoyancy ventilation in collaboration with earth-tubes for passive cooling and ventilation are finding new application today. This is the case even in the Netherlands where due to climate change summer cooling is fast becoming a requirement. A system utilising soil tubes to pre-cool and pre-heat intake air has recently been installed at the manor house of the Bingerden Estate in the Dutch province of Gelderland, for instance.

The variations of climate and context also mean that the composition of mortars can be expected to have altered differently over time. This mutation contains empirical context-specific knowledge with wider material application. The application of construction systems may have also lead to systemic problems. These building pathologies can be addressed, providing case-specific long-term solutions with low maintenance frequencies (Van Hees *et al.*, 2014). A good example of such a bespoke solution is the salt resistant plasters developed specifically for application to historic structures in Curacao (Groot *et al.*, 2009).

For urban operation to be efficient, it needs to include a pro-active management of the invested resources in the urban fabric. At the same time, the knowledge embedded therein needs to be operationalized where this can benefit sustainable development. This understanding forms the basis of a two-pillared approach we propose for collaborative South African - Dutch built environment materials and systems research:

a) Embodied knowledge to inform development:

The first approach would mine the aggregate knowledge embodied in historical structures for application in development of materials and components. Historic South African - Dutch ties allow for cross-contextual comparison of ageing, weathering and other context-related application and deterioration processes. Of course climate and other contextual factors will need to be taken into account: but these variants may prove interesting for comparison. The method could be based on the system developed by Quist (2011) where different (Dutch) cases were investigated and compared on their history regarding the conservation and replacement of natural stone. At the same time the evolution of exported construction techniques in response to different context can also inform materials development.

b) Maintenance and regeneration of embodied material resource investments:

It is clear that the monitoring, maintenance, diagnosis and repair of materials present a challenge for the sustainable city in South Africa. This is a lacuna to which the Netherlands with its long built environment monitoring tradition – exemplified by the Monumentenwacht (monuments guard) monitoring structure and its various organisations – and conservation tradition can contribute. To this the Heritage & Technology Chair – Department of Architectural Engineering + Technology, can bring its expertise on natural stone, historic in situ cast and pre-cast concrete identification analysis and repair, historic and purpose-designed mortars, salt crystallisation damage, maintenance and management systems and façade cleaning and maintenance. Much can be learnt from both partner countries, not only of the damage or the lack thereof caused by the two vastly different climates regards technology of maintenance and repair.

The Monumentenwacht of the Netherlands, investigated by Van Hees *et al.* (2015), could prove to have viable application in South Africa where such a system is lacking. This application could reach beyond monuments and find application in the larger built environment.

Where knowledge and know-how exits, this needs to be operationalized in a smart systems-based manner. A start has been made at the TU Delft through the Masonry Damage Diagnostic System (Van Hees & Naldini, 2002; Van Hees *et al.*, 2009). This was later developed within the framework of the national 'MonumentenKennis' (transl. monument and knowledge) programme into the Monument Diagnosis and Conservation System, which includes categories for brick, mortar, natural stone, plaster and structural damage (www.monumentenkennis.nl, 2017). These knowledge-based systems guide the process of diagnosis of damage to traditional brick and stone masonry structures. Integrated Building Information Monitoring (BIM) systems offer further opportunities for operationalization. The use of BIM in facility operation of extant structures is hampered by a lack of information on the construction standards, material qualities, construction methods, etc. The methods of mapping of material components embodied in the urban environment employed in the aforementioned AMS PUMA project could inform adaptive re-use projects with an aim to retaining the materials with the highest cradle-to-cradle environmental impact, but also assist in developing inspection and maintenance regimes through cross-reference to other datasets such as cadastral databases containing dates of construction etc.

6. Conclusions

The shared construction history, which developed further in divergent climate and cultural contexts, offers opportunity for investigation and re-application. Most obvious is the potential that climate-adaptive systems hold to inform current and future construction. A case in point would be the late nineteenth century application of buoyancy ventilation in combination with earth tubes at the Palace of Justice in Pretoria (Figure 5), the potential application of which is not limited in application to massive structures, but could inform ventilation systems for new innovative light-weight construction regimes.

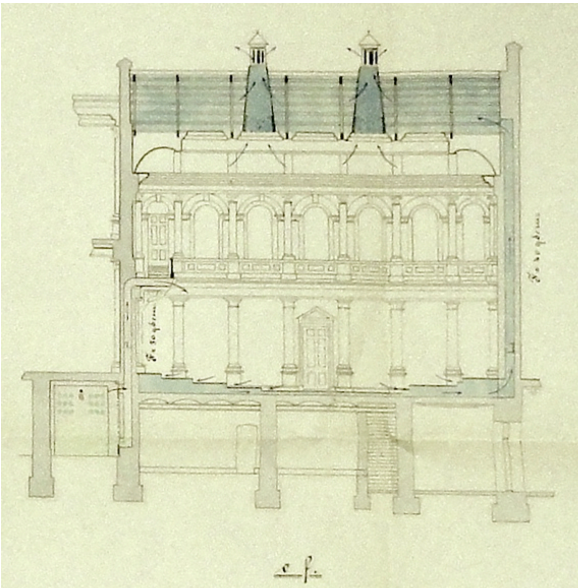

Figure 5: Cross section of the Palace of Justice, Pretoria, 1897–1902, showing the ventilation strategy employed (South African National Archive TAB, PW 166).

The potential mutual benefit of collaborative Dutch-South African research into the commonality of built material investments in the built environment calls for:

Theme *Materials*:

- A careful understanding of the characteristics of materials, both contemporary and historic;
- the study of decay processes;
- identification of urgent lacunae in materials maintenance and repair knowledge systems (some indications already exist);
- monitoring techniques and damage diagnosis methodologies;
- technically correct maintenance and repair;

- prediction, planning and monitoring of maintenance processes.

Theme *Construction logic*:

- Assessment of historic construction systems, including Life Cycle Assessments;
- evolution through mutation of typologies;
- climate responsive systems, their introduction, development and perseverance through time.

Theme *Smart systems*:

- Integration of material maintenance regimes into Smart City management and urban operation systems; and
- development of BIM systems of extant (historic) buildings.

To further develop the embedded aggregate knowledge resource presented by the embedded material residue of the shared South African-Dutch construction history, we propose to first conduct an overview of shared construction methodologies and historical material and component flows. This can be explored through archival sources, structured according to the periods defined above. We envisage a database on shared materials and components containing their context-based decay and repair methodologies, where these exist. This can inform further research either into the successes of evolutionary mutations or the development of different diagnosis and repair strategies that are context responsive.

Parallel research could focus on the modification of built form in response to climate and context variants as well as the emergence of vernaculars from imported prototypes. This knowledge can find application in contemporary context-responsive energy-neutral construction regimes.

The conclusions of for instance the Urban Green Lab of the National Trust of the USA (2011) prove that re-use is the most sustainable future option for extant built fabric, be that urban or rural. It is therefore imperative that the maintenance of the embedded materials with their embodied energies form an integral part of Smart and Sustainable City ecologies of practices. We need to develop holistic and smart maintenance procedures, taking into account the broader meaning of value, for the maintenance and regeneration of those embedded material resources contained by buildings and structures as an essential part of the *reduce-reuse-recycle* efficiency of smart and sustainable cities. They present an aggregate value investment that deserves stewardship.

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