

Architecture for Life: exploring regenerative and resilience thinking

Ms. Edna Peres

Department of Construction Economics, University of Pretoria, Pretoria
Email: edna.m.peres@gmail.com

Dr. Arthur Barker

Department of Architecture, University of Pretoria, Pretoria
Email: arthur.barker@up.ac.za

Prof. Chrisna du Plessis

Department of Construction Economics, University of Pretoria, Pretoria
Email: Chrisna.duplessis@up.ac.za

As built environment theory evolves, so does the awareness that built environments form an integral part of natural systems. Living systems are capable of renewal and regeneration, resiliently adapting to pressures and disturbances in order to sustain life and avoid environmental collapse. Through this perspective, the role of architecture in our cities can be seen as an opportunity to catalyse renewal in the urban system by working with and integrating various systems of life. Using the theme of water, this paper explores the latent potential of degraded urban sites to inform architecture that unlocks processes of renewal, resilience and regeneration in natural and social systems.

An Ecological perspective

Many modern cities have been shaped by an Enlightenment worldview in which nature was seen as separate from humans and their habitats - a force to be controlled and bent to the service of humanity. Natural systems became resources to be exploited without consideration for the long-term effects on their vitality and human well-being; this in spite of the fact that humans have an inherent need to be part of nature and its processes (Wilson, 1984; Kellert, et al, 2008). This reductionist scientific thinking sought to “simplify the urban system and make it intelligible by breaking it down into sub-systems, whose individual optimization leads to the sub-optimization of the whole” (Salat, 2011: 476). Today, the disconnection between built and natural environments threatens the physical functions of cities along with the physiological and psychological health and well-being of its citizens.

One response is to see the city as an ecosystem (e.g. McHarg, 1967; Lyle, 1994; Rees, 1997), instead of an engineering and economic system, drawing on ecological thinking to define the practices and study of urban sustainability. This has led to several approaches: urban ecology; using ecological concepts as metaphors or guidelines for human activities (e.g. urban metabolism, ecological footprinting, resilience); and using nature itself as the metaphor to guide the physical development of cities (e.g. ecological design and engineering, biomimicry). These approaches are founded in an emerging worldview that reintegrates humans and nature as partners in the biophysical world; cities representing social-ecological systems (SES) (du Plessis, 2008). The ecological worldview recognises the inevitability of change and that sustainability has more to do with sustaining the quality and diversity of life on earth, than sustaining the status quo. The far-reaching ecological, social and economic systems changes expected in the 21st century will change the world as we know it. Sustainability represents a search for strategies that can enable humans to navigate radical changes, allowing them to rebuild and redesign their world into one where life can flourish (du Plessis, 2013: 35). From this proactive perspective, two complementary concepts,

resilience and regeneration, emerge. They provide powerful strategies for this transition and while neither field is new, their application to the built environment is still in its infancy.

Urban resilience can be described as the capacity of a city to absorb or adapt to change brought about by slow pressures or rapid pulse disturbances. It is a passive quality, representing “the life sustaining aspect of nature that yields to external forces and in that yielding keeps the system from failing or being destroyed” (du Plessis, 2013: 35). Cities can experience both ‘positive’ resilience, brought about through healthy diversity (e.g. alternative roads to avoid a traffic jam), or ‘negative’ resilience brought about through lock-in (e.g. politics stalling the provision of well-located affordable housing and amenities). At times the goal of creating a thriving city may necessitate that a system is allowed to collapse and regenerate. This places a responsibility on professionals hoping to be ‘resilient and regenerative’, in that they must be able to identify which aspects may need to collapse in order to provide room for new life to take root in a site’s latent potentials (du Plessis, 2013: 38). Transformative resilience recovers a system's health (Chapin, et al., 2009; Gotham and Campanella, 2010) and is brought about through regenerative design, an active and creative quality that renews the system, which sees projects as “engines of positive or evolutionary change for the systems into which they are built” (Haggard, Reed & Mang, 2006). The point of departure for the projects discussed in this paper is to build conditions for life to regenerate degraded sites requiring systemic transformation in Pretoria.

Latent potential: Pretoria’s freshwater systems

The story of disconnection from natural systems in Pretoria is ironic, since its connection to water was integral to its establishment (Dippenaar, 2013: 6). The abundance of water and game drew many communities such as the Bakwena in the 1600s and the Matabele in 1825 (who were evicted by Zulu impis around 1832) (Andrews and Ploeger, 1989: 2) to settle in the area between the Apies river and the Steenovenspruit. British and Boer settlers began to arrive thereafter and in 1853 portions of the newly established Daspoort and Elandspoort farms were consolidated to form the town.

As Pretoria evolved, from settlement to city, the demand on local water sources could no longer be sustained (Dippenaar, 2013) and so the unmaking of the city began. Water was mainly sourced from the Apies River through furrows, but the river would often burst its banks damaging buildings and endangering humans (Engelbrecht et al, 1952, 66). In 1863, the *Zuid Afrikaanse Republiek (ZAR)* increased water supply by accessing two springs at Fountains Valley. The visibility of water diminished after the early 1890s when a weir was constructed just below the upper and lower fountains to feed water through brick lined furrows with slate covers along the streets (ibid, 1952: 26). Andrews and Ploeger (1989: 6) describe the early town as “disorganized; water from the aqueducts (water furrows) overflowed and the streets needed urgent care”. The 1880 floods (Engelbrecht et al, 1952: 100), led to the decision to canalise the seasonal Apies, Steenoven- and Walkerspruits streams, thus obscuring and eroding the natural flow of the original arteries, denigrating rivers to storm water channels (Jordaan, 1989:28). These were eventually sunken underground and now present a high risk for sink holes. In most instances, the city’s support systems and indicators of vitality have been removed far from sight, distancing the connection and perpetuating the deterioration of the system. The crisis of urban water quality and quantity is becoming so acute, that many are recognising it as a pronounced environmental problem (Dippenaar, 2013) making the protection and regeneration of this natural resource paramount to the resilience of Pretoria.



Figure 1

Pretoria in 1886 as seen from Daspoort Ridge. In the foreground, is the confluence of the Apies River and Steenovenspruit. (Le Roux (ed), 1991: 64)

Points of opportunity: remaking the city through the regenerative power of water

The restorative and regenerative qualities of water have been recognised by urban dwellers since ancient times (Kellert, Heerwagen and Mador, 2008). Conversely, dysfunction in a city's water systems can have disastrous consequences. Pretoria's relationship to water and its influence in the 'making', 'unmaking', and possible remaking of the city, is investigated through four Masters theses exploring regenerative architecture in neglected sites: Ingmar Büchner examined latent potentials at the Monument Park Quarry, Heidi van Eenden investigated industry at the Daspoort waste water treatment works, Marié Cronjé tapped into networks at the Steenovenspruit Canal, and Carla Taljaard explored transformative processes the Era brickworks¹. Abuse of water systems in these sites resulted in a reduced ability to provide services such as clean water, social amenity and economic activity. This begs the question: in systems which have collapsed or are at the brink of collapse, how can; a) collapse be transitioned or sped up; b) the latent potentials be harnessed for new uses, and c) existing narratives inform new interventions that build on positive qualities rather than trying to 'fix the problems'? This informed the following investigations which aimed to make the symbiosis between water system and its social system resilient in adapting to change, and regenerative in its functioning.

Monument Park Quarry: Destructive human action mitigated by placed-sourced potentials

The Rosema and Klaver coal-fired brick factory started production in 1933 (van der Merwe, 2013: 41) utilising a clay deposit in Monument Park. The site has had many "vocations, from ecological habitat, to resource deposit, productive industry [and finally] to a naturally reclaimed habitat" (Büchner, 2013:20). Although the quarry enabled the construction of the surrounding fabric (Fig. 2), its intrusive operations met with community pressure in the 1980s, resulting in a court order giving the company 10 years to close down. Invasive Black Wattle species, which further compromised ecosystems, were introduced to mitigate noise and dust. Mining operations were curtailed when the quarry excavation hit one of many underground springs, and this together with economic pressures and a workers' strike, resulted in the mine closure around 1993 (van der Merwe, 2013:40). The site is currently inhabited by a small group of homeless people and its infrastructure, partially demolished for safety reasons, is now overgrown. While the 'unmaking' of the quarry site began through mining activity, it unlocked ecological potential in the form of a large water body. Without an

understanding of this new potential for social and ecological regeneration on the site, it risks becoming another gated estate in a city already suffering the consequences of this typology.



Figure 2

The quarry site in 1976 surrounded by the transforming Monument Park (Büchner, 2013: 29).

The latent and patent potential of the quarry site water body, provides opportunities for social and ecological resilience (Fig. 3) represented by three 'potential sets' (Büchner, 2013:34-47). Social potential exists in the recreational and functional benefit the water body offers surrounding communities (Büchner, 2013: 38), fostering leisure activities and experiential qualities. Historical potential is evident in residual industrial infrastructure; remaining building materials can be reused in new buildings, while extant fabric tells the story of place through original functional operations informing new production processes. Bio-physical potential exists in the landforms, micro-climate, ecology and large water body; the by-products of clay mining are not too pollutive so invasive flora can be replaced with indigenous species to attract more fauna and increase biodiversity.

Production, education and recreation are the functional responses to the potentials of the site. Integrated fish farming (aquaculture) is introduced in a closed loop system where by-products of one process feed another. These processes include algaculture (algae farming), moriculture (mulberry farming) and sericulture (silk production) which foster industrial decentralisation, artisanal industry and natural water treatment processes. Educational facilities provide new knowledge either directly, through lectures or tours; or indirectly through movement routes which intersect historical elements, production processes and the natural topography of the site. Recreation is provided through restaurants, nature walks and water activities. But more importantly, the architecture is made and organised in a manner that allows visitors and inhabitants to reconnect with nature. Building forms align with and are formally influenced by existing landforms and water bodies. Extant ruins determine the architectural pattern for new production spaces, land forms and water define edge conditions, while new experiential routes cross these elements creating internal and external pathways. Together, these interventions mitigate past destructive and mono-functional mining processes through recreational and spatial linkages to the surrounding community, sustainable small-scale production and commercial prospects that extend beyond the boundaries of the site.

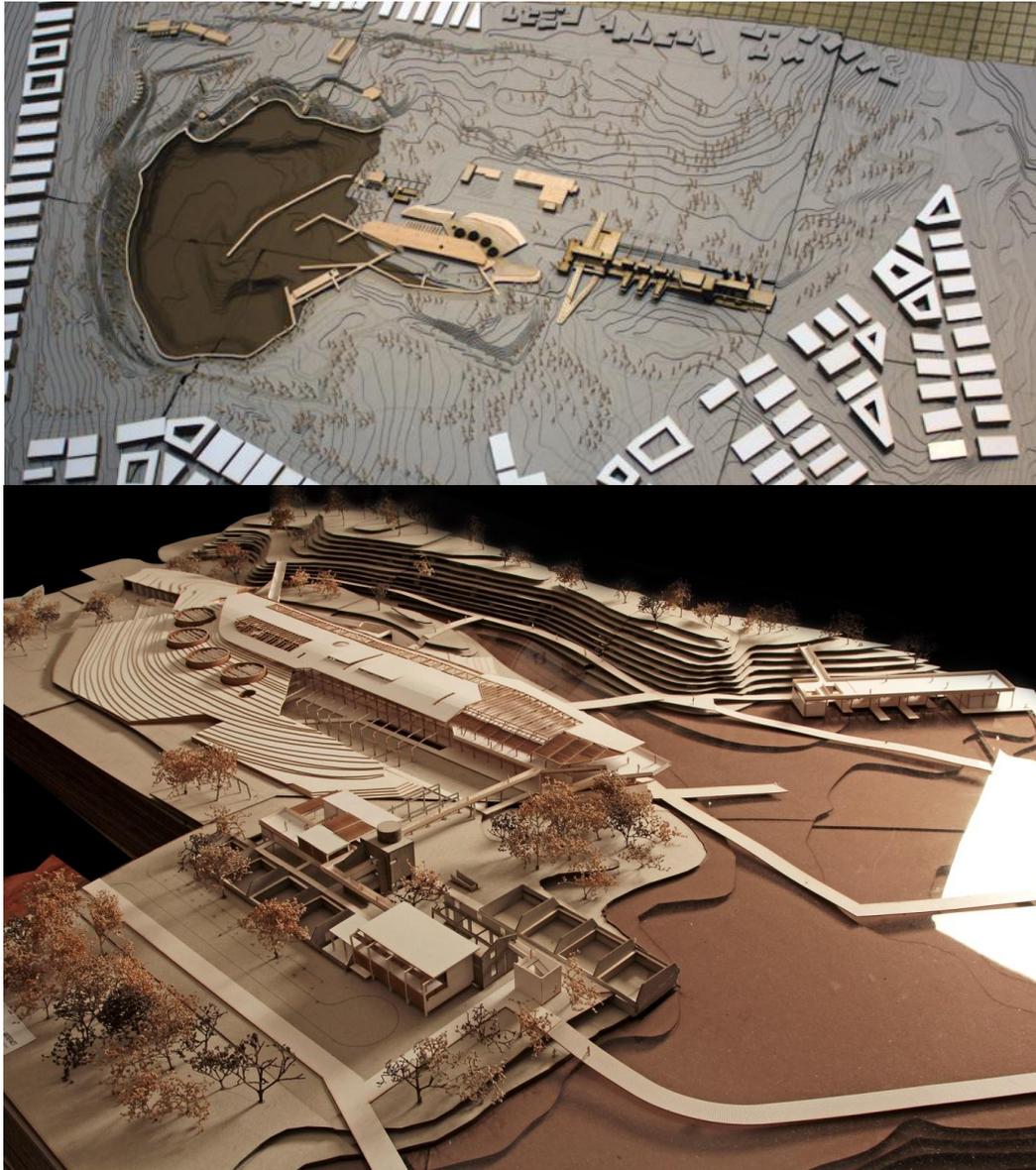


Figure 3

Top: The final site model showing the water body and various agricultural facilities housed in and alongside the new building located in the centre of the site (AuthorB, 2013). Bottom: Model of the facility with adapted heritage fabric in the foreground (Buchner, 2014)

Daspoort waste water treatment works: the politics of separation alleviated by a bio-mechanical machine

North of Marabastad, a culturally and historically significant district and transit node, is the Daspoort waste water works constructed in 1913 (Fig. 4) in response to polluted water furrows. It was erected at the confluence of the Apies River and Steenovenspruit (Jenkins, 1955: 364) separating the community from a valuable resource. This was exacerbated by the canalisation of Steenovenspruit in the 1920s and later, the railway line, Bel Ombre station and an incomplete freeway project. The plant's infrastructure has been upgraded overtime; leaving in its wake abandoned structures and out-dated technologies of which at least a third is currently unused or underutilised.



Figure 4

Daspoort waste water works site with settling tanks in the foreground, left-over Marabastad heritage to the right and in the background the Daspoort ridge (van Eeden, 2013: 6-5).

The site provides opportunities to link Marabastad with its historic natural border, preventing further degradation, and allow new resilient production processes to improve the local economy. A proposed twenty-first century textile mill reflects the architecture of a 'living machine' (van Eeden, 2013: 8_6)². Unlike traditional production processes that drain natural resources, the new textile mill acts as a bio-mechanical device that links industry with nature and the community with economic opportunities. The 'Machinarium' (ibid, 2013: 1_3) consists of interactive parts that "have some form of life, and are therefore unpredictable and largely uncontrollable" (ibid, 2013: 8_6). The western edge of the mill borders part of the existing water treatment works and acts as literal and metaphorical filter of water and production processes. Mills tend to consume large quantities of water, but 'Machinarium' takes over some of the functions of the Daspoort plant by directing water through an "architectural aqueduct" (ibid, 2013:8_10) before being discharged through a series of filtering ponds into agricultural fields and the Apies River (Fig. 5). Water is also used for hydro power, steam generation, algae cultivation, evaporative cooling and irrigation (ibid, 2013: 8_19). To the east, the truncated Jerusalem Street which formed part of the original Marabastad settlement is extended to the Apies River, reconnecting the inhabitants with nature.

Industrial activities are visibly and tangibly exposed on the eastern edge of the mill where steam used to drive the rotating wheel of the mill is expelled over the main public square. Spatial experience is heightened by algaculture water walls filtering daylight and dying processes exhibited through colourful canopies. New functions such as fashion, education and craft provide the visitor and local inhabitant with economic opportunities. An existing water furrow that is possibly part of the old water supply system of Pretoria, is given new life as a storm water garden that feeds the adjacent fibre growing fields. The old Marabastad church is enveloped by a pond celebrating its historical significance and renewal. "By exposing water as an architectural device, hydrology becomes an embedded layer of the human environment and is no longer seen as a separate natural resource" (ibid, 2013: 8_10). The "Machinarium" breathes life into a disconnected and derelict environment. Water is used and reused to limit waste, decrease pollution and increase future hydrological possibilities. Inhabitants can access new opportunities and the haptic and functional advantages of connecting to nature. A true 21st century mill adapts the old, mitigates the present and postulates a resilient future.

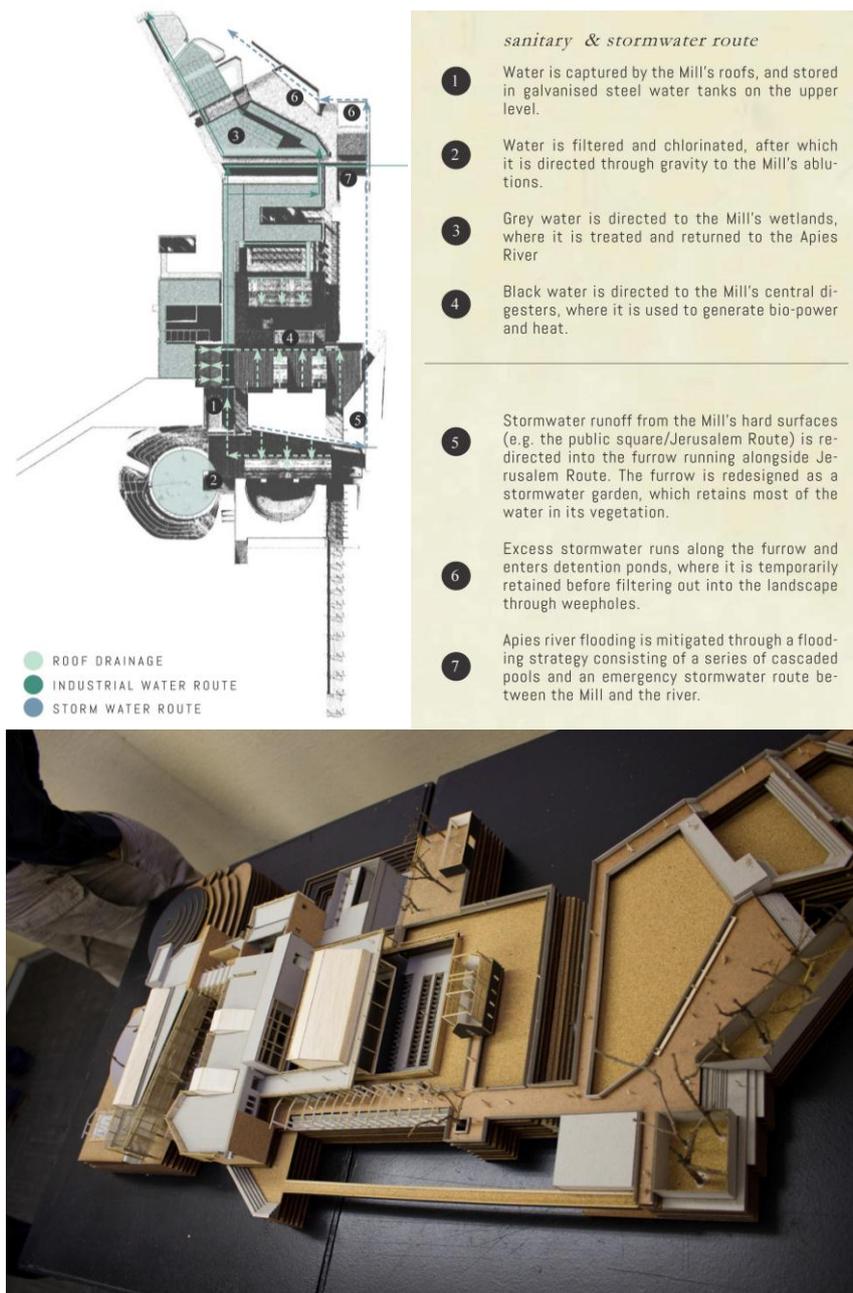


Figure 5

Top: Systemic principles for water use in the Machinarium (van Eeden, 2013: 9-18 to 9-19) and bottom: photo of model (AuthorB, 2013).

Control versus opportunism: systemic participation in Marabastad using the Steenhovenspruit Canal as a source of transformative resilience.

Initially, the Steenhovenspruit formed a natural boundary between racial groups that was aggravated by canalisation during the 1920s and which perpetuated the social-ecological unmaking of the city. Between 1938 and 1965, Marabastad was affected by forced removals and extensive demolitions of its fine-grained urban fabric (Cronjé, 2013: 56). Only the Boom Street precinct remains as evidence of a suburb previously described as the only area in Pretoria exhibiting the complex characteristics of a true city (Le Roux (ed). 1991: 109). Today, in the absence of adequate services, trade and opportunism (Cronjé, 2013: 57) extends to the use of the Steenovenspruit as a sheltered hiding place to wash or discard waste (Fig. 6). Marabastad's culture of opportunism is highly resilient and a source of economic energy,

however its resilience is sustaining perverse activities that are inhibiting local social and ecological well-being. Past strategies have focussed on ‘fixing the problem’ by eradicating negative aspects rather than understanding this resilience or its regenerative potential.



Figure 6
The canalised Steenovenspruit and surrounds in 2013 (Cronje, 2013: 69).

Augmenting the service provided by Steenhovenspruit can be achieved by increasing direct dependence on its resource, thereby encouraging more responsible water use (Kellert, Heerwagen and Mador, 2008). The proposed design on a site adjacent to Steenovenspruit and Boom Street makes water more accessible and builds on “various and diverse interactions between different actors within existing systems” (Cronjé, 2013: 123). Social and ecological interactions were mapped and then systemically integrated to generate an architectural solution that builds on historical production (beer brewing, bread baking) and existing trade. Interactions were grouped into three networks; ‘natural’ is seen as the primary and all-encompassing driver of regeneration, subsequently embracing ‘social’ and lastly ‘economic’ renewal.

The ‘natural’ driver is tackled by filtering polluted canal water through wetlands and retention ponds upstream. Canal banks are stepped using vegetated gabions and widened to mitigate flooding and improve visibility. The base flow in the canal is diverted into the building where a spiral pump generates electricity. Rain water is harvested and treated for use within the building and to irrigate productive gardens while permeable surfaces allow excess rain water to replenish the groundwater table. Perishable foods currently discarded by traders on site, becomes ‘harvested’ for brewing or composting within an integrated collection space in the ground floor; ‘social problems’ were harnessed for their potential to strengthen ecological networks. The ability “to recognise and exploit opportunity” (Cronjé, 2013: 40) as demonstrated through Marabastad’s resilient history of rebellion against control through subletting, illegal beer brewing, and informal street trade for example, is harnessed. Building edges encourage ‘exploitation’ while social spaces link to the canal. The characteristic Marabastad retail street edge typology along Boom Street is continued to support the strong networks between formal and informal economies (Fig. 7). By integrating existing practices, natural cycles and social interaction, architecture becomes the source of regeneration of the broader environment, feeding tangible and intangible potentials of life.



Figure 7

The final model with canal centre right, social spaces under the pergola, spiral pump system with water tanks in the centre and formal retail on the street edge left (AuthorP, 2013).

Confluence of potential: reversing industrial stigmas at the Era brickworks

The convergence of the Moreletta and Rietspruit rivers in Silverton was influenced by three significant factors (Taljaard, 2013: 12). Firstly, a third trade route north through a fault in the mountain range stimulated industrial production. Secondly, the deposit of silt and other soils ideal for clay brick manufacture enabled the establishment of the Era brickworks (Fig. 8). Lastly, political forces perpetuated racial segregation of communities on either side of the rivers by use of an industrial buffer zone. The brickworks lie within the buffer, but depleted clay levels have made quarrying unfeasible and production is in its final decade. Social amenities built within the buffer zone have had limited success, while park areas remain unsafe and cut off, perpetuating the stigma of industrial activity.



Figure 8

The Era Brickworks with clay factory in foreground and Rietspruit top right (Taljaard, 2013: 20).

The brickworks closure will profoundly affect the broader area. This revolutionary phase in the long-term evolution of the site is seen “not as loss or abandonment of obsolete capital, but as the release of energy and potential that can be positively restructured” (Taljaard, 2013: 17). It represents an opportunity to re-envision the life, use and purpose of the site, by integrating its water sources into the broader context and stitching together the social-ecological pieces of the segregated urban wasteland. Complementary potentials on site shift between evolution and resistance (ibid, 2013: 17). Water formed a primary component of the first potential set, which is acceleration and deceleration illustrated through ecological services on site over millennia. This led to an intervention that harnesses the clay-producing potential and the existing workforce on site to create a craft-based ceramic production facility (utilising the quarry, existing warehouses and kilns). The second potential, memory and imagination, describes perceptions toward industry and the buffering green space. The community, excluded from using these spaces, has both real and imagined memories about the site. By creating a porous public building that allows flows of life through the industrial structures, interaction is encouraged. Emotionally-charged memories can be harnesses to create new memories within adaptively re-used brick-drying and firing kiln structures that now house a museum, function venue, restaurants, and retail. Preservation of the cultural landscape allows obsolete industrial material to transform into a positive public amenity that challenges the stigma around industrial processes and creates stewardship toward the site.

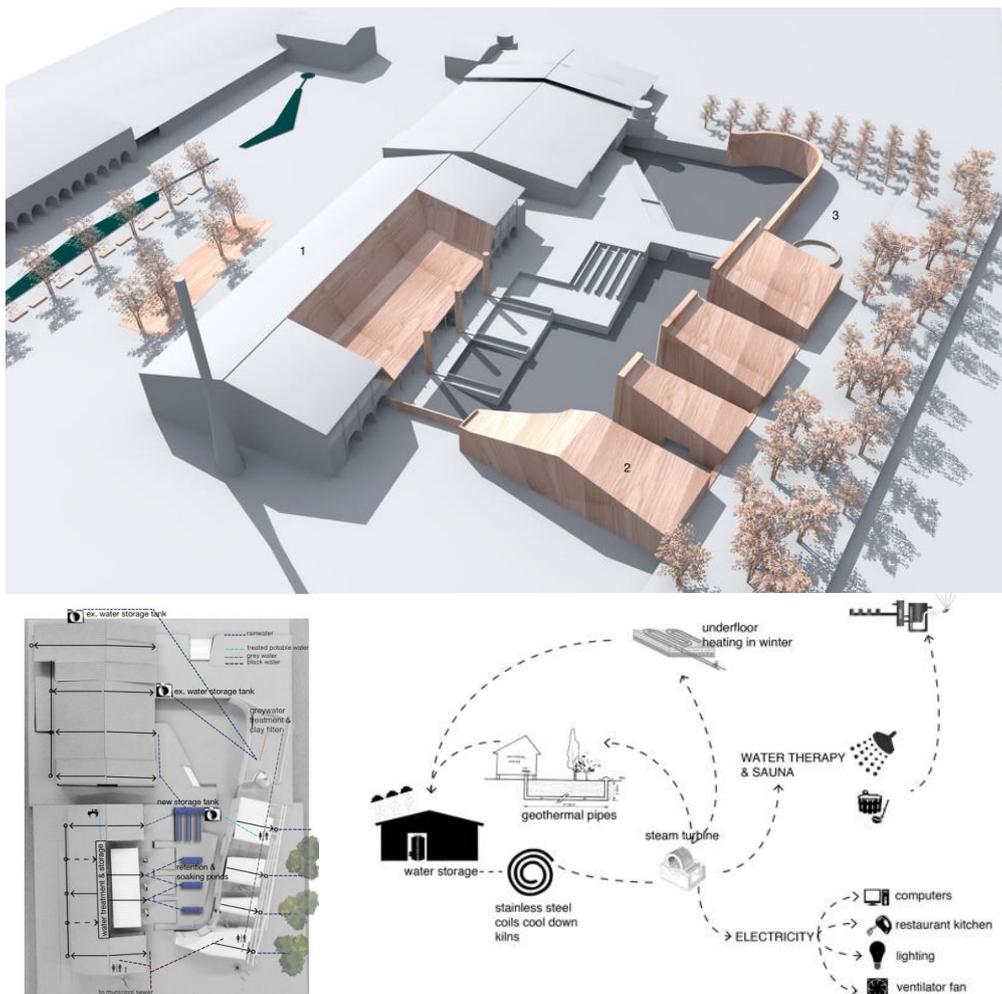


Figure 9
Top: rendering of the final proposal with new additions set against existing grey coloured extant factory spaces. Bottom: various water strategies (Taljaard, 2013: 104, 105).

Finally, revolution vs. evolution, represents the capacity of the site to transform and evolve while maintaining its identity and primary functions. Forces like politics, economy, and public opinion impact upon future trajectories as sources of regeneration or collapse. An imminent disturbance will be the brickworks closure, however skilled labour, flat open space, tangible cultural landscape from which to nurture intangible memories and awareness, clay residues and a large water body, will be immediately available. All these potentials can be utilised in the ceramic facility within existing buildings with new studio spaces built in a sunken courtyard along an inhabitable brick wall ‘spine’ that blurs the line between nature and industry (Fig 9). New kilns sensitively replace some of the obsolete heritage infrastructure and create an efficient closed-looped system that also heats water for the entire building. Humans and industry now co-exist, challenging the stigma of post-industrial sites.

Conclusion

Buildings that extend beyond their physical domain enhance their capacity to adapt, evolve, and nurture the diversity of life within cities. Four Masters projects revealed latent potential within derelict sites that could rebuild urban quality and generate awareness about the broader urban ecology. Strategies were based on the unique story of place in each site where water inspires resilience and regeneration in the architectural solution. Closed-loop food production and social recreation informed the design of a building that was moulded into its landscape, redirecting flows of energy to build social-ecological capacity at the Monument Park Quarry; transforming obsolete portions of the Daspoort Waste Water Works into an ecological industrial system veiled within a poetic building intervention, re-established connections between local communities to nature; assimilating networks around the Steenovenspruit generated a building based on positive qualities that provides opportunity rather than controlling ‘problems’; and lastly, aligning potential sets and new functions to the adaptive re-use of the brickworks site toward greater complexity evolves perceptions about post-industrial sites. Resilience and regenerative thinking offers clues to envision a positive future vision for architecture that can evolve and inspire the building practice to sustain a diversity of life.

Acknowledgment

The financial assistance (Grant no. 78649) of the National Research Foundation (NRF) toward research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the authors and cannot necessarily be attributed to the NRF.

Endnotes

¹ Students formed part of a funded NRF research project on resilience (Grant No. 78649), managed by Chrisna du Plessis, with student supervision during 2013 by Arthur Barker and Edna Peres.

² Heidi van Eeden recently won the national Corobrik student competition with judges commenting that "this project ...achieves a well-

considered urban design resolution...while...the depth of research is astounding. The completeness and thorough examination of the design of a complex building type is exemplary...and...the imaginative reuse of obsolete infrastructure is resourceful. The building will be an asset to the city of Tshwane".

Works cited

- Andrews, T. & Ploeger, J. 1989. *Street and Place Names of Old Pretoria*. J.L. van Schaik.
- Büchner, I. 2013. Latent Potential: A Post-Industrial Artefact. Pretoria: Unpublished Master's dissertation, University of Pretoria, Gauteng, South Africa.
- Chapin III, F. S., S. R. Carpenter, G. P. Kofinas, C. Folke, N. Able, W. C. Clark, P. Olsson, D. M. S. Smith, B. Walker, O. R. Young, F. Berkes, R. Biggs, J. M. Grove, R. L. Naylor, E. Pinkerton, W. Steffen, and F. J. Swanson. 2009. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution*, Vol. 25, No 4, pp. 241-249.
- Cronjé, M. 2013) The Liquid Network: a catalyst for participation in Marabastad. Pretoria: Unpublished Master's dissertation, University of Pretoria, Gauteng, South Africa.
- Dippenaar, M. 2013). *Hydrological Heritage Overview: Pretoria's fountains - arteries of life*, Pretoria: Water Research Commission SP44/13.
- du Plessis, C. 2008. Understanding Cities as Social-ecological Systems, In: *Proceedings of World Sustainable Building Conference*. SB'08, 21-25 September, Melbourne, Australia.
- du Plessis, C. 2013. Resilient and regenerative - the Yin and Yang of a new development paradigm, *Earthworks*, no. 13, April/May, pp. 35-38.
- Engelbrecht, S.P., Agar-Hamilton, J.A.I., Pelzer, A.N. & Behrens, H.P.H. 1952. *Centenary Album. Pretoria's First Century in Illustration*. J.L. van Schaik, Limited, Pretoria.
- Gotham, K.F. and Campanella, R. 2010. Towards a Research Agenda on Transformative Resilience: Challenges and Opportunities for Post-Trauma Ecosystems, *Critical Planning*, Summer, pp. 9-23.
- Haggard, B. Reed, B. and Mang, P. 2006. Regenerative Development: A new approach to reversing ecological degradation offers opportunities for developers and builders. Available online: <http://www.regenesisgroup.com/pdf/rd>. Accessed: 17/02/2014.
- Jenkins, G. (ed). 1955. *Pretoria 1855-1955*. Die Stadsraad van Pretoria. 1st Edition, Wallach's P&P Co. Ltd. Pretoria.
- Kellert, S., Heerwagen, J. and Mador, M. 2008 *Biophilic Design: The theory, science and practice of bringing buildings to life*, Hoboken New Jersey: John Wiley & Sons, Inc.
- Le Roux (ed), 1991. *Plekke en Geboue van Pretoria Volume Twee*. Stadsraad van Pretoria. Pretoria.
- Lyle, J.T. 1994. *Regenerative design for sustainable development*. New York: John Wiley & Sons Inc.
- Mang, P. and Reed, B. 2012. Designing from place: a regenerative framework and methodology, *Building Research & Information*, vol. 40, no. 1, pp. 23-88.
- McHarg, I. 1969. *Design with Nature*. New York: Natural History Press.
- Rees, W.E. 1997. Urban ecosystems: The human dimension. *Urban Ecosystem*, 1:63-75.
- Salat, S. 2011. *Cities and Forms: On sustainable Urbanism*, Paris: Hermann.
- Taljaard, C. 2013. New Era Ceramics: a solvent for the industrial boundary, Pretoria: Unpublished Master's dissertation, University of Pretoria, Gauteng, South Africa.

Wilson, E. O. 1984. *Biophilia: The human bond with other species*. Cambridge: Harvard University Press.

Van der Merwe, 2013. The Garden is us: in search of poetic dwelling. Pretoria: Unpublished Master's dissertation,

University of Pretoria, Gauteng, South Africa.

Van Eeden, H. 2013. *Machinarium*. Pretoria: Unpublished Master's dissertation, University of Pretoria, Gauteng, South Africa.