Institution: University of East London (UEL)		
Unit of Assessment: 12 Engineering		
Title of case study: Reusing industrial by-products for sustainable construction and development		
Period when the underpinning research was undertaken: 2000 – 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Alex Apeagyei Darryl Newport Mihaela Anca Ciupala Bamdad Ayati	Senior Lecturer Professor Senior Lecturer Research Fellow	2017 – present 2000 – present 2003 – present 2017 – present
Period when the claimed impact occurred: 2013 – 2020 (ongoing)		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact (indicative maximum 100 words)

Collaborating with national and international partners, UEL researchers have influenced development of engineering design guidelines and international best practices, resulting in more sustainable and cost-effective techniques for repairing failed roadways. New techniques for manufacturing lightweight aggregate (LWA) from waste drill cuttings have been developed in coalition with industrial partners to support reduction of waste.

The research has contributed to development of tools for quantifying carbon footprints of LWA concrete which has made industry collaborators more competitive as a result. From the highways of Nepal to the playgrounds of Poland and beyond, the research continues to improve livelihoods.

2. Underpinning research (indicative maximum 500 words)

The concerns arising from the environmental consequences of over exploitation of natural resources shaped the research around the innovative use of industrial wastes in construction, by understanding engineering performance of recycled materials.

Figure 1 Construction demonstration site and machinery

Sustainable construction materials development and use

The researchers investigated the use of industrial by-products such as excavated waste clay from underground tunnelling in London, energy from waste (EfW) residues, drill cuttings from the Oil and Gas industry and red mud from aluminium production in the manufacture of lightweight

aggregate (LWA) (**R1**, **R2**, **R3**), thus addressing a major challenge for the infrastructure industry.

Novel methods were developed, which can stabilise the contaminant within the LWA structure, making them non-leachable. The research has provided a better understanding of how material characteristics and production parameters affect the microstructure and physical properties allowing the design of LWA with a wide variety of end-use applications such as in structural concrete products, road construction, agriculture, and drainage systems. The bespoke research demonstrator facility attracted GBP250,000 investment through the C2CBIZZ Project (**G4**) providing innovative solutions to extract value from residual resource material.

The collaboration with Aggregate Industries resulted in the use of waste vegetable oil as a bitumen replacement in road construction. Bitumen was modified using both virgin and used vegetable oil to produce a range of equivalent penetration grade binders, allowing up to 30% replacement of bitumen with used vegetable oil **(S2)**. The project is still being used almost a decade after installation, due to enormous financial savings. The UK uses more than 1.25 million tons of bitumen every year at a cost of about GBP500 per ton. The LWA has been incorporated in diverse applications including the construction of a playground in Poland and various construction demonstration projects like demonstrations for the London Olympics and Bedfordshire highways.

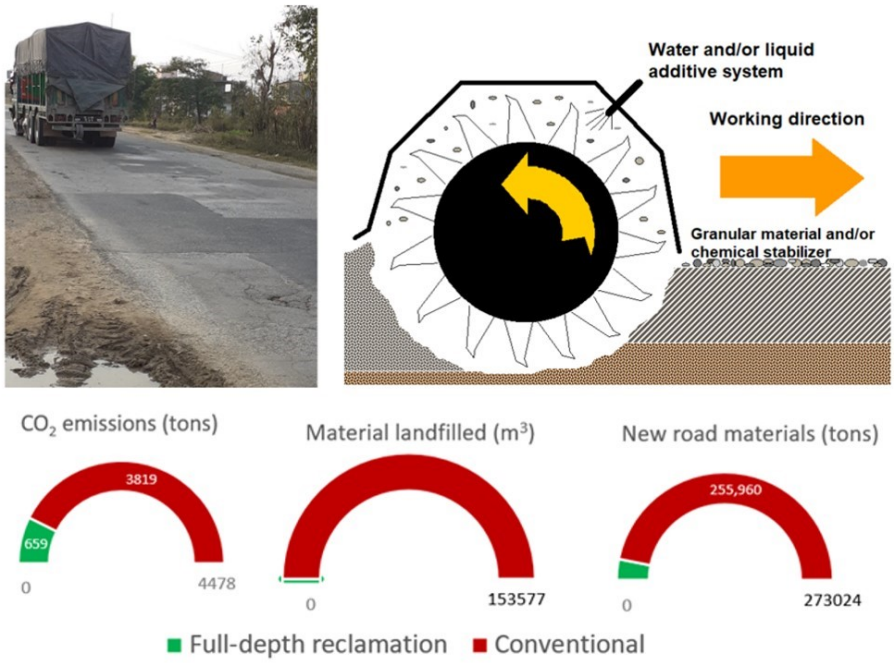

Figure 2 Research models and diagrams

Sustainable road building technologies

Finally, the work on highway pavement recycling has provided better understanding of the performance and durability of recycled materials for road construction. The cost of a mile of road is about GBP1,000,000 so outcome of this research significantly reduces infrastructure costs. Enormous quantities of non-renewable natural material are required to build road infrastructure that our current way of life depends on. In the UK, roads consume over 40% of all materials extracted from the ground as aggregates, most of which are difficult to recycle due to multiple technological challenges such as uncertainty in predicting performance, lack of standardized mix design procedures or lack of specification and design guidelines. Research at UEL has contributed to the translation, into technology, of fundamental research on the performance and durability of recycled highway materials and industrial by-products into building, maintaining and repairing roadways. This has contributed to the reduction of obstacles to widespread adoption of sustainable road construction around the world (**R3**, **R4**, **R5**).

3. References to the research (indicative maximum of six references)

R1. Ayati, B., Molineux, C., Newport, D. and Cheeseman, C. 2019. Manufacture and performance of lightweight aggregate from waste drill cuttings. *Journal of Cleaner Production* 208, 252-260.https://doi.org/10.1016/j.jclepro.2018.10.134

R2. Ayati, B., Ferrándiz-Mas, V., Newport, D. and Cheeseman, C. 2018. Use of clay in the manufacture of lightweight aggregate. *Construction and Building Materials* 162, 124-131. https://doi.org/10.1016/j.conbuildmat.2017.12.018
R3. Molineux, C., Newport, D., Ayati, B., Wang, C., Connop, S., and Green, J. 2016. Bauxite residue (red mud) as a pulverised fuel ash substitute in the manufacture of lightweight aggregate. *Journal of Cleaner Production* 112(1), 401-408. https://doi.org/10.1016/j.jclepro.2015.09.024
R4. Tebaldi G. et al. 2018. Cold recycling of reclaimed asphalt pavements. *RILEM State-of-the-Art Reports* 24, 239-296. https://doi.org/10.1007/978-3-319-71023-5_6
R5. Tebaldi, G., Dave, E., Cannone Falchetto, A., Hugener, M., Perraton, D., Grilli, A., Lo Presti, D., Pasetto, M., Loizos, A., Jenkins, K., Apeagyei, A., Grenfell, J. and Bocci, M. 2018. Recommendation of RILEM TC237-SIB on cohesion test of recycled asphalt. *Materials and Structures* 51, Article 117. https://doi.org/10.1617/s11527-018-1238-4

G1. Alex Apeagyei, Soils Stabilization and Full Depth Reclamation Expert (Relaunch), Millennium Challenge Account, Millennium Challenge Corporation, 2019-2021, GBP215,000.
G2. Sustainability Research Institute, UEL/Augean APCr LWA project, Augean Plc, Rolling: Initially, 2014-2017. Extension granted for 2019-2022, GBP85,000.
G3. Sustainability Research Institute, Calcium Carbonate Reuse, Tate & Lyle, 2017-2018, GBP8,000.
G4. Sustainability Research Institute, Contracted through C2C BIZZ, Interreg IV-B NWE Programme, 2014-2017, GBP250,000. C2CBIZZ Project
http://www.c2c-centre.com/news/blog-sre-about-c2c-bizz-project-sustainability-london

4. Details of the impact (indicative maximum 750 words)

Significant reduction in virgin construction materials

Our project with Augean PLC, the largest specialised hazardous waste management company in the UK on finding alternative to landfills for waste materials with no recycling option has secured more than £100k in funding. The outcome of this research provided an approach to reuse 400kt/y EfW residues and 70kt/y waste drill cuttings in the manufacture of environmentally friendly LWA (**S1**).

The new techniques benefited highway and transportation engineers through incorporation of our research in the development, enhancement and delivery of professional standards, design guidelines and professional training. The development design guides and associated training material for full-depth recycling with cement was the first of its kind in Nepal **(S8)**. Apeagyei appointment on commission by the Nepal government introduce all the technological requirements, that are associated with stabilizing soils and reclaiming pavements with cement in Nepal. (**S4**)

Significant reduction in greenhouse gas emissions

The research estimated manufacture of LWA from waste clay to emit ~0.22 tonne of CO_2 per tonne of aggregate, which compares favourably with the emissions from other major building materials such as Portland Cement. The research pioneered the use of biomass as a fuel to further reduce the LWA embodied carbon.

The use of technology, supported by the research, reduces CO_2 emissions by 600% compared to conventional construction methods because zero material is landfilled and the need for virgin materials is reduced about 94%. For the 91-km project being show-cased, there will be reduction of more than more 3.2 Mt of CO_2 emissions. This is significant because our research shows about 84% of the 4830 km strategic road network may be suitable candidates for this sustainable construction method (**S2**-**S9**).

Impacts on the economy and production

The collaboration with Augean PLC on the use of hazardous waste in manufacture of LWA has provided strong incentives to drive waste management companies to implement this approach because of the high cost of hazardous waste landfill (GBP130 - GBP150 per tonne) in the UK and increasing demand for lightweight and thermally insulating concrete. Research on highway recycled technology has enabled the use of 100% of exiting roadways resulting in cost-savings of at least 50%. (**S1**)

The researchers contributed to the translation of research to technology, through collaboration with international experts to develop recommendations on standardisation of the test methods under the auspices RILEM. Further partnerships with industry and academic colleagues from more than 13 countries in North America and Europe have led to recommendations for updating current EU standard EN 12696-11 for techniques evaluating moisture damage susceptibility of highway construction materials. This is a key durability measure that limits the wider application of recycled materials in highway construction.

Engagement with industry professionals

Apeagyei is appointed to serve on the prestigious National Academies of Sciences' National Cooperative Highway Research Programme as expert panel member for the project NCHRP 14-43 (Guide Construction Specifications for Cold In-place Recycling (CIR) and Cold Central Plant Recycling (CCPR) in order to influence changes in guidelines for design and construction specifications for highways. Further he is a member of Transportation Research Board (TRB) standing committees for pavement design. Apeagyei sits on CEB-fib Technical Group T4.7 – Structural Applications of Recycled Aggregate Concrete and Newport was appointed to the Institute of Civil Engineers Circular Economy Panel (**S3**).

The lack of generally acceptable specifications for the use of recycled or secondary materials as an alternative to virgin aggregates is a major hindrance to widespread adoption of alternative aggregate in highway pavement construction. Therefore, the work of Apeagyei has contributed to the greater use of alternative materials within construction (**S3**-**S8**).

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1. Letter of Support from Augean PLC for research carried out by Sustainability Research Institute.

S2. Chip fat used to resurface road, BBC news item on PhD student project on using vegetable oil as replacement for bitumen.
http://news.bbc.co.uk/1/hi/england/beds/bucks/herts/8318296.stm

S3a. Appointment letter NCHRP 14-43 Panel. NCHRP 14-43.
S3b. Apeagyei sits on the Standing Committee on Design and Rehabilitation of Asphalt, Transportation Research Board (TRB) Pavements, https://sites.google.com/site/trbcommitteeafd60/
S3c. Apeagyei sits on CEB-fib Technical Group T4.7 – structural applications of recycled aggregate concrete. https://www.fib-international.org/commissions/com4-concrete-concrete-technology.html
S3d.Newport is a standing member of the London and South East Circular Economy Panel for the Institute of Civil Engineeers. https://www.ice.org.uk/about-ice/near-you/uk/london/committees#economypanel

S4. Agenda from Apeagyei meeting with officials of Roads Board Nepal, Department of Roads Nepal and Millennium Challenge Account-Nepal.

S5. *Provides details of the innovative project that used combination highway pavement recycling technologies on major highway projects in the USA that involve Apeagyei.*
http://expresswaysonline.com/press/wp-content/uploads/2013/06/EQUIP-WORLD-APR-2015-FINAL.pdf

S6. *Provides evidence of impact of research on use of new highway pavement technology in terms improved pavement performance and cost reduction*
Diefenderfer, B., Bowers, B., Apeagyei, A. 2019. Initial performance of Virginia's Interstate 81 in-place pavement Recycling Project. *Transportation Research Record*. 2015;2524 (1), 152-159. https://doi.org/10.3141/2524-15

S7a. *Provides evidence of provision of consultancy service that have improved performance of engineering projects.*
Apeagyei, A. 2019. *Implementation of soil-cement stabilization and full-depth reclamation design technology in Nepal, Technical Report, Millennium Challenge Account – Nepal, 2020*.
S7b. *https://1df0c51cy4zu1wcs0n1byq8q-wpengine.netdna-ssl.com/wp-content/uploads/2019/09/MCA-Nepal-Contract-award-up-to-August-21-2019.pdf*

S8. Alex Apeagyei. 2020. Provision of 2-day training course on soil-cement stabilization and full-depth reclamation for selected engineers and staff of the Department of Roads, Nepal, the Nepal Road Board, and graduate student and academic staff of selected universities in Nepal.