Cities of Tomorrow R&D Programme – 1st Grant Call

Grant Call has closed on 2 August 2018.

S/N	Project Title
Vertical 1: Advanced Construction	
1	Research and Development of Technology and Methodology for Advanced 3D Concrete Printing with Reinforcements
2	Innovative Advanced Prefabricated Design Concepts for High-rise Residential Buildings
Vertical 2: Resilient Infrastructure	
3	Development of Technologies to Geo-reference and Detect Underground Services and Assets for New Estates
4	Research and Development of Automated Solutions and AI System for Inspection, Diagnosis and Maintenance on External Building Façades
5	Development of Lift Monitoring and Diagnostic System
Vertical 4: Greater Sustainability	
6	Development of Phase Change Materials for Effective Indoor Cooling in the Tropics
7	Co-existence of Streetscape Planting with Bio-retention System
8	Development of Solutions to Maintain Good Ventilation in Enclosed Spaces with Zero or Very Minimal Energy

Project Code: CoT_V1_GC2018-1_T1

Call Topic: Technology and Methodology for Advanced 3D Concrete Printing with Reinforcements

1 Background

1.1 The current state of the art for concrete 3D printers is the extrusion of mortar material horizontally and laying strips of mortar on top of the previous layers. Such 3D printed concrete is unreinforced and depends entirely on the strength of the mortar material for its tensile and compressive strength. The strength of any printed element therefore depends entirely on the interlayer bond strength. There are no connecting reinforcements provided horizontally along the layer or vertically across the layers. This limits the material and structural strength that can be achieved by a 3D printed concrete product. This also limits the application of 3D Concrete Printing technology for structural usage in construction.

1.2 There is currently a gap between what the 3D printer practitioners and industry is pushing out for concrete 3D printers and what is required for the construction industry. More in depth research regarding the automated provision of reinforcement during 3D concrete printing is required. It is currently known that 3D printing for metallic components has also been making inroads, and gradually improving with Direct Metal Laser Sintering (DMLS) being used for jet engine's parts, and ship's propellers being 3D printed.

1.3 There has not been any in-depth research done on different forms of reinforcing techniques to complement 3D concrete printing, and it is difficult to gauge how efficient or cost-effective these methods are. There is thus a need to develop solutions and evaluate an optimal and efficient way of automating the provision of reinforcement in the 3D concrete printed products. This will increase the possibility of extending the 3D concrete printing processes from architectural aesthetics to practical structural applications, thus widening the adoption of 3D Concrete Printers in the construction industry in future.

1.4 This Call for Proposal (CFP) seeks responses from 3D printing experts to carry out the next stage of necessary research and development to bring the industry to the next higher level of achievement. The amalgamation of two distinct areas of 3D printing will fulfil a practical need for the construction industry.

1.5 This will create boundless opportunities to fulfil the dream of creating practical structural 3D components that can challenge and disrupt the norms of conventional construction techniques, in line with true digital and robotics fabrication for the construction industry.

2 Objectives and Scope of Call for Proposals

2.1 The desired outcomes of the research are to:

(a) Investigate and develop reinforcement systems and robotic systems that can automate the simultaneous laying of reinforcement during the printing of the concrete products;

(b) Conduct comprehensive experimental feasibility assessment on the various technologies and methodologies of introducing reinforcement into the print element, to produce complex 3D concrete printed elements of high structural strength;

(c) Conduct comprehensive laboratory testing on the performance of such reinforced 3D printed concrete elements in accordance with the structural design code requirement; and

(d) Explore technology to improve the surface finish of the 3D printed concrete elements.

2.2 The project shall consist of 5 work areas as follows:

(a) Work area 1: Develop material or reinforcement systems (such as but not limited to metal meshes, polymer fabrics etc) that can easily be incorporated while 3D concrete printing.

(b) Work Area 2: Develop robotic system or devices for the inclusion of reinforcements (such as but not limited to polymer and steel fibers) into the concrete mix used for 3D concrete printing.

(c) Work Area 3: Develop robotic system or devices to draw reinforcements through the concrete layers while printing simultaneously.

(d) Work Area 4: Develop robotic system or devices for printing of 3D reinforcements. The strength of these 3D reinforcements should be equivalent to that of high tensile steel reinforcements, if possible.

(e) Work area 5: Develop mechanised smoothening technology and methodology that can improve the surface finish of the 3D concrete printed surface without creating dust or noise nuisance.

2.3 The raw material costs for 3D reinforcement printing are to be included under materials cost in the Call for Proposal. The robotic system or devices for the inclusion of reinforcements shall work together with a 3D concrete printing system located at the HDB Centre of Building Research.

2.4 The robotic system or devices should have the capacity to provide reinforcements for components of the following dimensions:

(a) Width: up to 3 metres; and

(b) Height: up to 3 metres

Project Code: CoT_V1_GC2018-1_T2

Call Topic: Innovative Advanced Prefabricated Design Concepts for High-Rise Residential Buildings

1 Background

1.1 Design for Manufacturing and Assembly (DfMA) involves shifting on-site construction works to off-site prefabrication in the factory as much as possible. The approach will bring about significant benefits including reduction in construction time, manpower and improved quality and safety at construction sites. DfMA covers a wide spectrum of prefabrication technologies, including Prefabricated Pre-finished Volumetric Construction (PPVC), Mass Engineered Timber (MET), structural steel, precast concrete, and also modular MEP (mechanical, electrical and plumbing) systems.

1.2 Concrete is the preferred material for residential developments. Although precast concrete technology has been widely used in local projects, there is still room for improvements. More innovative advanced precast concrete designs, with simple connections or joints that are effective, efficient and easy to assemble can be developed. Advanced precast concrete can be designed to allow bigger, more complex volumetric components which will help to decrease the number of components required. This would in turn lead to easier and faster construction.

1.3 While precast technology is widely used for the construction of HDB buildings, there is a need for an in-depth study on the feasibility of developing efficient, new building structural system and connecting joints design that is simple, efficient to produce and construct, and able to integrate with architectural and mechanical, electrical and plumbing (MEP) system, to increase productivity. However, this should not be at the expense of maintainability and joints developed should be watertight and withstand the water ingress from driving rain which is common in our tropical climate.

2 Objectives and Scope of Call for Proposals

2.1 The desired outcome of the research is to develop an innovative precast design at system level which would include design, production and method of construction that would allow mechanization of assembly, and test building structural systems and jointing connection designs that are able to:

(a) Improve construction productivity by at least 30% from current best practice or at least 50% from conventional practice (whichever is better), at cost parity with best-in-class in 2016;

(b) Achieve at least 50% reduction of cycle time from current best practice, without increasing the workforce;

(c) Achieve at least 30% reduction of construction period, without increasing the workforce;

(d) Develop and test building structural system and joints connection design that could complement the existing precast building system so as to enhance construction productivity; and

(e) Achieve good watertight joints i.e. no ingress of water and achieve good long term building performance with minimum maintenance cost throughout the service life of the building.

2.2 The project shall

(a) Develop a mock-up of the prototype/structural system;

(b) Include structural performance testing of the design concept to regulatory requirements; and

(c) Proposed system shall be constructed from cost-effective, durable materials and fire-rated. In the event of accidental damages or fire, the damage should be localised, contained, and shall be easy to repair or reinstate. The building system shall be easy to inspect and maintain, shall not lead to costly maintenance requirements, and shall also allow flexibility for renovation work by occupants.

Project Code: CoT_V2_GC2018-1_P1

Call Topic: Technologies to Geo-reference and Detect Underground Services and Assets for New Estates

1 Background

1.1 Embedded and underground services such as electrical trunkings and water pipes are commonly found in the building and residential estates. Existing services plans or as-built drawings may be available or obtained from authorities for references, but may not be accurately updated and documented. Thus, services detection and trial pits are still required to be done at site to verify the actual location of those services before carrying out any excavation works. Very often, services disruptions were encountered due to the damage caused by excavations and construction works due to failure in detecting these underground services.

1.2 This project will help to reduce the amount of time and uncertainty involved in locating the buried services and assets and thus improve accuracy and productivity. It will also help to reduce the risk of services disruption due to accidental damage of these services.

2 Objectives and Scope of Call for Proposals

2.1 The desired outcomes of the research are to:

(a) Develop spatial solutions through technologies that include, but are not limited to Drones, Global Navigation Satellite System (GNSS), and point cloud etc., to geo-reference and detect all types of underground services and assets (e.g. service shafts and culverts). The solutions will enable capture, documentation, and updating of as-built newly laid services, towards development of a services information database that can help to pinpoint the actual location, path and depth of such services before carrying out any excavation works in future;
(b) Develop scanning and geo-referencing technology for detecting underground services as well as assets for new estates, and automatically capture the digital information into drawings of as-built buildings, such as in BIM drawings format;
(c) Develop solution to provide 3D rendered models for closer examination of the underground services and assets; and
(d) Develop augmented reality device to provide the user with a composite view and details of potential underground services at site.

2.2 The research development shall be ready and practical for deployment in actual site environment and building projects.

2.3 Solutions developed shall provide quicker and more efficient scanning capabilities on site, and be able to minimally achieve a data accuracy of +/-100 mm, beyond current SLA survey standards for underground services and assets.

2.4 Solutions /technologies deployed shall allow the detection, scanning, and creation and updating of 3D models/data of both exposed and buried/covered underground services that are not in time for survey during construction. The solutions /technologies shall also be able to capture and update the as-built location of services as and when services have been shifted during backfilling and after installation.

2.5 Data/information captured shall provide details including, but not limited to, geo-reference coordinates, exact location with reference to site environment, depth, dimensions and type of services (e.g water pipe, high-tension cable, box culvert) etc.

2.6 The study shall include the review and understanding of current site practices of underground services installation and if required, propose new construction practices and/or new site protocols to support the new methodology of underground services detection and documentation.

Project Code: CoT_V2_GC2018-1_P2

Call Topic: Automated Solutions and Artificial Intelligence System for Inspection, Diagnosis and Maintenance of External Building Facades

1 Background

1.1 Due to aging building stock and the increasing complexity of façade design, it is necessary that building façades are regularly inspected and maintained to ensure safety. Current inspection processes are normally done within the confines of the building and can be manual and labour dependent. To have an effective inspection, the building professionals (e.g. Professional Engineers, Registered Architects, Resident Engineers, Resident Technical Officers etc.) are required to work at heights to carry out close range inspection. Such method of inspection is often laborious and prone to fatigue and human errors. There may also be areas that are difficult for humans to access.

1.2 To improve the inspection professional's safety (i.e. prevention of fall from height), there is an urgent need to explore automating the inspection process and transforming it to become less labour dependent by incorporating building diagnostics technology, such as seamlessly recording all defects and inspection data gathered from the autonomous inspection. This would thus improve various aspects of building inspection such as safety, productivity and inspection accuracy. The external façade inspection system should help to improve building inspection personnel safety, increase the reach of building façade inspection, and reduce the dependency on professional manpower willing to undertake such building façade inspections.

1.3 Further research on a portable non-destructive testing tool is also needed as defects on the façade systems are often concealed by the façade barrier. As facades get more complex, less visible and less accessible, these defects remain undetected until failure occurs. There is a need for a portable non-invasive and non-destructive equipment that can detect defects concealed behind façade barriers, so that they can be repaired before failures occur. The objective of this phase of research is to develop portable scanning equipment that can function as a quick diagnostic tool to assist façade inspectors in detecting defects and any tell-tale signs on the building facade safely and accurately, without the need to remove the façade layer.

2 Objectives and Scope of Call for Proposals

2.1 The desired outcomes of the research are to:

(a) Develop customised, autonomous and cost-effective robotic system that is capable of manoeuvring around building envelopes, including those with irregular profile, easily and safely. Using a combination of different technologies, the inspection robotic system should be able to conduct checks on external facades to detect building defects; and

(b) Develop an intelligent inspection software system to recognize building defects through data analytics based on data collected during the inspection.

2.2 The project shall consist of 4 work areas as follows:

(a) Work area 1: Develop two integrated robotic systems (system 1 & 2) that can check the façade of buildings' envelope efficiently and safely. System 2 shall consist of robotic solution that can scale and get in contact with the façade envelope, inclusive of façade with irregular shapes and profile, to carry out close-up inspection to detect potential defects area.
(b) Work area 2: Develop technology to incorporate various methods of building diagnostics and testing into the robotic inspection system.
(c) Work area 3: Develop artificial intelligence (AI) and machine learning capability and diagnostic tools for defects analysis.
(d) Work Area 4: Develop portable testing tool for inspection and detection of concealed defects behind claddings and/or curtain walls system without the need for dismantling. The device shall be able to be integrated into the robotic system as plug & play accessories.

2.3 The research development and solutions shall be ready for deployment in actual building inspection including prototyping and test-bedding. Specific design and requirements of the systems for each work area shall include but not limited to the following:

(a) **Work Area 1**

(i) System 1 - the Quick Scan Inspection System 1 to quickly scan 100% of the façade elevations to identify and detect defects. System 1 may consist of, but not limited to inspection solutions integrated with Unmanned Aerial System/drone technology. System 1 should be able to detect defects such as but not limited to: cracks, water seepages, hollowed or delaminated external finishes, tiles debonding, brickworks bulging, façade deformations, and corroded or deteriorated external fixtures, fittings or connections.

(ii) System 1: Quick Scan Inspection System shall include but not limited to:
- More than one (1) robot to be used in tandem during inspection;
- Software should include automated masking technology and identification of building windows openings to ensure privacy;
- Autonomous flight path software to be included;
- Software should include accurate stitching of images and 3D mapping reconstruction; and
- Automated solution to complement the system and enable inspection to be carried out despite loss of GPS signal.

(iii) System 2 - the robotic close-contact inspection system should be able to carry out identification or non-destructive tests to detect or confirm defects such as but not limited to: cracks, water seepages, hollowed or delaminated surface finishes, tiles debonding, and corroded or deteriorated external fixtures, fittings or connections.

(iv) System 2: The robotic system shall be able to carry out close contact inspection on the building, and should be:

- Lightweight, compact, efficient as well as aesthetically pleasing;
- Integrated with multi-sensors (Refer to Work Area 2); and
- The system developed shall have the capability to perform and inspect on the following areas and requirements but not limited to:

System	**Requirements**
Protrusions and Recessed Surfaces	Able to overcome recesses and protrusions of at least 1.0 metre from the edge of the building façade
Mobility of system	Ability to self-climb on various façade profiles and able to: (a) Adapt to existing building design (b) Work within narrow and confined external spaces (c) Move in x-, y-, and z-axis with rotational movement (d) Manoeuvre to inspect tight corners of façade surfaces and the top and bottom ledges / canopies (e) Auto-sense barriers or obstruction during movements (f) Inspect a building height of about 120 metres (g) Be easily transported and handled by a single man
Controllability	Ability to control: (a) via remote sensors or auto-sensing (b) with no interference to electronic products in the vicinity (c) despite the presence of a barrier in between or without line-of-sight
Public Inconvenience	(a) Minimize the need to cordon off large area around the building and restrict public access (b) Low noise generation

Safety	The operation of the system shall not affect or cause any damages to the adjacent and neighbouring premises or property, operator and pedestrians
Power supply	Ability to be powered by (a) preferably existing power sources from standard commercial and residential buildings (b) alternative power source / generator that is silent, portable and non-disruptive

(b) **Work Area 2:** Development of technology to incorporate various methods of building diagnostics and testing into the robotic inspection system.

(i) System 2 (Close contact inspection robotic system): Technology to be included but not limited to:

- Tapping device to check for hollowness behind plaster and tiles;
- Pulse/sound reader to accurately interpret the sound waves received;
- Infra-red scanner and/or other imaging technology that is able to detect various types of defects as mentioned above. More than 20 Mega-pixel camera;
- Laser depth scanner;
- Inclinometer

(c) **Work Area 3**

(i) This work area shall include:

- Development of automated system that is able to tag defects spatially, transmit and store the field data collected for defects diagnosis and analysis purposes;
- Integration with the various building diagnostics technology hardware as well as conduct defects recognition analysis;
- Perform predictive data analytics using artificial intelligence (AI) and machine learning for more accurate defect identification, classification and defects probability rating;
- Mobile application software for automatic generation of defects report so that reports can be viewed on portable viewing devices; and
- Data management platform and software to be provided to link and transmit inspection results back to Agencies' Smart Hub.

(d) **Work Area 4**

(i) This work area shall include:

- Development of a portable, quick scanning tool for detection of defects on cladding and curtain wall, and deterioration of fixings concealed behind the cladding system;
- The proposed equipment should be compact, safe-to-use, and portable (able to be held by a single person during the scanning process);
- The detection mechanism can either be contact or contactless and shall not affect or damage the façade material, or leave any imprint on it;
- Provide real-time on-board diagnostic ability and instant feedback to the user. The equipment should be able to capture and store field measurement data in a form that can be transferred to a PC;

- Perform predictive data analytics using artificial intelligence (AI) and machine learning for more accurate defect identification and classification. A PC-based software should be developed to provide further diagnostic and data analytics capabilities, to smartly identify anomalies indicating potential defects; and
- The equipment should be designed both as a standalone device and to be integrated with robotic inspection system (System 1 and System 2) as plug-and–play devices to provide multiple scanning methods and enhanced inspection capabilities.

(e) The proposal should include detailed descriptions of all safety features for System 1, System 2, and the portable quick scanning tool.

(f) All data sets derived from this research shall belong to HDB/BCA.

(g) Upon request by HDB, the prototypes created during this research shall be made available for long-term loan at the site(s) designated by HDB, such as the HDB Centre of Building Research, for training and demonstration purposes.

(h) The team should comprise personnel with expertise such as but not limited to automation, robotics, Artificial Intelligence (AI) and machine learning, external façade inspection, civil engineering, mechanical engineering, electrical engineering, etc.

Project Code: CoT_V2_GC2018-1_P3

Call Topic: Lift Monitoring and Diagnostic System

1 Background

1.1 There is currently a lift monitoring system in place to monitor lift operations and manage emergency events, for example man-trap cases. However, the current lift monitoring system does not provide sufficient information that could translate to meaningful diagnostics of lift faults. Moreover, lift fault diagnosis and rectification has to be done manually by the maintenance crew on site. Manpower demands for lift technicians are increasing with the growth in the number of lifts; whilst manpower supply is dwindling as our workforce ages. With aging infrastructure and a shortage of lift maintenance professionals, there is an urgent need to improve the productivity of this industry through the efficient use of technology.

1.2 One way to improve productivity is through the implementation of a Remote Monitoring & Diagnostics System. Whilst some of the major Original Equipment Manufacturers (OEMs) have these technical capabilities, it is costly for lift owners to procure such services. Furthermore, for lift owners with multiple brands of lifts, it is not cost-effective and efficient to use multiple lift remote monitoring systems. Having a 3rd party Remote Monitoring & Diagnostics System in the market will provide lift owners with a one-stop solution for their lifts. However, it is not easy to differentiate and assess them because there are many variations in their solutioning available in the market. In addition, their solutioning capabilities are still relatively unknown when compared to that of the OEM counterparts. It is therefore important to conduct research to develop an integrated 3rd party remote monitoring and diagnostics system.

2 Objectives and Scope of Call for Proposals

2.1 The objectives of the project are to:

(a) Develop a 3rd party Remote Monitoring and Diagnostics System that integrates requirements and functionalities of a variety of current lift technologies, as well as improves the accuracy of lift fault diagnosis, allowing predictive and proactive maintenance. This System should be comparable to or better than OEM systems in terms of monitoring methods and prediction analysis;

(b) Leverage Smart Technology and AI to improve lift monitoring and performance; and

(c) Identify and develop a common standard for Remote Monitoring & Diagnostics System to allow any 3rd party solution provider to develop such remote monitoring and diagnostics solutions for the market.

2.2 The project will be split into three areas: 1. Developing the system, 2. Enhancing the system through AI and, 3. Developing a common standard for lift remote monitoring and diagnostics.

Work Area 1

(a) Develop a 3rd party Remote Monitoring and Diagnostics System with the following capabilities:
   (i) Remotely monitor lift status and health;
   (ii) Remotely conduct lift fault diagnoses; and
   (iii) Integrate existing and new lift sensors

(b) System should be robust, easy to attach and require minimal configurations across various OEMs

(c) System should be comparable to or better than those of OEMs

(d) System should address and mitigate cyber-security risks

Work Area 2

(a) Enhance the System through Smart Technology and AI to continually increase the accuracy of predicting lift faults and lift part failures.

Work Area 3

(a) Develop a common standard for lift remote monitoring and diagnostics.

2.3 The developed remote monitoring system will also be assessed based on costs and ease of technical implementation.

Project Code: CoT_V4_GC2018-1_P1

Call Topic: Phase Change Materials for Effective Indoor Cooling in the Tropics

1 Background

1.1 Phase Change Materials (PCMs) function as a thermal mass and enable cooling via passive means by absorbing latent heat during phase transitions in a narrow temperature range. Currently, there has been extensive research conducted on PCMs in temperate climates. However, with relatively higher temperatures (25 – 35 degrees Celsius) and a smaller daily temperature variance (average range of 6 degrees Celsius) in the tropics, there is a reduction in the efficacy of these conventional PCMs. Moreover, with higher night-time temperatures, there is a greater heat penalty when the PCM "recharges" and releases the heat that it has absorbed during the day.

1.2 Thus, further research is needed to determine suitable PCMs, PCM dimensions, and placement locations (exterior surface, in-built into the wall etc.) that are able to achieve cooling via passive means for existing and new buildings in Singapore's climate. Additionally, there is a need to develop and evaluate methods to integrate these materials into building structures, such as structural/non-structural walls and roofs that are conventionally made of reinforced concrete. Lastly, there is a need to evaluate the effectiveness of the solution for various building types (eg. for residential and industrial interior volumes).

2 Objectives and Scope of Call for Proposals

2.1 The objectives of the project are to:

(a) Determine suitable PCMs, dimensions, and placement locations that are able to achieve cooling via passive means for existing and new buildings in Singapore's climate;

(b) Develop and evaluate methods to integrate these materials into building structures, such as structural/non-structural walls and roofs, conventionally made of reinforced concrete; and

(c) Evaluate the effectiveness of the solution for various building types (eg. residential and industrial interior volumes).

2.2 The project will be split into two phases. Phase 2 will be contingent on phase 1 being successful.

Phase 1: Proof of Concept (POC)

(a) Compare and contrast the various types of PCMs (Organic, inorganic, eutectics, etc.) based on latent heat storage ability and phase changes that are most suitable for thermal insulation
(b) Evaluate the safety of suitable PCMs in terms of chemical stability, toxicity, fire safety, explosiveness, corrosiveness, etc. for building applications
(c) Identify suitable PCMs (type, dimensions and placement locations) for thermal insulation of existing and new buildings based on Singapore's local climatic conditions
(d) PCMs identified should be safe (non-toxic, non-flammable, non-corrosive, non-explosive etc.), be chemically stable, and be minimally degraded after many heating-cooling cycles

Phase 2: Proof of Value (POV)

(a) Develop a prototype for a building material incorporating the suitable PCMs and analyse the results of thermal insulation and cooling loads
(b) Replicate or simulate similar experiments in various building components (eg. gable-end walls, roofs) and building types (eg. various scales of interior volumes)
(c) Provide an analysis of material, installation, operations, and maintenance cost

Project Code: CoT_V4_GC2018-1_P2

Call Topic: Solutions to Maintain Good Ventilation in Enclosed Spaces with Zero or Very Minimal Energy

1 Background

1.1 In highly urbanised environments, excessive noise is one factor that negatively affects liveability. Solutions to mitigate noise propagation include controlling the noise source, providing noise barriers to deflect noise, and active noise cancellation. For noise levels above certain thresholds (e.g. aircraft noise), such solutions may not be effective and a last resort is to enclose living spaces. However, this will reduce natural indoor ventilation and cause heat to build up within the space, requiring conventional means of mechanical ventilation and cooling, such as air-conditioning. Such approaches will increase the energy demand of a building and negatively impact our drive towards environmental sustainability.

1.2 A passive method of cooling buildings is through the use of a Solar Chimney, which is a vertical shaft that uses solar energy to generate convection currents and enhance the natural stack ventilation through a building. There have been past studies on Solar Chimneys, mostly done in temperate regions. However, due to differing factors such as the amount of solar irradiance, average temperature, humidity, cloud cover and the sun's path, it is not accurate to translate the results to Singapore's context. Moreover, studies conducted in the tropics have largely dealt with solutions for low-rise buildings. Additionally, many current passive ventilation strategies and technologies rely on opening up the façade of a building to channel external airflow through interior spaces. However, other solutions need to be developed to tackle the ventilation of fully enclosed spaces.

2 Objectives and Scope of Call for Proposals

2.1 The project aims to find innovative solutions to achieve good ventilation, and comfort of the inhabitants, in enclosed spaces in mid to high-rise residential buildings* using net zero to minimal energy. One of the main thrusts of the project is to relook at the design of solar chimneys in Singapore's context and determine effective parameters and design guidelines. This could include a detailed analysis on the air exchange within enclosed living spaces (e.g. optimal air flow for sufficient ventilation in HDB flats).
**With reference to BCA and SCDF classifications, mid-rise buildings are defined as 6 to 12 storeys, and high-rise buildings are more than 12 storeys.*

2.2 This project will be split into two work areas. Work area 1 looks at the development of solar chimney solutions as well as other ventilation solutions. Work area 2 looks at the development of ventilation standards.

Work Area 1: Development of Solutions

(a) Study and develop various Solar Chimney solutions that provide good ventilation in mid to high-rise enclosed spaces in the tropics. Solutions can generate convection currents through passive (eg. phase change materials, landscaping water features etc.) or active (eg. mechanical) means; however, if mechanical solutions are developed, they should consume net zero to minimal energy.

(b) Study suitable quantities and placements of the solar chimney in a building or flat for good ventilation (eg. the comparison between a few central solar chimneys or multiple chimneys throughout a branched ventilation network). Consideration should also be given to other factors such as inhabitant comfort, noise propagation, indoor air quality.

(c) Study and develop various other solutions that provide good ventilation in mid to high-rise enclosed spaces in the tropics (eg. hybrid solar chimney with passive downdraft evaporative cooling or district cooling systems).

(d) Test-bed and evaluate the solutions for Work Area 1 in mock-up environments for various residential building types (eg. mid-rise, high-rise). Collect and analyse the data (eg. indoor air quality data, air flow data, humidity and temperature data) to determine if the solution is able to provide good ventilation.

Work Area 2: Ventilation Standards

(a) Study and develop a standard for sufficient and optimal ventilation, and indoor air quality in enclosed residential spaces in HDB flats.

Project Code: CoT_V4_GC2018-1_P3

Call Topic: Co-existence of Roadside Planting and Bio-retention Systems

1 Background

1.1 Bio-retention systems make use of natural materials such as soil media and plants to cleanse rainwater runoff. Besides its cleansing function, these features also serve to enhance the aesthetic of the surrounding landscape. These features can be located along the roadside verges to treat the rainwater runoff from roads. At the same time, Singapore's efforts in urban greening through the planting of trees and shrubs at the roadside over the decades have led to Singapore possessing the highest Green View Index (GVI) of any urban city, according to MIT's Senseable City Lab. As such, recognising the benefits brought about by bio-retention systems coupled with lush street planting, the idea of co-locating bio-retention systems together with roadside planting have been mooted - further optimising Singapore's limited land resource.

1.2 So far, no studies have been conducted on the bioswales types, tree/plant species, and planting schemes that can be co-located within the various road verge typologies.

2 Objectives and Scope of Call for Proposals

2.1 The proposal shall be able to answer the following questions:

(a) Can fully-operational bio-retention systems be installed and maintained along new roadside verges without impact to the eventual health, stability, and choice of planting schemes, to achieve a lush, tree-lined streetscape?

(b) Can such systems be retrofitted and maintained along roadside verges with existing mature trees without compromising the health and stability of these trees, future planting choice, as well as the function of these retrofitted systems?

(c) Are there viable solutions to facilitate such co-existence, and if so, what are the trade-offs, if any? If there are no viable solutions to co-exist on the narrow roadside green verge, what other out-of-box or beyond-road-corridor solutions could achieve the same benefit of cleaning the rainwater run-off from carriageway?

2.2 Expected outcomes include, but are not limited to feasibility reports, data analytics, numerical modelling analysis/forecasting tools, and guidelines to answer the research questions in para 2.1 of this document.

2.3 For reference on bioretention systems, roadside greenery provisions, and typical roadside typologies, please refer to PUB's ABC Design Guidelines, NParks' guidelines on greenery provision and tree conservation for developments, and LTA's code of practice for street work proposals relating to development works, respectively.