

Built Environment Robotics R&D Programme
Open Grant Call 2020

1. Definitions

- 1.1 In this Call for Proposal, unless the contrary intention appears: -
- (a) “Collaborator” means any company, institution, incorporated body or other industry or academic collaborator, which is not an Investigator but is to be engaged in the Research in collaboration with the Institutions or any of them;
 - (b) “Host Institution” means the body or institution or administering organisation named in the Letter of Award as the “Host Institution” as the body responsible for undertaking and managing the Research;
 - (c) “Institutions” means collectively the Host Institution and the Partner Institutions and “Institution” shall mean any one of them;
 - (d) “Investigators” means collectively, the Lead Principal Investigator, Team Principal Investigators and Co-Investigators; and
 - (e) “Partner Institutions” means the bodies or institutions named in the Letter of Award as the “Partner Institutions” as the bodies responsible for working together with the Host Institution to undertake the Research

2. Introduction

- 2.1 The Built Environment (BE) Robotics R&D programme is a multi-agency effort, led by the Building and Construction Authority (BCA) together with the National Robotics Programme (NRP), that recognises the opportunities that robotics can offer in improving efficiency, safety and quality of work processes, reduce manpower and creating new higher value-adding job opportunities in the BE sector.
- 2.2 The programme focuses on research, development and deployment of innovative robotics in three focus areas (see Annex A) with practical implementation and commercialisation potential. It also supports Design for Manufacturing and Assembly (DfMA) and Integrated Digital Delivery (IDD) efforts, which are 2 of the 3 key transformation areas to chart the way forward in the Construction Industry Transformation Map (ITM).
- 2.3 This call for research proposals is for 2 solutions namely, (a) “*Centralised geo-spatial imaging & measuring systems for inspections*” and (b) “*Optimising earthworks with robotics*”. Please refer to Annex B and C for details of the call topics.

3. Eligibility

- 3.1 Principal Investigators (PIs) from all Singapore-based institutions of higher learning (IHLs), public sector agencies and not-for-profit research laboratories as well as companies and company-affiliated research laboratories/institutions, are eligible to apply.
- 3.2 The Lead PI who leads the Research must be based in Singapore and collaboration with foreign organisations and experts in the capacity of Co-Principal Investigator (Co-PI), or

as Collaborator is allowed. Research work should be done in Singapore unless expressly approved by the grantor.

- 3.3 PIs and supporting agencies will need to declare their other funding sources as well as participation in other funding initiatives during application. Proposals with similar scope, which are currently under evaluation by other funding initiatives, will not be considered until the results from the other funding initiatives are finalised.
- 3.4 Grant applicants should collaborate with companies in the construction industry and government agencies to develop innovative solutions that can address the call objectives and demonstrate strong potential for real-world application within Singapore. The collaboration, whether as Co-I or Collaborator, shall be included in the proposal.
- 3.5 Where applicable, we encourage the integration of relevant social and behavioural research to complement the R&D work under these grant calls, to ensure user-centricity and acceptability of the solutions proposed.

4. Funding Support

- 4.1 The Call for Proposals offers funding support for a period up to 18 months, including a 6-month deployment period. Proposals more than 18 months will require strong justifications.
- 4.2 When budgeting for funding under Built Environment Robotics R&D Programme, the total cost of the project should include all approved direct costs and indirect costs for research, development and deployment. All expenditure should be budgeted inclusive of any applicable Goods and Services Taxes (GST) at the prevailing rates.
- 4.3 Budget items are categorized as direct or indirect cost items. Direct costs are defined as the incremental cost required to execute the project. This excludes contributions in-kind, existing equipment and the cost of existing manpower as well as building cost. Indirect costs are costs that are incurred for common or joint objectives and therefore cannot be identified readily and specifically with a particular sponsored research project, but contribute to the ability of the Institutions to support such research projects (e.g. providing research space, research administration and utilities, and not through the actual performance of activities under the sponsored projects).
- 4.4 Supportable direct costs can be classified into the following cost categories:-
 - (a) Expenditure on manpower (EOM);
 - (b) Equipment;
 - (c) Other Operating Expenses (OOE); and
 - (d) Overseas Travel;
- 4.5 For all direct cost items proposed for the project, please note that:
 - (a) Host Institutions must strictly comply with their own procurement practices;
 - (b) Host Institutions must ensure that all cost items are reasonable and are incurred under formally established, consistently applied policies and prevailing practices of the Host Institution; and

- (c) All items/ services/ manpower purchased/ engaged must be necessary for the R&D work.
- 4.6 The Lead PI should exercise due diligence and ensure that the proposed budget is correct and free from error. The PI should also ensure that the rate of utilization of the budget commensurate with the project progress.
- 4.7 For proposed Equipment to be purchased, please ensure that they are currently unavailable in the Host Institution. In the event where the Lead PI is aware that a similar Equipment is available in the Host Institution, but has still proposed to purchase such Equipment, the Lead PI has to provide the necessary justifications for BCA and NR2PO's approval. Please also note that there is a requirement to share Equipment purchased using NRF funds with other researchers in Singapore.
- 4.8 At the end of the Research, BCA and NR2PO reserve the right to require the Host Institution to transfer ownership of any of the Assets to BCA, NR2PO or any other person or body at no cost.
- 4.9 The Built Environment Robotics R&D Programme will support 100 percent of the approved qualifying direct costs of a project for Singapore-based IHLs and Research Institutes (RIs), public sector agencies and not-for-profit hospitals and research laboratories. Companies and company-affiliated research laboratories or institutions will qualify for up to 70 percent of the approved qualifying direct costs of a project.
- 4.10 Support for indirect costs, in the form of overheads, will only be provided for Singapore-based IHLs, and not-for-profit entities. Funding support of 20 percent of the total qualifying approved direct costs (i.e. total direct costs less exceptional items) will be allowed. Host Institutions will be responsible for administering and managing the support provided by Built Environment Robotics R&D Programme for the indirect costs of research. Indirect costs must be specifically provided for in the grant, and approved by the Grantor based on the nature of the research.
- 4.11 Please refer to the document "Guidelines for the Management of Competitive R&D Grants" for information on Disbursement of funds, Variation requests, Audit and Progress reports and List of Non-Fundable Direct Costs for Research Projects.
- 4.12 BCA and NR2PO's decision on the funding support to be awarded for each project is final.

5. Intellectual Property Rights

- 5.1 Government agencies who are Institutions or Collaborators shall co-own any Intellectual Property (IP) arising from the Research. If Government agencies choose not to co-own IP, they shall make this position known prior to award.
- 5.2 The Institutions shall keep and maintain a full, comprehensive and updated list of all Research IP, which shall be made available to BCA and NR2PO for inspection at any time.

- 5.3 The parties shall use best efforts to ensure that Research IP is properly managed and wherever feasible, fully exploited and commercialized. When required to do so by BCA or NR2PO, the Institutions shall attend such meetings as BCA or NR2PO may direct to discuss the potential for exploitation and commercialization of Research IP.
- 5.4 The Government and public sector agencies shall reserve a non-exclusive, non-transferable, perpetual, irrevocable, worldwide, royalty-free right and license to use, modify, reproduce and distribute the Research IP for non-commercial, R&D and/or educational purposes.

6. Letter of Award & Acceptance

- 6.1 Successful applicants will be informed by BCA or NR2PO. Notification in the form of a Letter of Award will be sent to the Director of Research for the respective Lead PI's Host Institution, and copied to the Lead PI.
- 6.2 The Letter of Award will include the following:
- (a) Statement of Acceptance;
 - (b) Terms and Conditions of the Grant;
 - (c) Guidelines on Grant Management;
 - (d) Performance Indicators and Milestones; and
 - (e) Schedule and Budget Details.
- 6.3 The Acceptance Form must be acknowledged by all of the following:
- (a) The Director of Research (or equivalent);
 - (b) The PI; and
 - (c) The Co-Investigators (Co-Is).
- 6.4 Upon award of the project, the PI, Co-Is and Host Institution are bound by these clauses and all other terms as specified in the Letter of Award.
- 6.5 The PI or Co-Is cannot also be the authorised officer representing the Institution. In such cases, another officer duly authorised by the management of the Institution shall approve on its behalf.
- 6.6 The Acceptance Form and Annexes (if applicable) should be returned to BCA and NR2PO within a pre-determined time frame from the date of the Letter of Award. The date on which the Statement of Acceptance is signed shall be taken as the date of acceptance of the Award.
- 6.7 After the acceptance of the Award, the Host Institution, Partner Institutions and the Collaborators shall enter into a written agreement that is consistent with the obligations assumed under this Research and that includes conditions about: -
- (a) the role of each party in the Research;
 - (b) the provision of cash or in-kind contributions to the Research by each party;
 - (c) the work to be undertaken by each party and its technical/scientific contributions;
 - (d) terms relating to Intellectual Property ownership and commercialization; and

(e) any other obligations to be fulfilled as laid out in this set of guidelines.

6.8 The Investigators are responsible for putting in place research collaboration agreements where and when applicable.

7. Research Integrity Policy

7.1 The Host Institution shall ensure that all necessary approvals for the research, including all ethics approvals, have been granted prior to the commencement of any research activities.

7.2 The Host Institution is responsible for establishing a research ethics and integrity policy and enforcing its compliance. In carrying out any Research, the Host Institution shall agree to:-

- (a) Comply with the provisions of any relevant laws of the Republic of Singapore, statutes, regulations, by-laws, rules, guidelines and requirements applicable to it, as well as all applicable policies and procedures adopted by the Built Environment Robotics R&D Programme as the same may be amended or varied from time to time;
- (b) Have in place a research integrity policy which sets out the principles for the responsible conduct of research and procedures for investigating and responding to accusations of misconduct;
- (c) Provide training in responsible conduct of researchers, for all researchers;
- (d) Be held responsible for the conduct of research and researchers; and
- (e) Ensure compliance with best practice, as well as the ethical, legal and professional standards relevant to the research.

7.3 All PIs, research personnel and all other persons involved in the Research must comply with the research ethics and integrity policy, and other approval requirements needed to carry out the research programme. The PIs should undertake the following declaration:

- (a) In carrying out Research, agree to comply with the provisions of any relevant laws of the Republic of Singapore, statutes, regulations, by-laws, rules, guidelines and requirements applicable to it, as well as all applicable policies and procedures adopted by the Built Environment Robotics R&D Programme as the same may be amended or varied from time to time;
- (b) Agree to hold primary responsibility for the responsible conduct of research, and shall abide and comply with the ethical, legal and professional standards relevant to research, in accordance to the research integrity policy of the Host Institution; and
- (c) Declare any potential conflict of interest that may arise from the purchase of equipment/ physical items or engagement of manpower/ services in the course of carrying out Research.

8. Evaluation Criteria

8.1 Proposals will be evaluated based on the following criteria:

- (a) **Potential Contribution to the Built Environment Robotics R&D Programme Objectives**

- Relevance of proposed research in contributing to objectives stated for the Built Environment Robotics R&D Programme Call Topics.
- Ability to meet the deliverables and outcomes stated in the Call Topics.

(b) Potential for Breakthrough and Innovation

- Quality and significance of proposed research, including value for money, and the potential for breakthrough/innovation to advance knowledge and understanding within its own field or across different fields.

(c) Potential for Application and Deployment in Singapore and Commercialisation/Export

- Potential for application and deployment of research outcomes in Singapore by a public agency and potential for solutions to be replicated in Singapore beyond a single site/project.
- Feasibility and plans for commercialisation/ export in areas where Singapore has a competitive advantage.

(d) Execution Strength and Technical Competency of Research Team

- Quality of plans for execution and delivery of the research programme and goals, including the appropriateness of the proposed milestones and deliverables (specific to evaluation of full proposal applications)
- Quality, significance, and relevance of the recent research record of the PI and Co-PIs and the strength of the applicant group, including likely synergy in delivering research and potential for international leadership.

9. Submission Instructions

9.1 All proposals must be submitted to BCA_ROBOTICS@bca.gov.sg by **14 JULY 2020, 2359 hrs.** **Late submissions or submissions from individual applicants without endorsement from the Host Institution will not be entertained.** It is advised to restrict submissions to 10 MB.

9.2 Full proposals and supporting documents are only considered to be submitted to the grantor if all relevant forms with the relevant attachments are submitted. The documents required are:

- Form A – Full Proposal;
- Form B – Budget;
- Form C – Capability Indicators; and
- Form D – Undertaking Form

Important: Where relevant privileged or confidential information is needed to help convey a better understanding of the project, such information should be disclosed and must be clearly marked in the proposal.

Annex A: BE Robotics R&D Programme Focus Areas

1. The programme focuses on 3 key areas, namely, (a) Manufacturing, (b) Assembly and, (c) Smart and Sustainable Assets. Each area focuses on a different stage of the construction value chain, as follows.

a. Manufacturing

This research area explores advancing the degree of automation in DfMA factories and ICPHs as well as expanding their capabilities to meet future needs.

Examples of possible R&D projects include mobile robots that can carry out finishing works like tiling, painting and installation of architectural components within Prefabricated Bathroom Unit (PBU) and Prefabricated Prefinished Volumetric Construction (PPVC) module faster and more accurately.

b. Assembly

This research area explores solutions to improve on-site productivity through automation and robotics. It also intends to future-proof the industry against evolving on-site demands as the industry shifts towards a greater adoption of DfMA methodologies.

Examples of possible R&D projects include exploring robots which can quickly and accurately transport materials as well as assemble prefabricated components together on-site. Other areas to be explored are to automate labour intensive site monitoring and investigation tasks that are critical for large scale infrastructure projects. There is potential to integrate robotics into assembly techniques and methods for DfMA projects for structural, finishing and mechanical and electrical systems for different building types.

c. Smart and Sustainable Assets

This research area looks into developing smart solutions for facilities operation and management. In addition, it seeks to address problems that come with an ever increasing number of older buildings. This will include civil engineering works.

2. These 3 areas are further subdivided into 9 different sub-groups, each addressing a specific challenge. The R&D projects will be prioritised amongst these 3 areas. The description of each of these sub-categories are shown in Table A.

Table A – Built Environment Robotics R&D Programme

Research area	Sub-group	Description
Manufacturing 	PPVC assembly + finishes	The assembly of PPVC modules as well as the accompanying finishes work are labour intensive. Robotics can reduce the ICPH's reliance on physical labour and improve productivity.
	PBU assembly + finishes	PBU production within the ICPH currently takes up to 8 man-days, from assembly of carcass to architectural/finishing works.
	Production of moulds with complex geometries ¹	A 3D printer (<i>or other advanced manufacturing methods</i>) that can print the formwork of a building element that has a complex geometry
Assembly 	Site survey robot	A typical infrastructure project can have up to 1500 monitoring points spread over a large area. It can take a 12-man team 12 hours each day to take all of the measurements.
	Heavy duty transport robot	With many different trades working in one building site, a considerably amount of time is spent loading/unloading and transporting material across the work site. The goal is for an automated transport robot to improve productivity for the site.
	Smart crane + assembly solutions	Modifying crane/lifting equipment to quickly identify the correct prefab component and in the right sequence and location. Robot(s) to quickly align component for human workers to carry out jointing works.
	Digital supervisor	Mobile robots or drones that can travel easily and safely across different types of construction sites (deep excavation, tall buildings, etc.). These would be equipped with tools to accurately measure progress of construction, track workers and identify potential hazards
Smart and Sustainable Assets 	Civil engineering inspection robot	Mobile robot or drones to carry out inspections of tunnels during the construction phase. These would be equipped with instruments to accurately measure deflection and water leakage with minimal human intervention
	Facilities management robot	Mobile robot or drone that can access hard-to-reach areas. These would be equipped with non-destructive testing instruments to verify integrity of different structural and mechanical components.

Annex B

Call Topic: Centralised geo-spatial imaging & measuring system for inspections

1. Background

- 1.1 Several forms of inspections and checks are required in the built environment. These include tracking of construction quality and Temporary Occupation Permit checks. Currently these inspections are done manually and contrasted.
- 1.2 These inspections are time consuming and labour intensive. There are opportunities to improve these processes with technology.
- 1.3 This is especially critical to make the industry resilient against being disrupted by pandemics. Use of AI-assisted tools and robotics for example, would allow for such works to be done remotely.

2. Evidence based smart inspection

- 2.1 Building Information Modelling (BIM) is an important digital tool that supports decision making regarding a built environment asset. A BIM model is made during the design stage and it is updated (multiple times) as construction progresses until the building is commissioned.
- 2.2 With evidence based smart inspections, the BIM model can be updated continuously, with highly accurate data being collected regularly. The model can be assessed by various stakeholders at their convenience, to ensure there is only a Single Source of Truth (SSOT)

3. Project objectives and requirements

- 3.1 The research is to develop an evidence-based smart solution that includes:
 - (a) Developing an integrated robotics solution that can take geo-spatial measurements for various types of construction projects
 - (b) Developing solutions to relate measurements to BIM, generate as-built drawings, check progress for progress payments and flag out conflicts and non-conformities
- 3.2 The proposed solution must demonstrate
 - (a) an improvement of productivity of more than 200% over current methods of inspection
 - (b) improvement in safety by reducing total number of inspectors on site
 - (c) increase in accuracy, reduction in rework
- 3.3 A study of common inspections carried out in the BE industry would be necessary. This is to ensure that the proposed solution can accurately capture enough data to carry out those inspections in an acceptable manner.

- 3.4 A detailed project schedule (e.g. project timeline, Gantt chart) of major project activities and the milestone checkpoints. It should include a description of each milestone and deliverable of the project.
- 3.5 The project must be self-sufficient in all aspects. There will be no Authority-Furnished Equipment (AFE) or Government-Furnished Equipment (GFE) provided. PIs, co-PIs and Host Institution shall obtain the necessary approvals from the relevant authorities for the use and modification of any public space, amenity, equipment and facility needed for the deployment.
- 3.6 The proposed solution must comply with the Workplace Safety and Health Act & the provisions of the Workplace Safety and Health Act Subsidiary Legislations and any amendment(s) or re-enactment(s) thereto.
- 3.7 The project proposal must clearly indicate who are the construction industry collaborator(s), their involvement and the potential demonstration and deployment sites.

4. Programme Schedule and Deliverables

- 4.1 Quarterly progress reports shall be provided to BCA and NR2PO, to be presented at quarterly review meetings. These reports should provide information such as the degree of completion and other updates which might affect the progress the project.
- 4.2 Specifications and deliverables shall include, but are not limited to, the following:

<p>Phase 1 (1 month from date of award) –Literature review of local and overseas landscape of related robotics projects Submission of Interim Findings/ Results.</p>	<p>Deliverables at end of Phase 1: -</p> <p>Report: -</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of the report. • The literature review provided in the report should show a clear understanding of the local and overseas landscape in the area of study and identification of the constraints. <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted, which would include 3D graphic modelling to demonstrate the proposed concept. <p>Fine-Tuned Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and a soft copy of the fine-tuned report, which shall incorporate all feedback given by and NR2PO during the presentation.
--	--

<p>Phase 2 (3 months from date of award) – Submission of Interim Findings/Results and preliminary design</p>	<p>Deliverables at end of Phase 2: - Report:</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 1. • The report shall include a preliminary design of the proposed solution <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Final Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and soft copy of the final report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.
<p>Phase 3 (6 months from date of award) – Submission of interim findings and results</p>	<p>Deliverables at end of Phase 3: - Report: -</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 2. • The report shall include testing data and results from the development and testing of proposed solution <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Fine-Tuned Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and a soft copy of the fine-tuned report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.
<p>Phase 4 (9 months from date of award) – Submission of final design report and trial test plans</p>	<p>Deliverables at end of Phase 4: - Report: -</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 3. • The report shall include final design report • The report shall include clear plans for conducting trials on a public sector site with letter of intent from industry partner to deploy at their work site

	<p>Presentation: - Conduct one (1) presentation to BCA and NR2PO after the above report is submitted.</p>
<p>Phase 5 (12 months from date of award) – Finalization and Submission of Final Report with data from trial</p>	<p>Deliverables at end of Phase 5: - Report:</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 4. • The report shall include the finalised findings including final design of proposed solution and trial data. <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Final Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and soft copy of the final report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.
<p>Phase 6 (18 months from date of award) Deployment at public sector site</p>	<p>Deliverables at end of Phase 6: - Report:</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 5. • The report shall include the report of deployment at public sector site. <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Final Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and soft copy of the final report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.

4.3 In addition to the deliverables in clause 3.2, the PI, Co-Is and Host Institution shall attend to present for both (i) the progress update monthly to BCA/NR2PO and (ii) the engagement sessions to the industry's stakeholders after the submission of the final reports.

4.4 Where required by BCA/NR2PO, the PI, Co-Is and Host Institution shall attend ad-hoc meetings, briefings, presentations and discussions relating to the project. This will include a commencement meeting to work out the communication channel and to set

the specific deadlines of each milestone etc. before the commencement of the engineering study.

- 4.5 The PI, Co-Is and Host Institution may propose other deliverables deemed as improvements to the above and where necessary, to show their commitment and value added services.
- 4.6 The PI, Co-Is and Host Institution shall be deemed to have fully understood the requirements. In the event that the outcome delivered does not meet the requirements, the PI, Co-Is and Host Institution shall ensure fulfilment of the requirements at the PI, Co-Is and Host Institution's own additional expenses.

5. Reports

- 5.1 All reports shall:
 - (a) Be available in hard copies and soft copy for ready reference;
 - (b) Have comprehensive indexes to facilitate quick reference;
 - (c) Be in the format that is editable by BCA or NR2PO's existing software; and
 - (d) Be subject to approval and acceptance by BCA and NR2PO.
- 5.2 All reports shall be succinct and be accompanied by an executive summary. The executive summary shall not be more than five (5) pages in length.
- 5.3 The PI, Co-Is and Host Institution must be able to demonstrate how the information given in the report are derived such as through fundamental principles or quoted sources, which shall be accompanied with clear explanation on how the information are derived. All supporting documents and materials of quoted sources shall be included in the appendices. All assumptions used in the report shall also be clearly stated and validated.

Annex C

Call Topic: Optimising civil engineering works with robotics

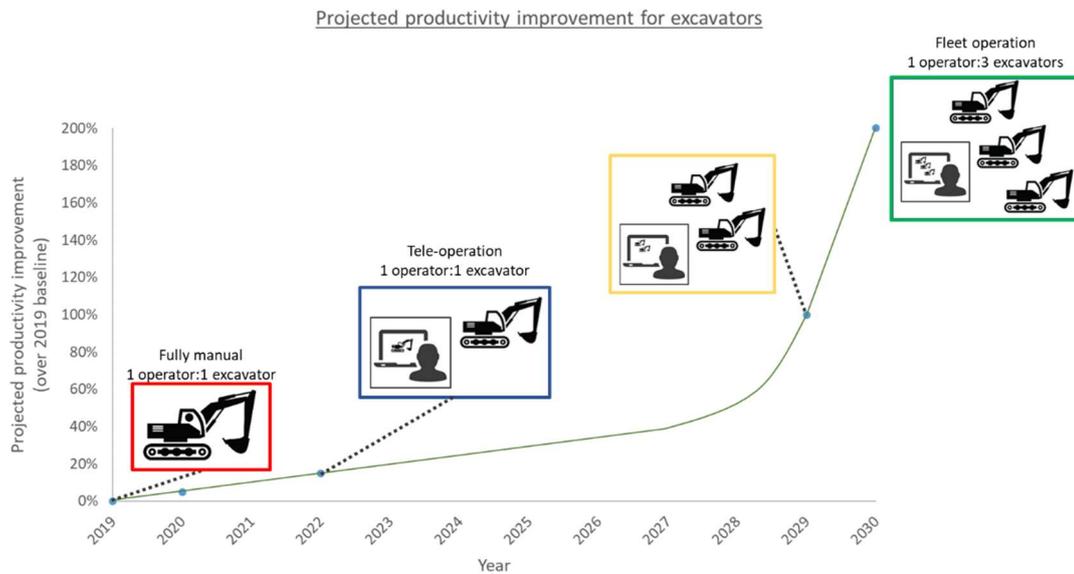
1 Background

- 1.1 Climate change represents a real problem to Singapore as several areas are vulnerable to rising sea levels. These include places such as Jurong Island and the eastern coastline. Corrective actions would be necessary to safeguard these at-risk locations.
- 1.2 Among the steps taken to combat this threat is an extensive upgrade of the local drainage system, with \$400 million budgeted for the next two years in drainage improvement works. For the longer term, Singapore is exploring mega engineering projects such as construction of polders and reclamation of offshore islands along the eastern coast.
- 1.3 Such mega engineering projects tend to be resource intensive, with manpower requirements expected to put a strain the built environment sector's workforce. In order to alleviate this, R&D efforts can be directed towards improving construction productivity, particularly in the field of earthworks, which is a critical on-site activity that is common across these projects.
- 1.4 One of the technologies considered for further R&D are the heavy construction equipment. Through automation and tele-operation, there are opportunities to further improve heavy construction equipment in terms of both productivity and safety.

2 Heavy construction equipment usage in the built environment

- 2.1 The excavator is a type of heavy construction equipment that can be utilised on site in a variety of ways. Such tasks include digging and materials handling, which are a large part of most civil engineering works. Additionally, an excavator may have different attachments, which expands its usage to include other tasks such as demolition and piling.
- 2.2 Other examples of heavy construction equipment include rollers, pile boring machines and pile driving machines. Most of these are operated by a single operator. However, these operators work in tandem with surveyors that mark out the site for them and check on the accuracy of their work, as well as a safety team to guide their movement about the site safely.
- 2.3 Technology for autonomous and tele-operation of such heavy construction equipment is already possible. However, these are limited to greenfield site and would need to be adapted to operate safely in local construction sites.

- 2.4 Integration with survey equipment is key to ensure accuracy of work and prevent-rework. It is also critical to integrate with detection tools, to ensure that the heavy construction equipment does not cause disruption to nearby services.
- 2.5 Productivity can be maximised if such heavy construction equipment can be operated as a fleet, as illustrated in Figure C1.



3 Project objectives and requirements

- 3.1 The research is to develop a solution that works with common heavy construction equipment that will allow for autonomous fleet operations together with survey tools and infrastructure. The proposed solution's concept, demonstration and trials must meet the following objectives:
- Safety and security as a top priority at all times;
 - Effective earthworks operations through autonomous fleet operations;
 - Improvement in productivity of >200% - *one operator oversee and operate remotely a fleet of at least 3 machines, integration with surveyor*
 - Have the capability of interoperating with other robotic OEM solutions and IoT devices on site
 - Improvement in safety by reducing total number of workers at site, integration of tools to detect services and carry out precision measurements
- 3.2 A study of conventional civil engineering work processes is necessary. This is to quantify improvement in productivity and precision. PI must demonstrate that they solution can work for several different use cases, such as deep excavation works and road construction.
- 3.3 A detailed project schedule (e.g. project timeline, Gantt chart) of major project activities and the milestone checkpoints. It should include a description of each milestone and deliverable of the project.

- 3.4 The project must be self-sufficient in all aspects. There will be no Authority-Furnished Equipment (AFE) or Government-Furnished Equipment (GFE) provided. PIs, co-PIs and Host Institution shall obtain the necessary approvals from the relevant authorities for the use and modification of any public space, amenity, equipment and facility needed for the deployment.
- 3.5 The proposed solution must comply with the Workplace Safety and Health Act & the provisions of the Workplace Safety and Health Act Subsidiary Legislations and any amendment(s) or re-enactment(s) thereto.
- 3.6 The project proposal must clearly indicate who are the construction industry collaborator(s), their involvement and the potential demonstration and deployment sites.

4 Programme Schedule and Deliverables

- 4.1 Quarterly progress reports shall be provided to BCA and NR2PO, to be presented at quarterly review meetings. These reports should provide information such as the degree of completion and other updates which might affect the progress the project.
- 4.2 Specifications and deliverables shall include, but are not limited to, the following:

<p>Phase 1 (1 month from date of award) –Literature review of local and overseas landscape of related robotics projects Submission of Interim Findings/ Results.</p>	<p>Deliverables at end of Phase 1: - Report: -</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of the report. • The literature review provided in the report should show a clear understanding of the local and overseas landscape in the area of study and identification of the constraints. <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted, which would include 3D graphic modelling to demonstrate the proposed concept. <p>Fine-Tuned Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and a soft copy of the fine-tuned report, which shall incorporate all feedback given by and NR2PO during the presentation.
--	--

<p>Phase 2 (3 months from date of award) – Submission of Interim Findings/Results and preliminary design</p>	<p>Deliverables at end of Phase 2: - Report:</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 1. • The report shall include a preliminary design of the proposed solution <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Final Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and soft copy of the final report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.
<p>Phase 3 (6 months from date of award) – Submission of interim findings and results</p>	<p>Deliverables at end of Phase 3: - Report: -</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 2. • The report shall include testing data and results from the development and testing of proposed solution <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Fine-Tuned Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and a soft copy of the fine-tuned report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.
<p>Phase 4 (9 months from date of award) – Submission of final design report and trial test plans</p>	<p>Deliverables at end of Phase 4: - Report: -</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 3. • The report shall include final design report • The report shall include clear plans for conducting trials on a public sector site with letter of intent from industry partner to deploy at their work site

	<p>Presentation: - Conduct one (1) presentation to BCA and NR2PO after the above report is submitted.</p>
<p>Phase 5 (12 months from date of award) – Finalization and Submission of Final Report with data from trial</p>	<p>Deliverables at end of Phase 5: - Report:</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 4. • The report shall include the finalised findings including final design of proposed solution and trial data. <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Final Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and soft copy of the final report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.
<p>Phase 6 (18 months from date of award) Deployment at public sector site</p>	<p>Deliverables at end of Phase 6: - Report:</p> <ul style="list-style-type: none"> • Submit three (3) hard copies and a soft copy of report. • The report shall incorporate all feedback given by BCA and NR2PO at the end of Phase 5. • The report shall include the report of deployment at public sector site. <p>Presentation: -</p> <ul style="list-style-type: none"> • Conduct one (1) presentation to BCA and NR2PO after the above report is submitted. <p>Final Report: -</p> <ul style="list-style-type: none"> • Upon the completion of the presentation, submit three (3) hard copies and soft copy of the final report, which shall incorporate all feedback given by BCA and NR2PO during the presentation.

- 1.1 In addition to the deliverables in clause 3.2, the PI, Co-Is and Host Institution shall attend to present for both (i) the progress update monthly to BCA/NR2PO and (ii) the engagement sessions to the industry’s stakeholders after the submission of the final reports.
- 1.2 Where required by BCA/NR2PO, the PI, Co-Is and Host Institution shall attend ad-hoc meetings, briefings, presentations and discussions relating to the project. This will include a commencement meeting to work out the communication channel and to set

the specific deadlines of each milestone etc. before the commencement of the engineering study.

- 1.3 The PI, Co-Is and Host Institution may propose other deliverables deemed as improvements to the above and where necessary, to show their commitment and value added services.
- 1.4 The PI, Co-Is and Host Institution shall be deemed to have fully understood the requirements. In the event that the outcome delivered does not meet the requirements, the PI, Co-Is and Host Institution shall ensure fulfilment of the requirements at the PI, Co-Is and Host Institution's own additional expenses.

2 Reports

- 2.1 All reports shall:
 - (a) Be available in hard copies and soft copy for ready reference;
 - (b) Have comprehensive indexes to facilitate quick reference;
 - (c) Be in the format that is editable by BCA or NR2PO's existing software; and
 - (d) Be subject to approval and acceptance by BCA and NR2PO.
- 2.2 All reports shall be succinct and be accompanied by an executive summary. The executive summary shall not be more than five (5) pages in length.
- 2.3 The PI, Co-Is and Host Institution must be able to demonstrate how the information given in the report are derived such as through fundamental principles or quoted sources, which shall be accompanied with clear explanation on how the information are derived. All supporting documents and materials of quoted sources shall be included in the appendices. All assumptions used in the report shall also be clearly stated and validated.