1 Title

Design-to-Robotic-Operation: Design and Integration of a Meshed and Heterogeneous Wireless Sensor and Actuator Network into Cyber-physical Spaces

2 Full name and affiliation of the workshop leaders

After graduating in architecture (1998) from the University of Karlsruhe in Germany, Henriette Bier has worked with Morphosis (1999-2001) on internationally relevant projects in the US and Europe. She has been teaching (2002-2003) computational design at universities in Europe and since 2004 she teaches and researches mainly at the Technical University Delft (TUD) with focus on digitally-driven design and architecture. She co-developed the education and research frameworks for Non-standard and Interactive Architecture at Hyperbody and Border Conditions at Public Building, TUD. 2008, she defended her PhD in System-embedded Intelligence in Architecture after which she started developing the academic education and research framework on Robotic Building. 2011, she joined Delft Robotics Institute (DRI) and later on she established the Robotic Building (RB) group, which produced work that has been exhibited internationally and more recently in Paris at Centre Pompidou. Results of Henriette Bier's research are published internationally in more than 120 journals, books, and exhibits. She is member of several editorial boards and scientific committees and co-organized conferences and co-edited several books and journal issues on computational design and robotics in architecture.

Alexander Liu Cheng is a Ph.D. candidate at Robotic Building, TU Delft. His work on intelligent built-environments situates Cyber-Physical Systems within the Adaptive Architecture discourse. Alex obtained a B.Sc. in Computer Science from the New York Institute of Technology; a professional M.Arch. from The University of British Columbia; and a post-professional M.Sc. in Advanced Construction and Building Technology-Automation, Robotics, Services from Technische Universitat Munchen. In addition to his academic pursuits, Alex previously worked as Architectural Designer at GRAFT Architects.

3 Content / Design brief

The workshop introduces students to Design-to-Robotic-Operation (**D2RPO**) in order to achieve physical and sensorial reconfiguration. Students are asked to identify reconfigurable components (lights, ventilators, heaters, or shading devices, furniture, and other reconfigurable building components such as walls, floors, etc.) and possible reconfiguration strategies (turn on/off, move, rotate, bend, etc.).

The workshop engages in the investigation of utopian/dystopian visions about future habitats by reinterpreting Constant's New Babylon and introducing static and dynamic functionalities such as infrastructure (structural frame, circulation, water and electricity, etc.) and reconfigurable furniture respectively. For instance, Swarmscape (fig. 1) as in/deflatable reconfigurable mattress with functional i.e. cell differentiation may serve as indoor-outdoor furniture, etc. placed in static mega-structures.

Utopian/dystopian aspects are addressed by exploring on the one hand the potential of cyber-physical systems in architecture, on the other hand the challenges of overpopulation and urban densification, etc.

A. Utopia/Dystopia

Utopias envision ideal communities or societies possessing perfect socio-politico-legal systems. The term is derived from More's book titled *Utopia* (1516). For instance, Constant's New Babylon (fig. 2) envisioned a city of the future where land is owned collectively, work is fully automated, thus human work is replaced with a *nomadic life of creative play*.

In contrast dystopias are communities or societies that are undesirable or even frightening as for instance described in Orwell's *1984* (1949). These are characterized by dehumanization, totalitarianism, environmental disaster, or other characteristics associated with a cataclysmic decline in society.

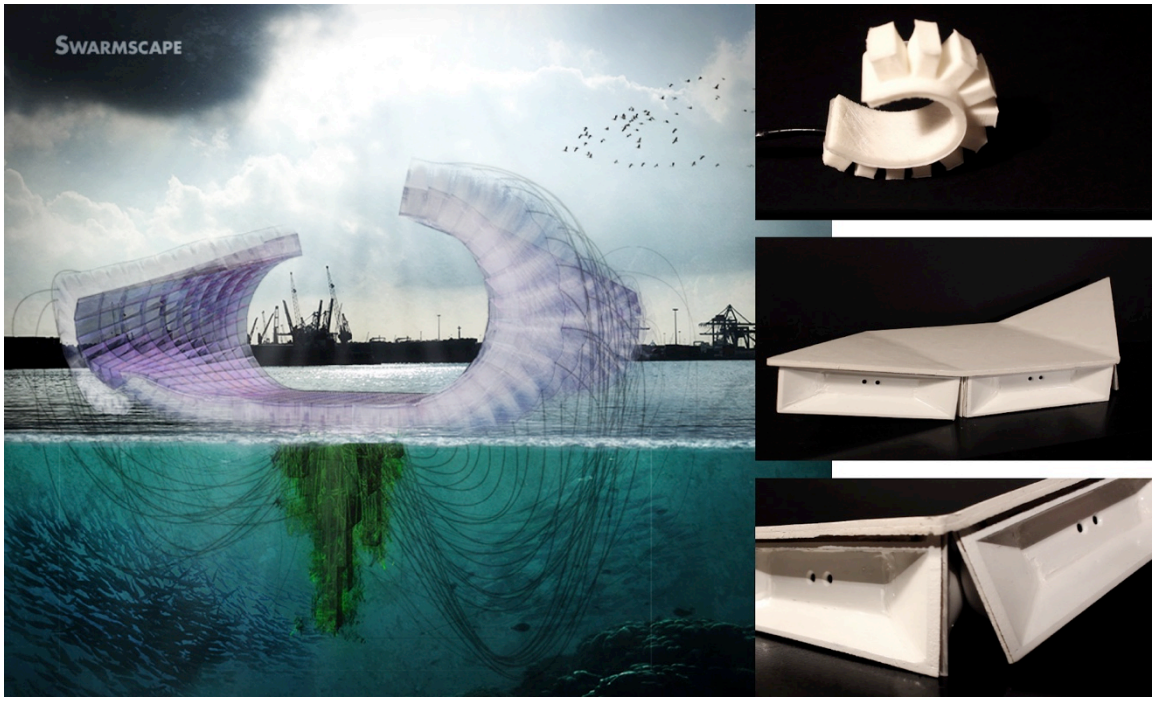

Fig. 1: Sensor-actuator mechanisms allowing spatial reconfiguration according to environmental and human needs

B. Customization and reconfiguration

The proposed Cyber-physical Space (CS) is controlled or monitored by computer-based algorithms, integrated with the Internet of Things (IoT) and its users. Physical and software components are, in this context, deeply intertwined. The static and dynamic modalities of the space involve customization and reconfiguration, which will be achieved by means of D2RO.

Approach

Students will work with a generic bounding box representing a part of the megastructure that is overimposed on an existing city. Within this bounding box students will develop designs for customizable and reconfigurable units based on user scenarios. Main questions to be answered are: If the static superstructure harbors dynamic components and each individual or group can customize and reconfigure its environment, what are the utopian/dystopian scenarios that are considered, which are the static and the dynamic components, what is the required degree of customization and how its is to be achieved, what is the desired/possible frequency of reconfiguration in order to achieve what performances, etc. Performances considered are physical *comfort* (P1), *privacy* (P2), and *playfulness* (P3).

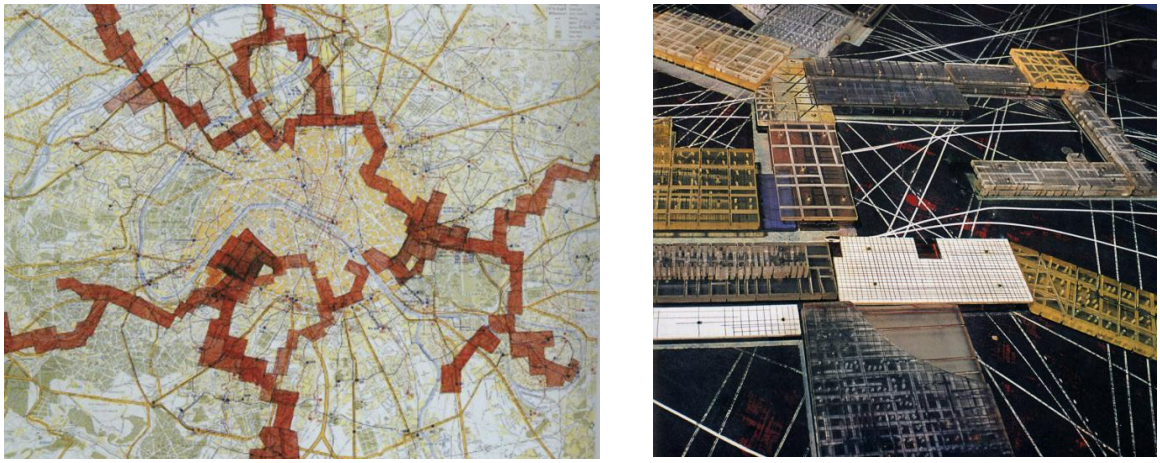

Fig. 2: Constant's New Babylon

4 Objectives, scope, contribution, and expected outcomes or skills acquired by the participants

The principal objective of the proposed workshop is to teach participants to design and to integrate a fully functional *Wireless Sensor and Actuator Network* (WSAN) into a Cyber-physical Space. WSANs lie at the core of *Cyber-Physical Systems* (CPSs) [1], which represent *State-of-the-Art* enablers of both *Architectural* and *Computational Intelligence* in the built-environment. Strategies and methods pertaining to *Design-to-Robotic-Operation* (D2RO) [2–11]—an emerging *computational intelligence in the built-environment* paradigm developed at *Delft University of Technology* (TU Delft) [10–12]—are used to develop this WSAN in an open, scalable, and decentralized manner.

D2RO subsumes capabilities and motivations typical expressed via *Ambient Intelligence* (AmI) [13] / *Ambient Assisted Living* (AAL) [14], which are research fields situated at the intersection of the Engineerings (viz., Electrical, Electronic, Mechatronic, and Information Systems), Architecture, and Medical Sciences. Accordingly, an inherited motivation behind D2RO is to develop built-environments where systems and services expressed in terms of *Information and Communication Technologies* (ICTs) promote and sustain the general well-being, qualitative spatial experience of the inhabited space, and the comfort of the occupant(s).

In this workshop, participants will acquire the skills necessary to develop and to implement WSANs that build on or are informed by notable pioneering projects in the field of intelligence in the built-environment such as *RoboticRoom* [20], *Wabot-House* [21], *The Aware Home* [22], *The Center for Advanced Studies in Adaptive Systems* [23], *PlaceLab* [24]; *Living Independently in Südtirol Alto* [25], and the presently on-going *Responsive Engagement of the Elderly promoting Activity and Customized Healthcare* project [26], funded by the EU's *Horizon 2020* scheme.

Participants will be provided with a designed geometry, and will be asked to

i. Define region of intervention within the corresponding interior space,
ii. Develop an *Interior Environmental Quality* (IEQ) decision-making criteria,
iii. Develop a Quality of Spatial Experience / Comfort / Function / Service / Performance

decision-making criteria,

iv. Define Actuations corresponding to the above-defined criteria, and
v. Determine a corresponding Feedback-loop mechanism to ensure continuous Physical / Computational adaptation given an uninterrupted flow of sensor-data.

After each group has identified points *i-v* above, basic *proof-of-concept* systems will be built on the RPiWZ nodes with corresponding sensors, motors, etc. Once all systems are performing as intended, they will be integrated into a unified WSAN, mutually exchanging sensor data, actuator state, etc.—that is, the data acquired by any one node will be accessible by all other nodes wirelessly via WiFi (high-frequency, medium-range), ZigBee (low-frequency, long-range), BLE (low-frequency, short-range).

5 Tentative program

i. 1st day:
   a. Introduction to D2RO and design brief.
   b. Design challenge, development and identification of intervention context, conceptualization of mechatronic systems within provided geometry.
ii. 2nd day:
   a. Set-up of RPiWZ nodes; development and implementation of *Sensor* / *Actuator* systems pertaining to proposed intervention solution.
   b. Test-drive of mechatronic systems and debugging.
   c. Installation of required Python libraries for subsequent WSAN integration and operation, and integration of all RPiWZ nodes into a unified WSAN, where any node is able to access the information gathered by any other node.
iii. 3rd day:
   a. Preparation of presentation.
   b. Final review.

6 Prerequisite skills of participants

Participants should possess

- *Basic* knowledge pertaining to *Sensors* and *Actuators*.
- *Intermediate* knowledge pertaining to programming logic—i.e., understand function structures, data types, loops, etc.
- *Intermediate* knowledge pertaining to parametric / interactive models—e.g., reactive systems developed in *Grasshopper, Arduino, Processing,* etc.
- *Basic* understanding of Wireless Communication Protocols—e.g., WiFi, XBee/ZigBee, BLE, NFC, RFID.

7 Logistic and technical requirements

7.1 Required Infrastructure (participants)

- Laptop with Win. x32/x64, OSX ,or Linux; working *Wireless* adaptors (WiFi, BLE).
- PuTTY—*free SSH and Telnet client.*
- DIGI's XCTU—*XBee antenna configuration software*.

7.2 Required Infrastructure (organizers)

- 2 HDMI-ready projectors (one to display code, another for visual output).
- 12-15 *Raspberry Pi Zero W*s (RPiZWs) (**EUR 26.00** / unit)[1] (development platforms and *de facto* nodes for the WSAN) with corresponding (i) Power Adapter (**EUR 10.03** / unit)[2], (ii) 16 GB Micro-SD cards (**EUR 9.49** / unit)[3], (iii) Protoboards (**EUR 2.65** / unit)[4], (iv) cables (20 male-male (**EUR 1.75**)[5], 20 female-male (**EUR 1.47** / unit)[6]) per unit.
- At least 1 HDMI LED/LCD monitor (to enable SSH on the RPiZWs) (**EUR 5.99** / unit)[7].
- 3 low-cost Air-Quality sensors (e.g., Methane, CO2, Hydrogen) (**EUR 4.06** / unit)[8].
- 3 low-cost Temperature & Humidity sensors (e.g., DHT-22 / -11) (**EUR 4.02** / unit)[9].
- 3 low-cost *Light Dependent Resistors* (LDRs) (**EUR 8.22** / 10 units)[10].
- 3 low-cost water sensors (**EUR 2.62** / 2 units)[11].
- 3 low-cost Infrared sensors (i.e., for fire detection) (**EUR 2.39** / unit)[12].
- 3 *Peltier* devices (for heating / cooling) (**EUR 7.40** / 3 units)[13].
- 3 6V DC motors (**EUR 1.63** / unit)[14], with corresponding (i) PN2222 Transistor (**EUR 6.28** / 10 units)[15], (ii) N4001 diode (**EUR 1.29** / 10 units)[16], (iii) 270 Ohm resistor (red, purple, brown, stripes) (**EUR 1.29** / 20 units)[17] per unit.
- 3 1-4KG 180 degree servo motor (**EUR 12.99** / unit)[18].
- 3 1-7KG continuous rotation servo motor (**EUR 10.50** / unit)[19].
- 6 28BYJ048 stepper motors with corresponding ULN2003 drivers (**EUR 2.54** / unit)[20].
- An assortment of low-cost 220 (x20), 10K (x20) Ohm resistors (**EUR 24.89** / assorted

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[4] https://www.amazon.de/SODIAL-Steckbrett-Breadboard-Experimentierboard-Steckplatine/dp/B00JGFDKBQ/ref=sr_1_2?s=computers&ie=UTF8&qid=1498145890&sr=1-2&keywords=protoboard
[5] https://www.amazon.de/Breadboard-Steckbr%C3%BCcken-Drahtbr%C3%BCcken-Stecker-Jumper/dp/B00IRYUU8S/ref=pd_sim_107_1?_encoding=UTF8&psc=1&refRID=5RPGNKY7S141190MDN0F
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[9] http://www.dx.com/p/dht22-2302-digital-temperature-and-humidity-sensor-module-184847#.WUvnD2SGNhE
[10] https://www.amazon.de/10Pcs-GL5528-Dependent-Resistor-Photoresistor/dp/B00CN8RSY8/ref=sr_1_1?s=ce-de&ie=UTF8&qid=1498146643&sr=1-1&keywords=light+dependent+resistor
[11] http://www.dx.com/p/hengjiaan-rain-water-level-sensor-modules-for-arduino-2pcs-463356#.WUvnpmSGNhE
[12] http://www.dx.com/p/arduino-flame-detection-sensor-module-135038#.WUvn2WSGNhE
[13] http://www.dx.com/p/tec1-12706-50-72w-semiconductor-thermoelectric-peltier-cooler-heaters-463343#.WUvn-GSGNhE
[14] http://www.dx.com/p/dc-3v-6v-diy-motor-micro-motor-for-four-wheel-car-fan-toy-silver-433778#.WUvoKGSGNhE
[15] https://www.amazon.de/Adafruit-NPN-Bipolar-Transistors-PN2222/dp/B00XW2OK7M/ref=sr_1_1?s=ce-de&ie=UTF8&qid=1498146564&sr=1-1&keywords=pn2222+transistor
[16] https://www.amazon.de/Gleichrichterdiode-Diode-1N4001-Rectifier-Dioden/dp/B00IJEVWV0/ref=pd_bxgy_147_img_2?_encoding=UTF8&psc=1&refRID=8D38MPA8RYNYHN04RX3F
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[20] http://www.dx.com/p/28ybt-48-stepper-motor-with-uln2003-driver-dc-5v-126409#.WUvprmSGNhE

box)[21].

TOTAL (MATERIAL BUDGET): EUR 953.46

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