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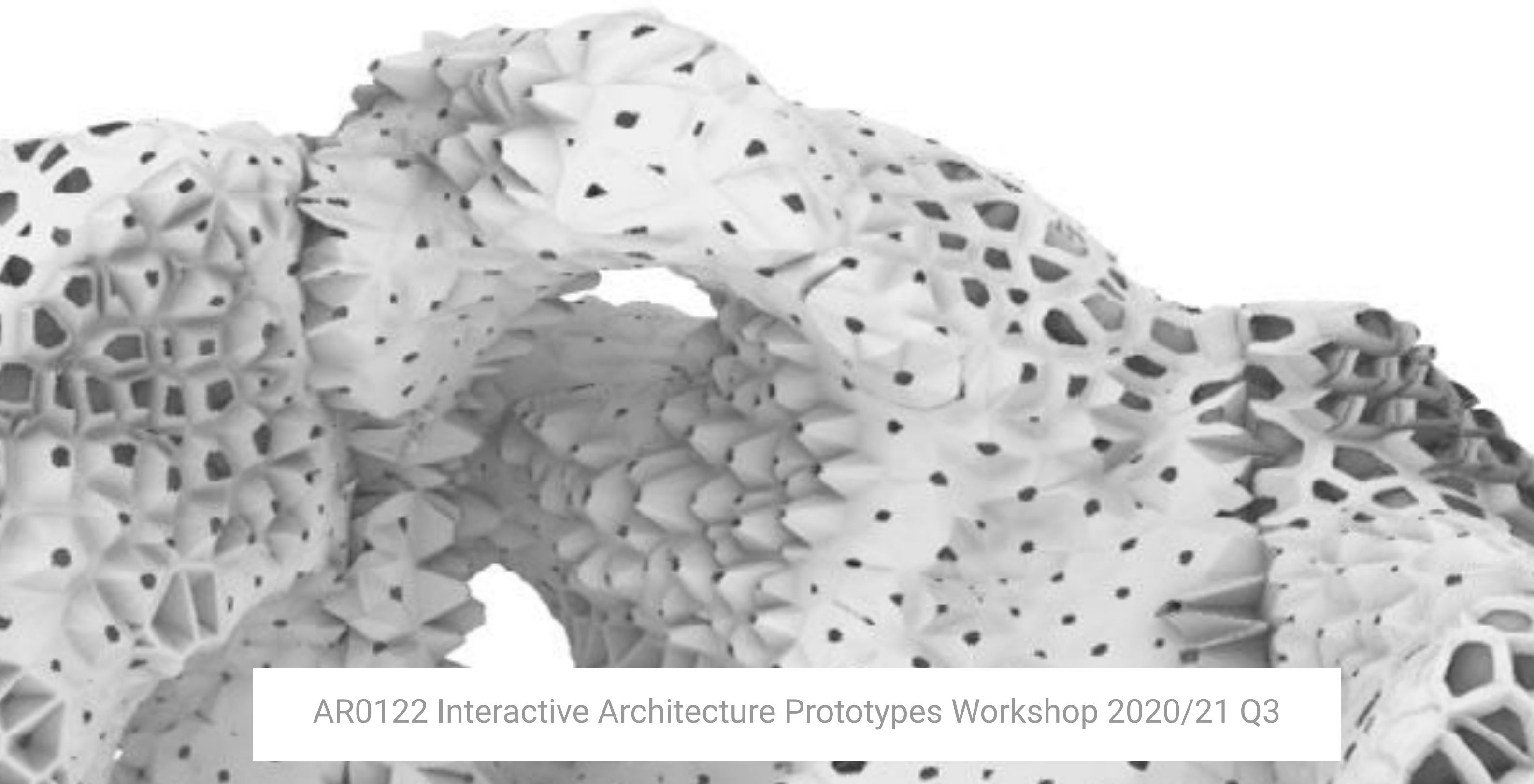
Integration of advanced computational design with robotic techniques in performance driven architectural formations

Creating cyber-physical Bio-Dune



AR0122 Interactive Architecture Prototypes Workshop 2020/21 Q3

I. Introduction

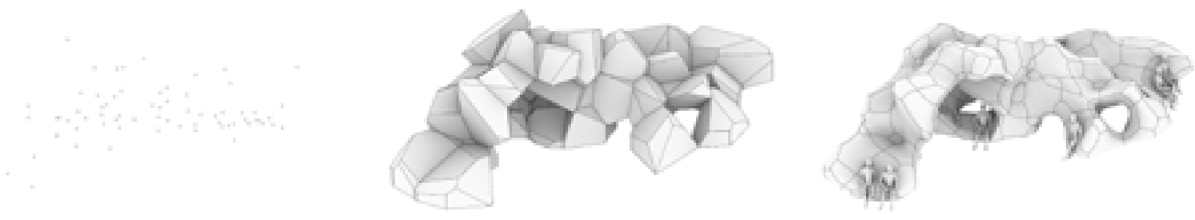
Presented design acts as a response to the urban needs of its inhabitants, be it humans, animals or any natural habitats. The aspect of retaining the biodiversity in modern cities emerges to the forefront, the response takes inspiration from the natural environment and possibilities that the most innovative technology offers. It was established as a part of the AR0122 1:1 Interactive Architecture Prototypes Workshop at TU Delft and included the use of Design-to-Robotics Production and Operation (D2RP&O) techniques.

The design is based on a shape of a dune that later on is translated into a 3D printed structure, the use of 3D printing technology allowed to produce a form that corresponds to the functional division, propose a solution efficient both in the use of materials and the process, as well as integrate data and information within the built structure. The use of sensor-actuators brings the possibility to interact with the users and collect data useful for determining future decisions of the bench placement, its main functions, as well as informing any parties interested in data harvesting.

II. Parametric Design-to-Robotic Production

Form generation

The final form of the design derived from entry parameters required for the selected location. Each function is assigned a point or a cluster of points with inscripted data like size and elevation, which is then distributed according to the desired functional mix. Based on the parameters, a 3-dimensional voronoi structure is generated, which after smoothening becomes a base form. In the final step, some areas are adjusted to the human body to achieve ergonomic seating positions.



(a) (b) (c)

Figure 1 *Main stages of the form generation: (a) designated functions as point cloud (b) voronoi structure (c) subD with fragments adjusted to human body*

The resulting design is tailor-made for specific location and context. Thanks to the parametric approach every dune is unique and responds to specific needs. The shape itself goes together with the optimization and configuration logic that can be seen in nature, which has been evolving for millions of years and now can be achieved easily through computational design. This approach provides optimal distribution of functions without the loss of space and material. Due to Voronoi logic, the form is based on components from the very start, which is beneficial for the further division and production.

Computational design process

The process of BioDune creation has been developed through parametric modelling using Rhinoceros and its built-in programming environment Grasshopper with additional plug-ins, for example, Karamba used in structural analysis.

On a macro scale, the initial form of BioDune has been analysed and optimized regarding its structural integrity and performance. Additionally, an external load, equivalent to average human weight (80 kg), is applied in chair components. The principal stresses are a result of the structural analysis. Red colour indicates tension and blue- compression. The point clouds used in later stages for Voronoi creation come directly from structural analysis and reflect these results.

In both macro and micro scales, the material is optimized and adjusted to outcomes. The functional division of the urban furniture is also reflected in structural composition: higher material density is used in areas with planned seating for people, whereas increased porosity is applied in parts designated for planting or animal shelters. This functional optimization is also reflected in outer skin cells formation. Diverse users have different requirements and due to manual influencing the end result of skin, these needs can be fulfilled. The lower portion of Biodune consists of open and deep cells for planting, seating areas of closed and even surfaces and higher parts extrude and open increasingly to create nesting habitats.

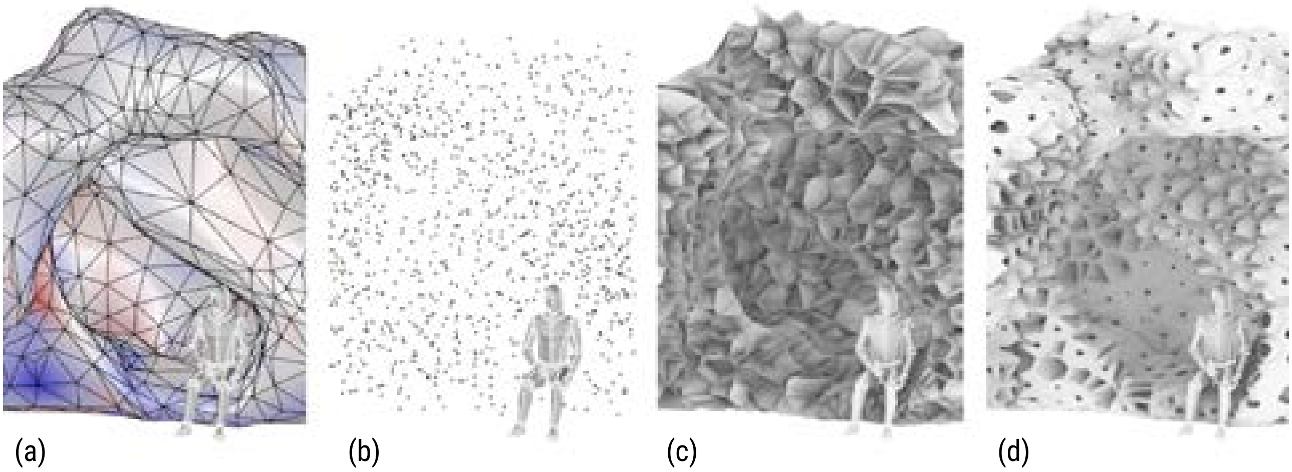


Figure 2 *Computational optimization stages developed in Rhino and Grasshopper: (a) structural analysis (b) point cloud (c) interior cells generation (d) skin extrusions*

Prototyping and materials

The process is based on Design-to-Robotic-Production (D2RP) techniques developed at the Delft University of Technology for additive and subtractive manufacturing, which allows for fast and customizable production. Each of the urban furniture forms can be designed with an adaptive strategy to the site and local conditions. This approach allows for diversified ecosystems in a united master plan for urban furniture. Thanks to the 3d-print simulation - toolpath generation possible in Grasshopper, the prototyping process is easy to control and the final outcome can be modified before the physical fabrication takes place. Therefore mistakes can be avoided early on in the process and the shape of the element can be adjusted to better respond to the possibilities of the chosen production method.

The cellular structure of the urban furniture allows for fabrication by additive manufacturing executed by a robotic arm. Due to this technological process, it is possible to perform freeform printing, which allows for the liberation of some aspects in the form-finding process. The constraints are given by the robotic arm, however, are influencing the size of the components and material composition, which need to be taken into consideration in the D2RP process. The cellular structure is shaped in a self-supporting way to avoid any additional support and waste of materials.

The use of 3D printing for urban furniture design allows for customization of printing material. According to needs and design intentions, the components can be printed using various proportions of ingredients, achieving different properties, a quality which was used in BioDune. The material proposed for printing is a mix of plastic polymer with wood. The seating component of the dune is created from a higher percentage of plastic polymer for structural strength, whereas nature components have an increased wood percentage for organic microclimate. The authors are reflecting that material composition for the project could further explore the use of sand to enhance the initial inspiration by a natural dune environment.

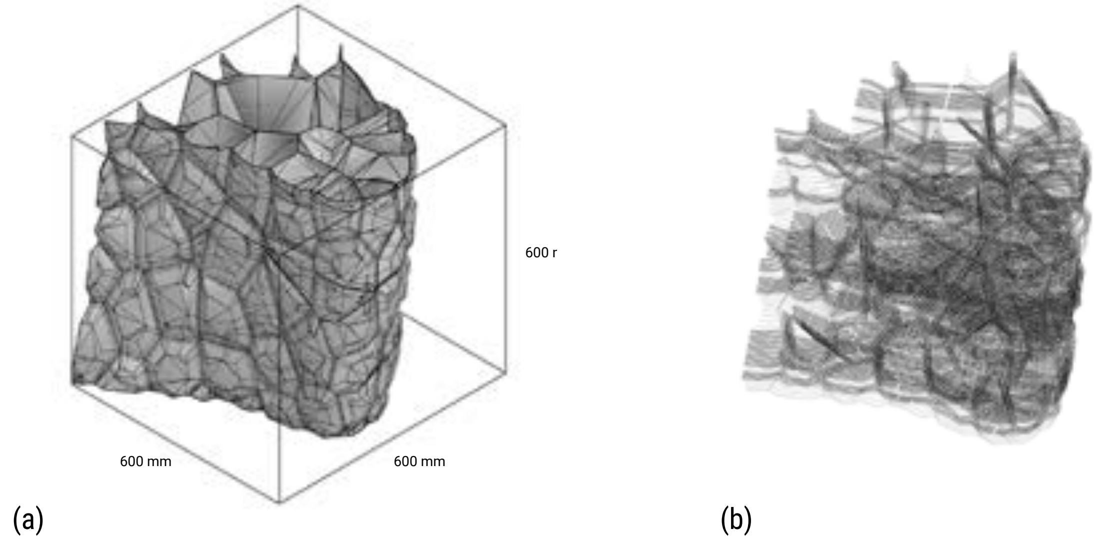


Figure 3 *Prototyping stages (a) chosen fragment as a proof of concept (b) continous print path generated with Grasshopper*

III. Design-to-Robotic Operations

The sensors integrated within the design allow for the separate zones not only to provide functions according to their purposes but also to gather data for further information on bench distribution and its behaviour. For assesing the radius of data gathering and the area of influence of each dune voronoi diagram is used as the most optimal division method. There are two main zones within each dune: natural and urban, that have different sensor-actuators assigned to them.

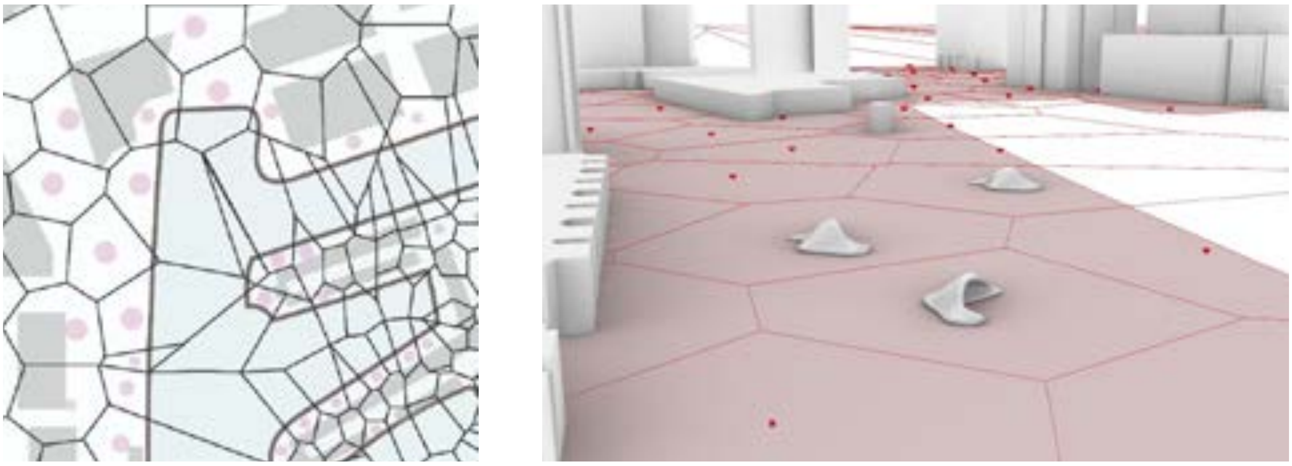


Figure 4 *Area of influence and data gathering of each dune is based on voronoi tessalation diagram*

In the nature zone sensors are designed to monitor, control and predict various environmental changes happening around the dune. The sensors include infrared-based solutions monitoring the activity of animals and chemical sensors are used. They have two functions- sensing and pattern recognition, which was chosen due to their ability to distinguish species of animals. All creatures produce different volatile compounds, which are possible for the sensors to recognize. Moreover, sun exposure, temperature, air quality, level of soil moisture, size and movement of animal populations are measured, which helps in understanding and responding to the current challenges biotic community faces in the urban environment - in reference to the micro, meso and macroclimate. The harvested data is used to both improve the quality of the urban environment around the existing dunes, but also informes the ualities of the future dunes.Thanks to the involvement of robotic operations a balance within man-made and natural environment can be achieved, so that all species could benefit the most from the existence of each other.

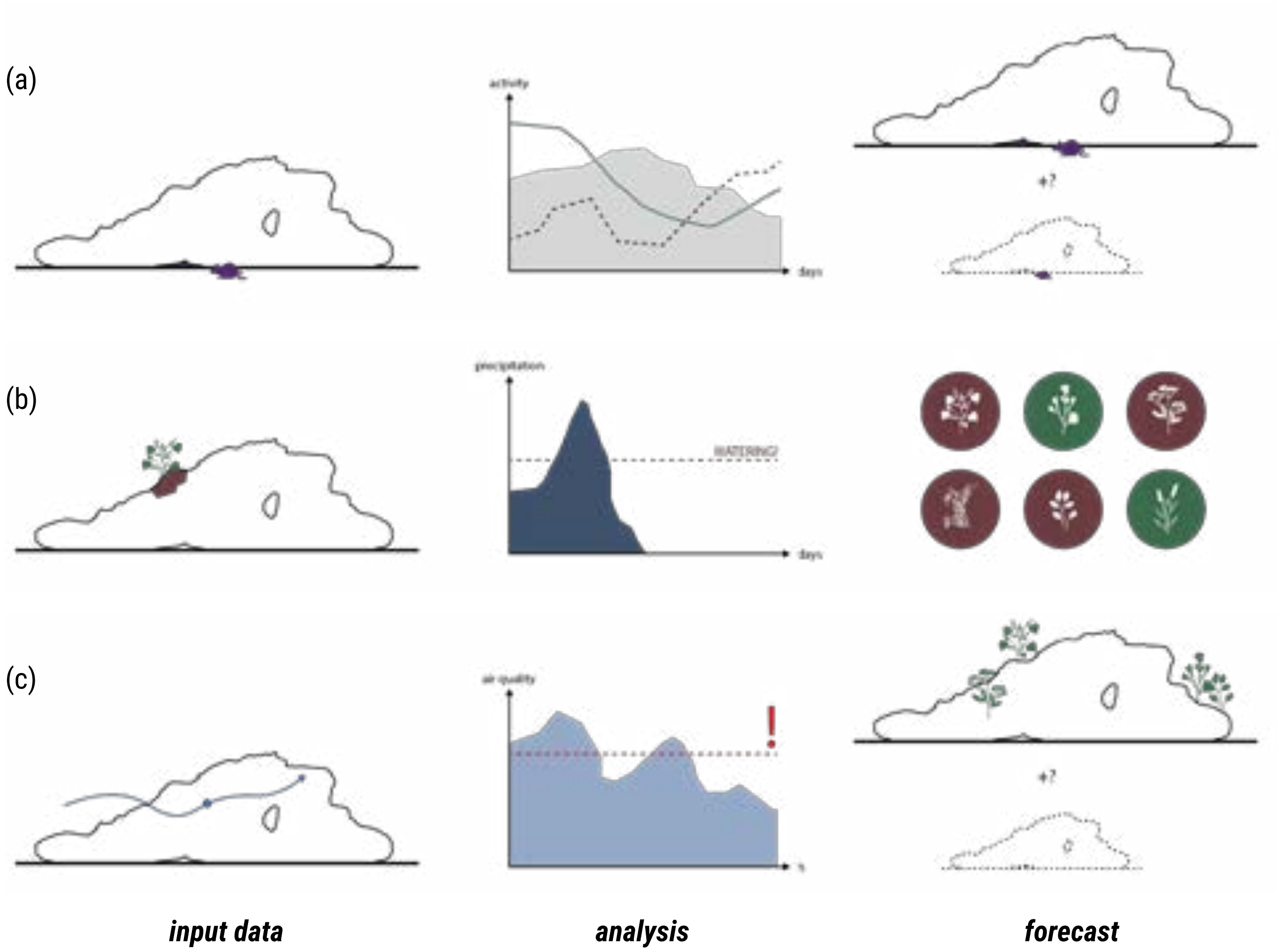


Figure 5 *Selected sensor-actuator operations (a) animal population tracking (b) soil moisture and plant watering (c) air quality*

The urban zone is mostly dedicated to study and improve human habitat in cities. Sensors are gathering data on the preferred seating positions and interaction with urban furnitue - most common locations, time spent on dune, most frequent type of interaction etc. The use of robotic operation, mainly lighting actuators, enable better integration and interaction of the human with its environment and between each other. Through passive infrared sensors, urban furniture responds to the passerby by sending ligt signals inviting them to use it. It also detects an already sitting humans, interacting with their touch. The sensors are integrated within the structure itself and the geometry of the bench on different scales take into consideration spatial requirements of the electrical distribution. The lighting consists of LED stripes within the hollow parts of cell edges, they are equipped with a motion sensor, both are connected to the central city grid with cables integrated within the dune. The light in the design serves the users and in order to connect with other benches around the city. The three modes are dependent on the users' behaviour.

The data collected by the sensors is also used in an application. The app was created for the users to be able to track processes in the environment around them and also to find out what their behaviours are in relation to other users. Also, it is a way to interact with other people because it is possible to send signals to other dunes and invite people to sit. The aim of the app is to educate people and help them see themselves as a part of urban environment - coexistence of humans, animals and nature.

IV. Conclusion

Our project shows how advanced computational design integrated with robotic production and operations can result in a performance-driven, cyber-physical architectural proposal. Thanks to robotics the complex problem of the lack of biodiversity in cities is tackled from different perspectives. Physical and software components are intertwined, exhibit multiple and diverse behavioural modalities and interact within a network to change the existing environmental context.

Voronoi logic is used in macro, meso and micro scale of the design ensuring its functional, structural and material optimization and the feasibility of the project. Additive manufacturing process secures time-efficient production and customization of elements enabling effortless integration of required technical installations into the form.

Optimal division based on the Voronoi diagram is also used in relation to proposed sensor-actuator systems to assess the area of influence of each dune and the radius of data gathering. Sensors implemented in the design are a way of interaction between people, the environment and the project itself. They gather data which is later used for environmental forecasts but also forecasts helping to understand how the future dunes should be formed. Collected information helps to respond to environmental needs on an unprecedented scale thanks to the use of artificial intelligence and expanding network of elements. The process improves itself with every iteration and more input data. Web-based communication is a way for people to learn about their surroundings and interact with one another through the application which controls light modes.

Integration of advanced computational techniques in the design process leads to the altered role of an architect, who becomes a curator in all phases of form generation. He does not have full control over the final outcome but works together with the computer that becomes an integral part of the design team. This approach results in a new design aesthetics which fuses organic and man-made features. Unexpectedly, the use of robotic techniques in architectural design gives more possibilities of meaningful integration between urban environment, nature and humans themselves thus should be a focal point of future studies and be widely implemented.