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FAB Vernacular: Data-driven On-site Robotic Fabrication

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Abstract

The Digital Construction Platform (DCP)is an enabling technology for large-scale on-site fabrication using real-time data for process control. The DCP is a micro-macro manipulator arm system composed of hydraulic and electric robotic arms, carried on a tracked mobile platform. Following the vision of a self-sufficient robotic platform, the DCP is outfitted with sensors to extract environmental data that can inform geometric parameters of the built structure and enable automated design and construction in changing conditions.

Here, we present a data-driven framework leveraging the capabilities of the DCP. By deploying wind, thermal, and topographic sensors, we generate a virtual representation of the site of potential construction. We then demonstrate how this virtual space might be combined with a parametric design environment to infer viable structures specifically tailored for that site. We also discuss further extensions of this framework, including real-time process control. We conclude that the emergence of on-site robotic technologies in architectural design will in the future enable higher degrees of design customization, offering flexibility and adaptation of shape and material composition informed by real-time environmental data from the construction site.

Keywords: Data-driven, Robotic Fabrication, On-site, Autonomous construction, Vernacular.

1. Introduction

The paper presents an approach to site-specific digital design and manufacturing driven by environmental data. The DCP extracts environmental data through onboard sensors. This data is then used to inform geometric parameters of the built structure, enabling it to be adapted to extreme environmental conditions.The deep relationship between design and environmental conditions makes it imperative to associate and implement the two in concert. Current day construction technologies lack tools to autonomously integrate environmental parameters, and are instead multi-step processes, which limit how structures can be customized to address environmental conditions.

2. Background

2.1. Vernacular Construction

We approach contextual awareness through observing vernacular methods in architecture that rely on needs of users, environmental surroundings, and resource availability. Like poems, buildings are culturally aware and reflect contextual identity [3]. Architecture that integrates into its context dates back thousands of years. Some of the earliest examples include the use of bamboo construction in West African lands. Bamboo as a construction material assisted in local challenges such as soil stabilization and lightness in construction. Today, vernacular methods rely on the availability of local technology in construction and tools that aid in site analysis and observation. Architecture that is environmentally aware relies on user needs, offering higher degrees of site adaptability even in extreme conditions and remote sites.

2.2. Autonomous construction

The emergence of robotic technologies in architecture allows greater customizability of design. To be customizable on an architectural scale is to be adaptable to environment specific conditions, thus incrementally solving traditional limitations. In data-driven fabrication, the use and implementation of site data along with robotic construction offers a wider range of possibilities that are aware of their context.

DCP: Previously presented in Science Robotics [1], the DCP consists of a 5-axis Altec AT40GW mobile hydraulic lift unit with a 6-axis KUKA robotic arm mounted at its endpoint in a micro-macro manipulator configuration. While the large arm is used for gross positioning, the small arm performs finer positioning and error compensation, allowing it to execute higher-precision tasks.With a 10.1 m radial reach and a 158 kg lift capacity/10 kg manipulation capacity, the DCP is able to work at architectural scales. It is controlled using a custom Simulink-based control architecture, which provides the modularity and adaptability required for the wide range of tasks the DCP is intended to take on, and is easily adapted to incorporate new sensors, tools and other hardware. Finally, the DCP is designed as a *platform* system, intended for use by multiple disciplines for a variety of fabrication tasks, in both research and industrial applications.

3. Definitions

Environmental sensing enables the DCP to gather on-site environmental data, which can then be leveraged in design tasks. We categorize sensing in two different scales, local and global. Local sensing pertains to data that is contextually unique and may change in close proximity from the inspected site, e.g. surface texture, roughness and topography **(Figure 2)**. Conversely, global sensing is related to data that changes within farther proximity from the site or over longer periods of time, e.g. wind, temperature, and humidity **(Figure 2)**.

4. Methods

4.1. Environmental data collection

The DCP is outfitted with an array of sensors to extract data from its surrounding environment **(Figure 1(a))**. Due to the flexibility, as well as the wide reach of the arm, it can explore a volume of more than 2,700 m^3 while the base remains stationary. The types of data collected include topographic profiles, wind velocity, humidity, and temperature.

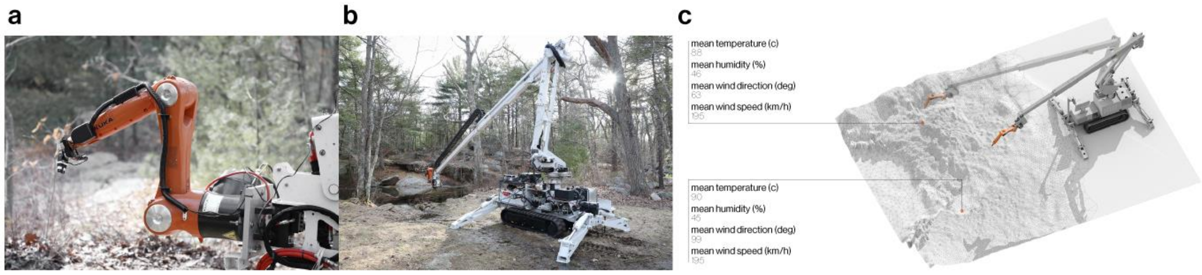

Figure 1 Overview of an on-site surveying test taken at the Ravenswood nature reserve. (a) The environmental sensing end effector attached to the electric arm of the platform. (b) The DCP is

positioned on site, scanning it's surroundings at given locations. (c) Environmental data gathered at two positions on the analyzed site, which then construct a corresponding virtual environment.

4.2. Tools

A Garmin LIDAR-Lite V3 rangefinder is used to create a 3D map of its environment adapting the DCP's tool-path to its surroundings. Global humidity and temperature measurements are gathered using an AM2302 sensor, a combination temperature and humidity sensor. Data is taken in degrees Celsius and percent relative humidity. Finally, wind speed and wind direction are measured using a Davis Instruments 7911 Anemometer.

3. Results

On site environmental surveying tests were conducted at the Ravenswood nature reserve in western Gloucester, Massachusetts Over a period of seven hours **(Figure 1 (a) and (b))**. Mounted to the DCP's end effector, the rangefinder is attached to servo motors that sweep it around the DCP's field of view. A micro-controller then converts a one-dimensional range output to a point in three-dimensional space in the coordinate frame of the end-effector. The gathered points are then combined into a point cloud. This process is repeated at different locations at the surveyed site determined by a planned tool path traveled by the arm **(Figure 1 (c))**. The changes in the arm joint positions between each location are then calculated to combine the collected point clouds into one. Overlapping areas between scans are averaged, while extreme noise generated by scanning water is eliminated. The remaining points are then connected to construct a triangulated mesh **(figure 1(c))**.

The temperature and humidity sensors return a data point at the end of each azimuthal LIDAR pass. While this sensor stream is quite slow – generally around 0.5 Hz – this is believed to be sufficient to capture the slower rate of change in global conditions. Data from this sensor provides insight into local temperature and humidity conditions as a function of position throughout the site,as shown in **(Figure 1(c))**.

Wind speed and direction data can likewise be leveraged in design to determine location, arrangement, and porosity of built structures **(Figure 2)**. Furthermore, in the context of additive manufacturing processes, wind data is imperative for Print-in-Place process control [2]. Furthermore, wind speed data can be used in real-time to drive toolpath adjustments and *a priori* as an indicator of times during which it is more favorable to print [2].

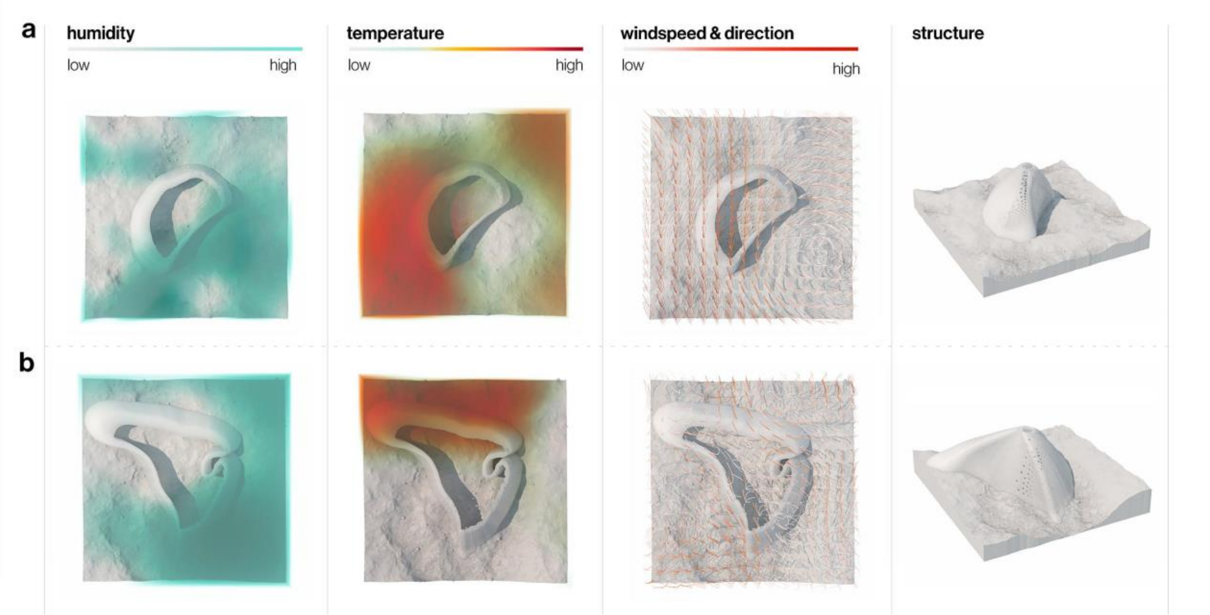

Figure 2 Visualizations of the use of environmental data in the design of architecture in remote sites. Shown are global- and local-scale weather parameters reflected in the constructed architecture, influencing it's overall geometry, material thickness, orientation, and porosity. Here, an initial circular cross section is evolved to exhibit minimal wind resistance (third column). Wall thickness is adjusted according to a heat distribution (second column) and pores are introduced into the structure according the humidity map (first column). We show two structure (a) and (b) emerging from a different set of initial condition, thereby exhibiting the flexibility of this approach.

4. Conclusion: submission of contributions

We have presented an integrated framework for collecting on-site environmental data by an autonomous fabrication platform. We demonstrate how the Digital Construction Platform can be used to gather environmental data such as topography, wind speed/direction, temperature, and humidity. We then use this data to construct a corresponding virtual environment, and discuss how this virtual environment can be used to inform the design and fabrication of architecture on site. From sensing, to design, to building, we present an approach to connect contextual conditions to architecture across scales.

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References

[1] S. Keating, J. Leland, L. Cai, N. Oxman, Towards Site-Specific and Self-Sufficient Robotic Fabrication on Architectural Scales, Science Robotics, Volume 2, Issue 5, 2017.

[2] S. Keating, N. Oxman, Compound fabrication: A multi-functional robotic platform for digital design and fabrication. Robot. Comput. Integr. Manuf. 29, 439–448 (2013).

[3] P.Oliver, Built to Meet Needs: Cultural Issues in Vernacular Architecture, Amsterdam: Architectural, Print (2006)