Physical Form Finding by Embedded Sensors

Using 'sensor chaining' in various temporal and spatial scales

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Abstract. *The paper concerns the potential of sensors as architectural design tools in different spatial and temporal scales. In particular, the focus is on how sensors are able to operate in a constantly changing environment, and how sensors might nurture an intuition of otherwise non perceivable aspects of performance within architecture.*
The study discus two set-ups. Firstly; an onsite sensor reading of changing performance between a refurbished and a classic Arabic house; the study is in large spatial and temporal scale. Secondly; a model design setup where the performance of the same Arabic house typology is tested in small spatial and small temporal scale. The study shows how large scale architecture can be investigated through the use of sensor chaining and how simple sensors can be implemented in a design task in order to give insight to certain aspects of performance. The paper concludes with a discussion on a more general sensor strategy for changing environments and design setups.
Keywords. *Air flow; sensors; sensor chaining; tippu tip; form finding.*

INTRODUCTION AND PRECEDENCE

Vernacular architecture in extreme climatic settings often respond with ingenious low-tech solutions, able to cover several aspects of architectural performance, such as thermal, luminance, ventilation, privacy and other comfort criteria. There are great potentials within these building traditions and techniques given through heritage. They often build on a less mechanically developed technology, never the less there are principles which might be developed to further extend by utilizing modern information technique. "(The architect) must renew architecture from the moment when it was abandoned; and he must try to bridge the existing gap in its development by analyzing the elements of change, applying modern techniques to modify the valid methods established by our ancestors, and then developing new solutions that satisfy modern needs" (Fathy, 1986).

When introducing these modern needs and applying change, the initial performing principles might not always be obvious, and modern techniques are no guarantee to identify those principles fully. The intentions of the original principles can easily be disturbed by smaller refurbishments, and unknowingly certain aspects of performance can be lost.

After the revolution in 1964 and the creation of the United Republic of Tanzania, the vernacular architecture from both the Omanis and the Arabs, were inhabited by the surrounding original population. Many houses with flat roofs and a central shaft, performing as central communication for air, light and sound, were obstructed in order to make more floor space for the increased number of inhabitants.

The refurbishment and resulting decrease of natural ventilation has been damaging to the core structural elements, indoor climate, and architecture in general (Syversen, 2007 p 109).

Computers and digital technology can be used for system analysis and simulation of material behaviors. By applying algorithms to all the specificities of the system, they are able to simulate the entire behavior of aggregates. (Hensel and Menges, 2010; Reiser, 2006). Looking at complex interrelated parts of the urban fabric, circular causal effects clutter intuitive understanding of effects, affects and performance. That makes it difficult to even setup correct aspects for a simulation model, so how are we best equipped to recognize and decode performing aspects of vernacular architecture?

Conventionally, sensors are installed into known environments, calibrated to give data concerning specific fluctuations. If the environment and the fluctuation is of complex sort, fusion sensing is utilized, facilitating a cross referential measurements, to exclude or include certain phenomena and occurrences. (Toko, 2000). This strategy might prove particularly interesting within an architectural discourse, because architecture has that character of negotiation between criteria.

In 1995 after the late 1980ies where sensors really were embraced by industry, Nicholas Eror says "Today, online sensing of material properties, combined with real-time control, is making the goal of self-directed, intelligent processing a reality." (Eror, 1995) He concludes that sensors are to be placed in particular places of concern or embedded as components in structural elements and that material technologies facilitate the development of new sensor materials with specifically designated properties, and invention of new composition matter. He argues that a novel approach to sensing is needed, such as fusion sensing responsive to physical phenomena.

PROPOSITION

This paper proposes to utilize sensors in the search for performing aspects of architecture. When identified, sensors and computation is also suggested as design tools for developing and modifying those performing aspects. It is also proposed that the sensors and computation might build and nurture the architects intuition in certain design tasks. Two cases investigate whether the approach has resilience to various temporal and spatial scales, they are chosen for their thematic commonalities and scalar differences.

In order to use sensors both real time and in complete changing environment, I propose a sensor strategy which I call sensor chaining. Sensor chaining is a method where multiple of the same type sensors are used simultaneously, but in different locations in the environment, and through different times or states of the environment. By observing these otherwise in-perceivable aspects, changes can be traced, and a certain intuition can be built upon. By having several sensors a relative change can be observed. It requires no pre-calibration and can operate where environments are completely changing. The method has resilience because the interest lies in the relative change between locations. The large amount of data with relative change over time and relation to the changing environment is best understood through a graphic interpretation, where patterns and causal connections become evident. The method of sensor chaining require a solid amount of documentation, and processing, especially because of the amount of data and different sensors that must be kept associated in time and location to the environment.

The strategy helps giving an immediate understanding of performance alterations in the environments both in location and time.

As drivers for the proposition and in order to develop sensor chaining as a method, the following questions are raised:

- How do we confirm our recognition of performing aspects within vernacular architecture, and how do we know whether all aspects of performance are recognized?
- Which tools and visual models might help our intuitive grasp in aspects which are hard to perceive, and how close need the visualization be brought to the real material of architecture?

METHODOLOGY AND SETUP

Two experimental studies are discussed, one is large spatial and temporal scale and the other is in small spatial and temporal scale.

- The large scale measurement is done in two different Arabic influenced houses in Stone Town, Zanzibar. One house, 'Tippu Tip House', has been refurbished, and the central shaft has been covered and a pitched roof is covering the original flat roof. The other, 'Sohkomohogo 478', is kept original with a shaft and flat roof.
- The second is a small scale experimental setup, where a cardboard model is built to replicate the typology and principle of the Stone Town urban constellation. Here the setup is small scale and small temporal scale.

Large scale buildings in transformation

In order to look at the performance of the Arabic influenced house typology, I chose to look at the unchanged house 'Sohkomohogo 478' which has the original shaft going from the base through to the top intact. As opposed to the refurbished house; 'Tippu Tip House'. This house has had the shaft obstructed and a new pitched roof added.

Specific method for sensor chaining in the large scale study

In this case the sensor chaining consists of a combination of light air flow sensors (LAFS) and a camera. There are four LAFS equally spaced from one end to the other on a 3 meter long glass fiber rod. An IC chip records the main data capture from the LAFS, when the user press the record button, simultaneously a multicolor light diode emits a color and an infrared diode sends a signal to the camera to take a picture. In this way the image records the location of the sensors, and the color in each image compose a color code which acts as verification that the series of images correlates with the recorded data. The image and data can later be linked to compose an image with the data overlaid. The images are not necessarily the background for the data, but acts as a tool to locate the sensor recordings. Any other diagram or drawing can be used as background for the visualization. In this case I use section drawings as well as the original images from the measurements. The JAVA-application written for the purpose supports the process by handling the large amount of data and images, and placing data points in the image material.

With this system it is easy and fast to setup a series of recordings, with proper accurate documentation of the location for each recording. The data can then later be visualized in the various ways seen in Figures 1 through 6.

The refurbished Tippu Tip House

As the shaft in Tippu Tip House was covered by a floor construction and insitu cast concrete, I chose to make the measurements horizontally. Two measurements are done, one in the large open bright second floor, and one in the dark base floor. Figures 2 and 3 show the data overlaid on the images taken with the measuring equipment and camera.

The experience of the two floors in the house was significantly different. The 2nd level was bright and well ventilated. It was relatively dry compared to the high average humidity of the tropical climate. The base level was moist, slightly cooler, but without the same sense of fresh air, and the most significant difference was the complete darkness. There was an artificial light fixture mounted in the ceiling just where the shaft was closed off (Figure 3).

Figure 1-5 shows the sensor data translated to a color gradient going from green to red, where green is little air flow passing the sensor and red is much flow passing the sensor. All figures are done with the same setting of color, so reading across the figures gives an understanding of the distribution of airflow through the spaces.

The unchanged Sohomohogo 478

The house has three floors like the surrounding and connecting neighbor houses. The front façade to the street has windows with perforated shutters and small balconies. Behind the first set of rooms facing the street is the staircase in conjunction with the

Figure 1
Tippu Tip House, the blocked shaft can be seen having gone up through the middle of the house. (source; Fournier, 2011)

core shaft. This shaft is the main interest. Although onsite it became evident that main staircase connected to the shaft, is potentially performing similarly to the open shaft. Additionally when being in the house, it became evident that there were multiple purposes for the shaft through the house. Below are listed the ones recognized.

- Translation of light from top to bottom. There are plants growing in the base level (Figure 4), and when closing the main door to the street, the base level was still comfortable lit by the light flowing through the shaft.
- Ventilation throughout the house. The base level and all other levels had a fresh, not overly humid local climate. There was not a fast flow of air sensible to the skin, but it was not still-standing air. All rooms between the street and the shaft had on both sides, traditional perforated wooden shutters, so that air could flow freely but there was still privacy, safety and no direct sunlight
- Translation of sounds for communication throughout the house. Much of the practical sort of communication went through this shaft. A clear voice sent in the direction of the shaft could be heard from the base all the way to the terrace on the top, and vice versa.

The shaft acted all together as a gathering vertical element in the house. It was not so much an architectural space as an infrastructural element. Some other houses in Stone Town has more wide and decorated shafts, more like atriums. This did not act as spatial element, rather it supported the quality of the spaces that connected to it, which in this case was all spaces of the house.

Two vertical measurements was done in spice house. One through the shaft and one through the staircase connected to the shaft. Figure 5 and 6 are sections which are seen in a plan view perpendicularly oriented. Figure 5 shows a higher intensity in

Figure 2
Tippu Tip House 2nd level. Visualization shows a lot of cross ventilation close to the windows.

the flow closer to the top of the shaft. The measurement has no indication of direction, so some of that increased intensity might also be gusts of wind in a more horizontal direction at the very top opening of the shaft. Figure 6 shows a similar tendency, only more distributed flow all the way to the base level.

Small scale model and design study

Assuming the particular design parameters for a ventilation shaft like the one in traditional Arabic houses is not known well. This study suggest that a method using sensor chaining of light air flow sensors can be utilized as real-time design input. An input from the sensors and computation that helps the design decisions and helps the designer build an intuition in that particular matter of the design.

This model design setup has a small spatial scale, although it deals with a large scale situation. The temporal scale is small in the sense that designs can be tested and iterated within seconds. The experiment is able to deal with all the conventional design aspects as a model normally does, yet in addition this setup facilitate the understanding of ventilation as criteria of performance. It does not give accurate measurements but rather indications to how the different designs perform differently on the sensors in their particular locations.

Specific method for sensor chaining in the small scale study

The setup consists of card model houses distributed in a configuration similar to the situation in Stone Town. The hight-width size and the street-height size is maintained. One of the model houses has cut holes in the two facades, and the roof is interchangeable. Three sensors are placed in the model; one on the top of the adjacent house model roof, one inside the central model, and one on top of the

Figure 3
Tippu Tip House base level. Almost no air circulation.

central model. Now the data is fed to a computer and the custom application generates a graph, by plotting the values of each sensor over time. This way the relative change of each sensor can be read. By comparing horizontally through the graph and knowing what the correlating design look like, the user can start a design process based on an additional layer of intuition.

The first model, model no. 1 has the flat roof without a shaft, the red sensor is in this case on top of the flat roof. It seems to read slightly higher flow, maybe due to the fact its closer to the fan than the green sensor. Model no. 2 has a flat roof with a square hole. The red sensor is here lowered a bit into the space inside the box, it has significantly less flow in this position, and less than for any of the other models. Notice a slight increase in the flow around the blue sensor inside. Model no. 3 has the classic Arabic inspired shaft ending in a flat roof. The red sensor is lowered a bit into the shaft where it senses a higher airflow. When looking at the overall performance of all the models, model 4 has highest reading around the inside sensor. That doesn't necessarily mean that model is the best in ventilation performance, but for this particular constellation of the sensors, the inside sensor (blue), senses the most flow. Looking at the last model no. 6 the inside (blue) flow reading drops again. The experiment was only done with these 6 models, more different and inventive models could also have been tested.

OBSERVATIONS AND EVALUATION

The tools for each of the experiments could have been equipped with various types of other sensors as well. Graphic representations could be made for these, similar to the graphics presented here. Instead of comparing two Arabic houses in full scale, one could have been investigated in two cases,

Figure 4
Sokomohogo 478 open shaft with a plant growing at the base level.

where a temporary intervention was made, a sort of full scale prototype. In the best case this full scale prototype could be real-time informed by sensors.

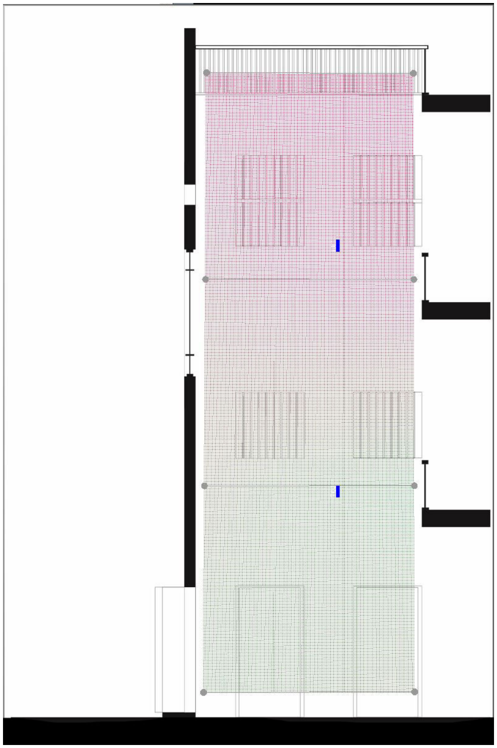
These studies focus on the use of flow sensors, although it is crucial for the given climate to have ventilation and air circulation, many other architecturally relevant aspects could be monitored using simple sensors. For the case of clarity and development of the method, one type of sensor seems to be able to report on a complex environment where our senses and intuitive understanding already start to be insufficient. The use of sensors with computational tools seems versatile for describing performing aspects, although the methods does not describe much further than the assumption of the performance. The already recognized performance was verified but the method did not help to recognize additional hidden performance aspects.

When introducing an aspect of modification which can answer to the sensor readings, intuition and understanding of specificities starts to build. The dialog between sensor readings and modification can negotiate a single aspect of performance without knowing which way to modify, the sensors can simply report on a change in that one aspect. In further studies more sensor types can be included in a productive setup, it might then be possible to negotiate several aspects simultaneously.

Further studies could develop ways of recognizing performing aspects by utilizing sensors able to sense aspects beyond human perception. These aspects might simply be aspects that are hardly accessible by the human sensing apparatus.

CONCLUSION

There are lots of experience and conclusions to be drawn from this study, but first and foremost the study poses a line of new questions that could be



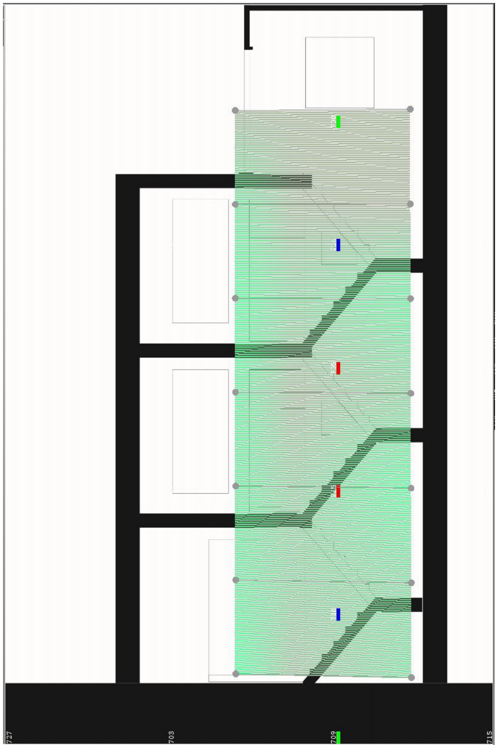


Figure 5
Sokomohogo 478 open shaft.

Figure 6
Sokomohogo 478, Staircase next to the open shaft.

addressed in several additional studies. For this study it is worth considering whether measuring over a longer time period could show more accurate data or whether the sensor chaining immediately provides sufficient qualitative snapshot.

The readings could be more real-time understood. Giving the measurements relevance on site might open to a real-time design method. Or if not directly informing the design, one might imagine a system that on site gives information to the user how and where to measure more.

It is important to note that these tools must facilitate a productive approach. They should generate many different things, information, designs and intuitions. The tools should not be giving determinate results or answers.

Like many other emergent technologies that are already used for creating music video, drawings and shapes, I believe the tools consisting of integrated computation, sensory devices and user interfaces can nurture our creative potential, and in particular help our intuitive understanding of causal relations in our physical environment.

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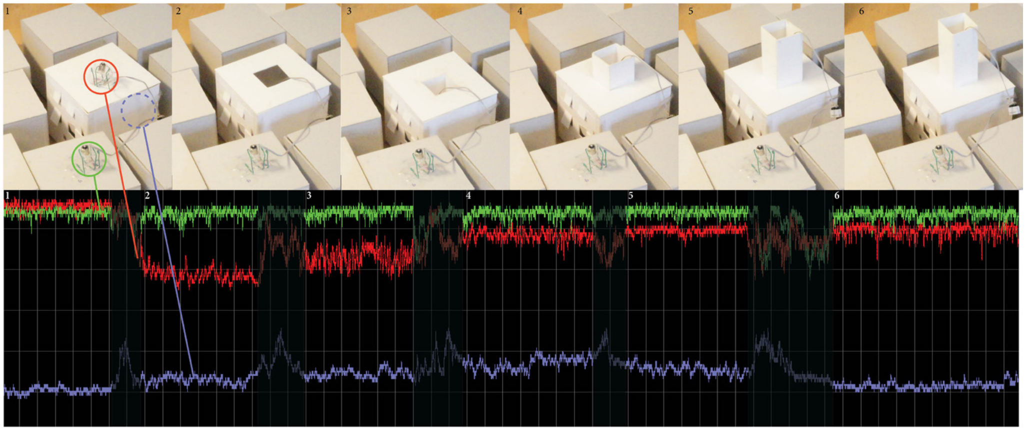
Figure 7
Top part shows the different design iterations, and the bottom part shows correlating the relative change and relation between the LAFS readings. Readings are from three sensors located differently, one on rooftop, one inside and one in chimney opening. The darker areas are where the design iterations were changed. When changing the designs, hands and card board parts were disturbing in the readings.



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