Propositional Architecture using Induced Representation

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Introduction

Propositional Architecture for Refurbishment

What if we could employ a strategy of constant modification to our built environment, a strategy where small modifications would accommodate needs from the inhabitants, in the rate with which the needs arise? Such a process should be a continuous adjustment rather than stepwise changes. The strategy makes use of information-technology, especially sensors and machine-learning, in order to address complex pattern of needs arising. We do not propose a dynamic built environment mechanically controlled by machines. We suggest an approach to use technology for continuous modification and initiation of refurbishment of the existing building mass, in order to create a robust built environment encouraging urban life, social encounters, while still preserving the sense of the local, and the spirit of the place. As proposition for modification being crucial for the approach, the paper outlines three main steps of investigation which are central to the strategy, and presents experiments that discuss the opportunities and difficulties. The steps are:

Step A: Data collection from the environment.

Step B: Machine cognition, learning, prediction.

Step C: Proposition, visualization, and embodied representations for quick implementation.

Potential

Anne Power summarizes the evidence and arguments in the ongoing discussion on whether we should demolish and build new or refurbish existing buildings, and with the context of UK, she concludes that refurbishment makes sense in most cases, both on the basis of time, cost, community impact, prevention of sprawl, re-use of existing infrastructure and protection of existing communities. In the UK new buildings adds only about 1% to the existing building stock each year. And from the existing 24 million homes, 87% will still be standing in 2050. At that time, 70% of the existing building stock will have been built already today. This means there is a huge potential in refurbishment and modification of the existing built environment, and in the occurrence of an energy crisis, material scarcity will force us to upgrade and refurbish what we have in order to minimize material use and energy cost (The Economist 2007) (Office of Climate Change 2007). Building Performance Institute Europe has several ongoing projects dealing with energy efficiency of the existing building stock, but there are many additional aspects in the discussion on refurbishment (BPIE 2013).

Demography and changing needs

As society, culture and especially demographic setting changes, many aspects of the architecture should follow. As an example, 70% of newly formed households in the UK are people living alone. With this tendency, of families getting smaller and more people living alone in the same size appartments as 50 years ago, density drops and causes changes on the urban scale. Drop in density, makes it harder to run efficient public transport, and small scale local shopping demise. If the existing housing mass would continuously adapt to the need, mixed use could nurture social integration, less transportation, and lower general consumption. Much of this adjustment could be achieved through subdivision infill buildings or merging of existing property (Power 2008).

Design versus Proposition

Design has been increasingly managed by machines throughout the past century, perspective perception apparatus for hand drawing and parallel drawing machines for geometrically constructed perspectives. In the last few decades, computer aided design machines has developed and the late twenty years computerized parametric machines has come about. These technologies has been enabling architects on a level of design and development of ideas, -ideas that are already conceived fundamentally. The computation and technology in this project is not for designing existing ideas, rather aiding in the conception of the ideas. Propositional aid, pointing out potentialities in the environment, and suggesting modifications. Similar to how internet browsers works today, proposing search sentences, based on the available data affiliated with the user, previous searches and context. This way and others, machines are aiding us in the everyday, managing complexities.

Machines finding phenomena and trends

'Big Data' attract a lot of attention recently, we will suggest using various data flows, to detect the occurrences of events through the use of 'Sequential Pattern Mining', 'Self Organizing Maps', 'K-means' and other algorithms (Cabanes 2010). Various types of machine-learning can be used for analyzing data, finding relations and sequences. This enables us to assign machines to the task of speculating on the occurrence of future phenomena. The systems or machines we propose here become instead of design machines, assigned to a higher level than design, namely that of initiative and proposition. This method permits the identification and instantiation of what is necessary and missing, they grow the frames for these future phenomena.

Guidance and modification

The strategy explores interplay in the environment between materials, morphologies and inhabitants, in order to attain an ongoing development of both subtraction, addition and reconfiguration. Architects, developers, politicians and the population would have to define the guidelines and general aims, but the monitoring and guidance towards these greater aims could be done by means of technology. Employment of information and sensor technology should assist us in modifying the environment not towards specific formal or aesthetic goals, but rather social, sustainable and performative goals.

Coupling Representation to the Matter

Most construction today is made in stepwise initiatives, and through a rather conventional planning and construction strategy, we suggest a new approach to representation and construction, where there is no preconceived design. We will outline some viewpoints from theory of architecture, robotics, computer-science, and mathematics in order to get on a track towards this sort of constant modification.

So far we have found that the architectural representation should be strongly coupled to matter. In the matter, our models are able to represent intents and potentialities rather than the manifested matter. We should make use of multiple representation rather than attempting to have singular discrete understandings. We call these two opposing concepts 'Induced Representation' versus 'Discretization'.

Sensors should be used to inform these representations, and the sensors can either be ingrained, embedded, or external to the matter (Fig. 1). Ingrained means that the sensors are an actual part of the material composition, Embedded means that they have close contact with the materials, placed in strategic places where particular events can be detected and External sensors are on the other hand not in contact with the material directly, but placed so that they detect an overview. The difference between these three types of sensors seems to have a great impact on the amount of computation needed for managing the sensor data. Previous experimentation dealing with this difference suggests that ingrained sensors can produce sensible decisions using very little coding, while external sensors needs a far more cumbersome software system to make sensible decisions (Nielsen 2013).

Fig.1
From right to left, external sensors, ingrained sensors and embedded sensors.

Induced Representation

The idea of Induced Representation is borrowed from the Mathematical 'Group Algebra', where the representation of a higher topological level is built from multiple representations of subgroups. In Induced Representation, an understanding of the whole group is constructed through multiple representations of subgroups, this works, so far as they maintain the Frobenius reciprocity (Rieffel 1974). Here we will use the term conceptually. In our use of the term, representation can be much more than 'representation of linear vector spaces' or homomorphisms. Representations can be supported by various data types in different spatial and temporal scales.

John Frazer proposed in the 1970 to use computers and rule-base coded systems to reach an evolutionary architecture. Through the use of 'intelligent physical modelling' his experiments were through exchange of information and external representational models, able to understand more about themselves and the context in which they were related to the rest of the experimental model. Frazer also proposed virtual models for the environment which should be used for influencing the evolution of these architectural models (Frazer 1970). "*Another important issue for our model of an evolutionary architecture is that it should be responsive to evolving in not just a virtual but a real environment*" (Frazer 1970).

Embodiment -and of systems

Today we have quite well established ways of modelling both architecture and the environment. But as architecture becomes or changes, it affects the environment. Consequently the architecture plans and models need to adjust according to these unforeseen changes, caused by the interdependence between the built environment and the new build.

It is important to underline that we consider the environment neither systemic nor divisible (Kaklauskas 2004), therefore no full model can be made for the environment, and this is why the approach of induced representation might be useful.

Supposed the representational models could be merged with the physical materialization whilst constantly negotiating multiple criterias of performance locally and globally throughout the design. There would be no need for representation of the existing matter, but the issue might be the extraction and remapping of information. The models can hardly any longer act as pure representation, they rather becomes indications or guides, something more operational. Glanvilles describes 'models for' architecture as being more operational than 'models of', which merely illustrate (Glanville 2012). But models, and matter used in this research are coupled so closely that they are carrying their own function. The material functionality and computational powers of the substrate become both carrier and processor of information.

Representation in the Matter

Models for action become important in the interaction between material and morphology. We can say that 'model for' is what Frazer describe as 'coding'. When merging material and representation, it would be no longer interesting to represent the physically present material, as it is already manifested, instead the 'mode for' represents the intended modifications to the existing.

Robotic designs often operate with models of their environment, in order to navigate and perform tasks. But in 1991 Rodney A. Brooks proposed to eliminate or rather merge the representation with the environment, this way the environment becomes its own model. His article 'Intelligence without representation' challenged the contemporary understanding of how to create Artificial Intelligence and suggested that robots should not use any central representational model of their environment. Instead, the environment is used as its own model, and reactions from the robots are directly based on sensor input from the environment. Brooks and his research group could create simple but very robust robotic systems capable of interacting with rich, constantly changing environments, so maybe our research can learn from the approach they took in the 90-ies (Brooks 1991).

The same way these robots overlay representation to their environment, traditional architecture also develop without the use of representational models. Much traditional architecture is also its own model in direct interaction with the environment. It is developed through improvements and modifications to each instance, from one to the next. Christopher Alexander describes this as the 'unselfconscious process', where there is no preconceived representation in any other media. There are only the existing build examples which can be modified or re-iterated, guided by immediate need, local craft and constrained by traditions. We may compare this need, craft and tradition to the hierarchical behaviors of Brooks' robots, some are driving forces, other inhibit (Alexander 1973).

Evolution is generally discussed amongst scientists and Bongard argues through an empirical study using evolutionary algorithms in virtual environments;

"*By evolving virtual organisms for locomotion in a variety of environments [...] more complex environments tend to lead to the evolution of more complex body plans [morphology] than those that evolve in a simpler environment. This result supports the idea that the morphological complexity of organisms is influenced by the complexity of the environments in which they evolve*." (Auerbach & Bongard 2014).

Brooks argues that complex behavior can emerge from simple rules and interaction with the environment, and Bongard show how morphology can evolve through interaction with the environment. It seems interaction is an important driver of behavior and evolution.

Sensor Fusion

"*If you cannot find the sensor you need in any manufacturer´s catalogue then you can probably make your own - in Software. This is the basic premise behind sensor fusion. The idea is that if you combine the data from a variety of different sensors, you will be able to measure parameters for which no single sensor exists*" (Laughlin, 2002).

In Experiment A we make use of sensor fusion extensively, although we are not designing for specific purpose, the system will combine data from different types of sensors.

Mining Phenomena Patterns in Induced Representations

When translating Induced Representation to an architectural approach, the 'whole group' is the continuous environment. The subgroups and representations of these, are multiple different representations of data from the environment. The representations produce sequences from which we might extract phenomena and detect noumena or at least notions of episodes and events.

"*An episode is a collection of events that occur relatively close to each other in a given partial order*." (Mannila 1997).

The relevance of mining phenomena patterns in data across time is, that we automatically identify relations which could be previously imperceivable. What Immanuel Kant describes as noumenon, might, through this method be detected and changed to phenomenon. Then, once identified we can start constructing to nurture certain phenomena (Rescher 2014). This way, relations are established which could be useful to nurture social, material and performative goals (Mooney & Roddick 2013).

Experiment description - Induced representation

In the coming paragraphs we will describe three experiments A, B and C. They attempt to resolve issues related to the steps A, B and C described in the introduction. Some parts of the experiments will overlap between the steps.

Experiment A:
Two-dimensional and multidimensional sensors, sensor fusion, and phenomena detection and proposition

This experiment introduce a multi-dimensional sensor hub which is feeding data to a machine-learning process. Through visualization we demonstrate how the machine-learning process clusters similar events captured by the sensor hub. This method gives a visual indication on when similar phenomena has taken place in the environment, and how often.

Two-dimensional sensors depicting a single aspect

The red curve in Fig. 2 shows plotted values from a single light sensor for the duration of about 45 seconds (X-axis). The blue curve is the average from the red curve of the last 10 values. Clearly we can identify three smaller peaks each followed by larger peaks. This pattern can be caused by several different events in the environment, but instead of relying on the accuracy of the light sensor to differentiate the three different events, we can introduce other types of sensors, that react to other types of events in the environment. This is how we establish sensor fusion.

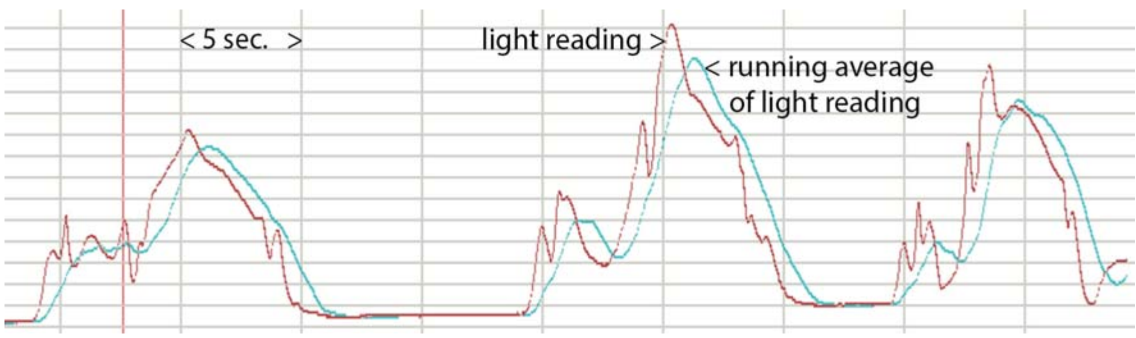

Fig. 2

A simple light sensor traced over about 45 seconds produced the red plotted curve. The blue curve is an average of the past 10 readings from the red curve. the relation between this type of short memory can be used as an easy way to tell if the light intensity is increasing or decreasing. In this graph we can identify three more or less similar intervals of a small peak followed by a larger peak. They are describing three somewhat similar events that occurred in the light sensor environment at those given moments in time.

Sensor fusion: multiple aspects - multiple dimensions

The sensor hub makes use of several types of sensors, in order to give a multi-faceted or multi-dimensional picture of each moment in time. Through software we can start to group these readings. For example we can look at two situations which both has little light, but where one has high temperature and the other has low temperature. These two are likely be assigned to different groups despite the similar light condition. Using computation, we can add as many dimensions to a given time unit as we find relevant. There are several algorithms capable of data mining on n-dimensional objects, and we found K-Means useful for this experiment (Cabanes 2010).

This approach of adding dimensions is what we call Induced Representation, where many, although simple, representations are used for describing a larger setting, in this case the environment around the sensor hub. Notice that Induced Representation work over many time scales and spatial scales, as well as in layers.

K-means Clustering

This algorithm, commonly used for signal processing, is partitioning or grouping the observations into any given number of clusters. Like we could quickly partition 2-dimensional points on paper by circles, the algorithm quickly partition 14-dimensional readings into any number of clusters. If we set the number of clusters to two, the algorithm will assign all the states, where nothing particular happens, into one cluster, and the other cluster will contain all the event-full time units where sensors are reading changes.

Time windows

Fig. 5 is a diagram showing conceptually how patterns can be found across multiple data streams (y-axis) and across time (x-axis). Fig. 4 shows a visualization of the different sensor readings over time, and across the graph, the color coded clusters indicate which cluster each time unit is assigned to. The major size cluster is the turquoise cluster we could call that the normal state, just because of the fact that it contains most time units. Another characteristic cluster is the yellow, this is recurring and it seems like it has same short duration. Other than that is difficult to say more about the clusters. Because many events or phenomena takes place over longer time than the instance captured by the sensors, it makes sense to look at time windows. The exact same approach is taken, we just increase the dimensions, to look at many time units simultaneously.

Event-based modifications

From this K-means clustering we do not know what the events are, we only get a notion of when the same types of events occur, and how often. But before running the algorithm, we have to decide how many clusters we want to sort the time units into, and thereby we risk both to separate events into different clusters or have different events clustered together so we overlook the difference. Other algorithms like Self Organizing Maps can decide on the number of clusters (Cabanes 2010) and this type of clustering could provide better results, but for the purpose of this research, K-means is sufficient as proof of concept. With this data capturing and learning algorithm, we are able to say something about the occurrence of distinct events or phenomena, and we could easily make a prediction of future events either by forecasting the frequency or simply by statistical forecasting.

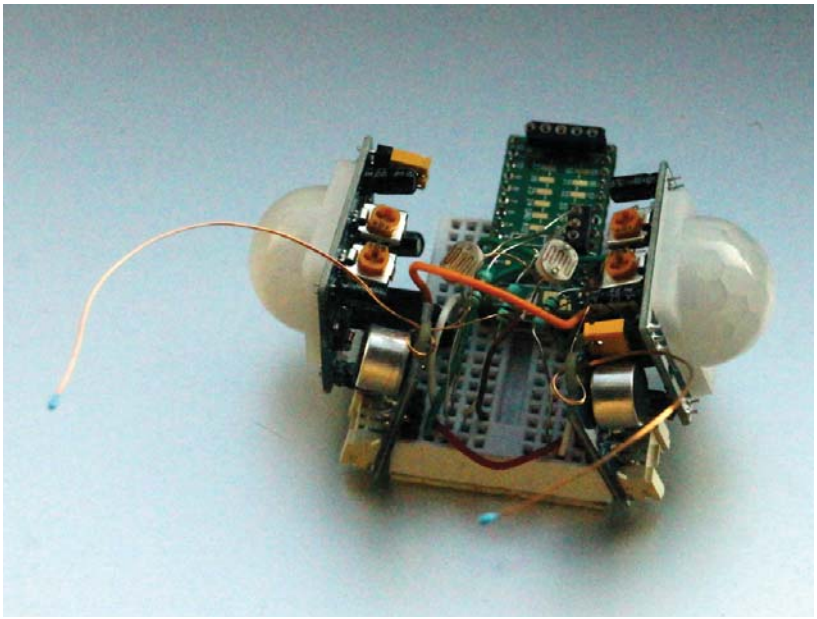

Fig. 3

The sensor hub for the experiment consists of two motion sensors, two sound sensors, two temperature sensors, and two light sensors, all attached to a programmable chip which sends data to a laptop using a serial port.

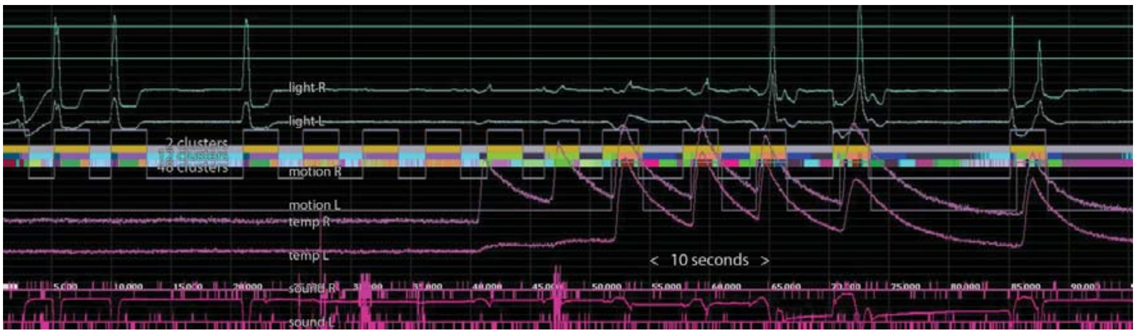

Fig. 4

Sensor readings are plotted over the duration of about 100 seconds. The data is analyzed, and vertical time sections with similar sensor readings are clustered. The result is shown as the polycolored bar across the middle. Same color time sections has similar sensor readings.

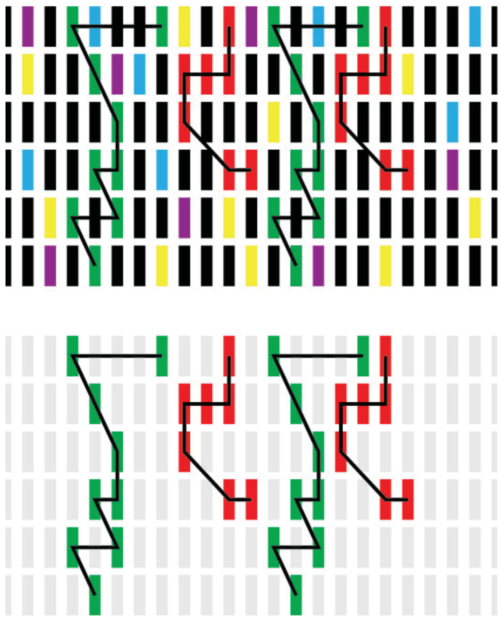

Fig. 5
Conceptual diagram of patterns across datastreams and across time.

Experiment B:
Edge detection and construction proposal

In this experiment we attempt to make an application which recognize the edges in a plate structure, finds the length and angles of the edges, and design a plate with the angle and length of sides that would fit the existing conglomerate of plates, all in real time.

Advanced large-data sensors, enhanced to make spatial cognition.

The Kinect sensor can capture geometries in the space in front of it as 3D point clouds and transmit the large amount of data with up to 30 Hz. The Kinect itself does not concern what meaning the points has, this is, through post processing, up to whatever application uses the Kinect sensor. Many libraries has been developed already, most of them for game applications, with the purpose to recognize human beings.

Three-dimensional edge detection, on-the-fly-design

In the experiment we use a Kinect sensor in combination with a recursive algorithm, as an alternative to the manual process of measuring lengths and angles, and drafting the 1:1 drawing for the next plate. When the Kinect sensor is aimed at the area of interest, a recursive function starts jumping from point to point in the pointcloud, favoring the edges, and terminating on corners and surfaces. As edges are found, a 2d-viewport represent the edges laid out flat with the correct angle. Then, a plate that fulfills the criteria of being foursided, and not a parallelogram is drafted to fit the construction in the environment.

The system functions in close to real-time and recognize plate edges and designs new plates in just under one third of a second, close to 60 times faster than the process of measuring, and drafting the next plate. The final system is running well, but it needs adjustments and calibration continuously. As the Fig. 5, 6, 7 show, it can fail in some conditions; the recursion can run around a corner without noticing, or it can pass from a convex edge to a concave without noticing.

There are countless material, morphologies and ways of constructing. This system is very constrained to this particular task, and the method of processing point clouds is just one possible way of proposing a particular construction aid system. Future system conducting construction should be diverse and capable of managing many types of morphologies and materials. And we should invent entirely new, more adaptive approaches for the purpose of constructing onto the existing environment.

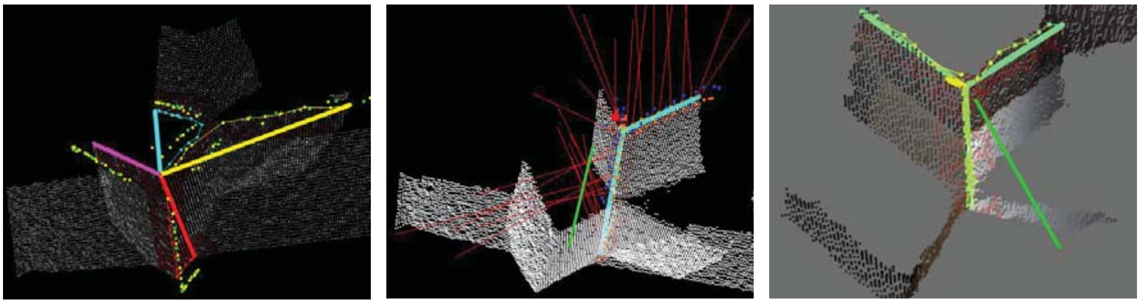

Fig. 6-8

The recursion moving along edges of the plates, and ignores the corners where it should otherwise terminate.

The recursion ignores an edge going from convex to concave.

The recursion behaves as intended, moves on the edges and terminates when the edge ends.

Experiment C: Coupling of (matter, environment and proposal) representational models for quick implementation

In earlier experiments we have achieved a close coupling between matter and representation through the use of projection (Nielsen 2013). This method has severe technical and practical issues. Projections must be calibrated for the position of the projector, and non-physical elements must be reflected on existing matter, they cannot stand out in free air.

Augmentation works by overlaying a 3D-model on a real-time video image. The 3D-model is often positioned in the video using a tracker. Trackers can be all sorts of flat images, although some are more suitable for recognition than others. If the system knows which model to associate to what tracker, the model can be loaded from a da-

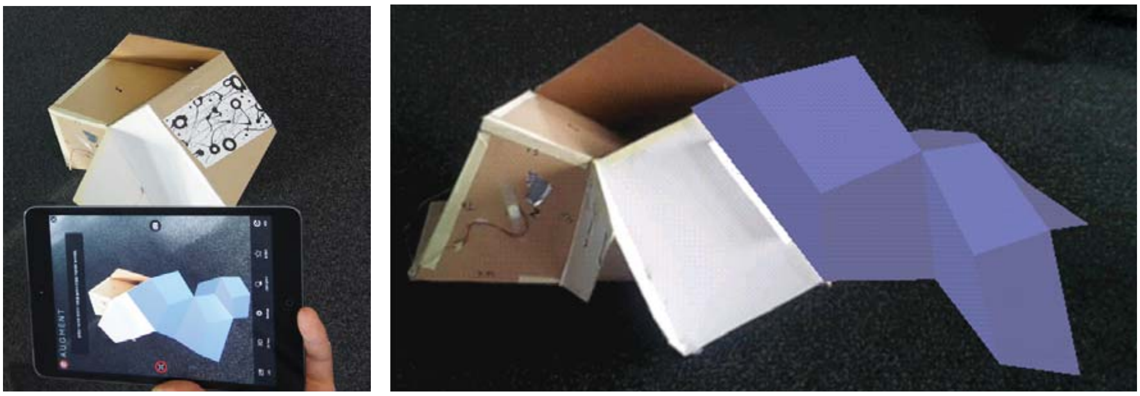

Fig. 9-10

The application Augment showing how the proposed geometry should be constructed in the environment. The pattern on the plate is the tracker which helps placing the model in virtual space.

Illustrate how the 3d-model is turned when the camera turns around, still placing it correctly according to the viewpoint of the camera.

tabase, once the camera software has tracked the image. In this experiment we used a free Android application called Augment, but Vuforia, a plug-in for the game creation system Unity has proven more suitable for other experiments.

Augmentation does not have the same disadvantages as projection, on the other hand it has the disadvantage of not being displayed in the actual real environment. Instead it is on a display which re-represents the environment and add on top, any type of representation, 3d model or 3d animation. Luckily, the brain is extraordinary capable of hinging the situation on a 2d flat image to the real, especially when held up, next to. With Augmentation, pattern recognition facilitate a constant calibration for position of camera and augmented information, and in opposition to projection, the information does not need to be displayed on existing matter, but can be in free air, which is convenient when it comes to construction processes (Fig. 9). This way the construction representation is linked accurately, but not directly to the existing matter. It ensures quick modification, and feedback on whether the part is in the correct position. In this experiment we have not solved the issue of holding a device while using the hands for constructing, but this could be easily solved.

Discussion

There are overlaps, as well as holes in when relating the experiments above to the steps suggested in the introduction. Experiment A answer to both step A and B, and experiment B answers to step B and C. However no parts of the experiments really deal with the aspect of proposition. In the coming paragraphs we will speculate on how to conceive proposals. Some aspects from Christopher Alexander's theory could help, in that tradition could be driving, and alterations is found by need.

Learning from modifications

Whenever a proposition is constructed and the environment is modified, entirely new phenomena might take place. These would be relevant to look for, through the use of data mining. This way we may be allowed to learn from modifications. But we are still asking - how to conceive a proposal?

Forecasting

The idea that we can use Induced Representations to identify phenomena occurring in a given environment, and that this type of learning enables us to predict the statistical chance of an event in the near or far future, depending on the scale of the system, is appealing. If we look at a given time window, it has a center, some time before center, and some time after center. If we could instantly, when a new short period of time is recorded, compare it to all the 'before' times, and find the one that look the most alike, then the time just after that 'alike' could be the events to come - the forecast. Also other approaches could be useful, for example trends could be found and forecasted. But forecasting and proposals are entirely different.

Proposal

The beginning is always difficult, so maybe we don't need to conceive the grand master plan, but rather just start somewhere and learn from the causes. So, if we take the existing material morphology and construction technique as a type of local tradition, then construct something with that material in a similar morphology, just before the moment of which we forecast a certain phenomena to happen, then look at what phenomena the modification allowed for instead of the forecast. Then, learn from this. In turn, we allow learning to influence the tradition. Further experiments in this research should focus on such a stepwise approach. Stepwise approaches has shown great potential in algorithms, because we apply an answer in order to nurture emergence.

The Meaning of Induced Representations

The experiments are supposed to illustrate many different approaches to Induced Representations. It is worth noting that Induced Representation is not trying to gather enough material for one all encompassing model, but rather make several different types of productive representations available at all times, whether it be a simple sensor signal from a single spot, or an overall augmentation of all possible futures. Induced Representations may affect several aspects of the building industry, it might enhance the workers skills and reduce errors on site. Causal effects on surrounding ecosystems might be better understood etc.

Propositional Architecture

If large environments starts learning from modifications and phenomena, these proposals could be anything from subdivision of living spaces opening of ground floors, addition of balconies, infill houses, demolitions to create parks, and urban spaces. Basically including all scales of modification to the build environment, and both subtract, add, and modify. The important contribution is, to propose modifications, in order to follow the changing needs that constantly come from the change in society.

Conclusion

Built environments are completely intertwined with relations, making it difficult to confine. When managing these continuous built environments, opportunities are present in the matter and constellations. The approach of Induced Representation is possible through the use of contemporary technology and the capacity to handle multiple streams of large amounts of information.

This paper has through theory and experiment suggested how to establish a build environment in constant modification. We have shown how phenomena and events can be traced, and discussed the potential of forecasting and how it can lead to propositional architecture. We suggested how propositions can be guided through the use of both high dimensional sensors, as well as advanced visualization techniques. The environment has been used effectively as its own model, and representations has been merged with the environment. Still, making actual propositions based on the past and the present phenomena has not been implemented fully, but it seems as if learning from the ongoing modifications in the environment, is a way to get started.

Our current living environment contains vast amounts of both matter, in the form of existing buildings, and information, in the form of intertwined relations and interactions. These are resources that we should take care of, and not forget to make use of.

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