THE AGENCY OF EVENT
EVENT BASED SIMULATION FOR
ARCHITECTURAL DESIGN

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ABSTRACT

Design increasingly becomes a matter of balancing between the different agencies, boundaries and implications of architectural intentions and material performances. To synthesize these new constellations, complex design systems can be decomposed into flexible and scalable integrations of autonomous, heterogeneous sub-models. When each sub-model has its own goal, the making of design decisions, as well as the registration of their impact, becomes distributed throughout a computational model.

This research explores the notion of agency within event-based models. Event-based models decompose continuous systems into components. These components are not designed to work with other components in a traditional sequential mode, or to share a common time-step, but instead communicate asynchronously. This characteristic is particularly well suited to supporting and synthesizing multiple agencies.

In this paper we distinguish between three forms of agency: material agency, structural agency, and design agency. We present an event-based modeling approach that supports and synthesizes these types of agency by linking interdependent sub-models. The application of this approach is demonstrated through two case studies: Transmissive Assemblies (Figure 1) and Reflective Growth.
AGENCY WITHIN A SYSTEM OF EXCHANGE

(Glanville 2007) suggests understanding design as a system of exchange between the object being designed and the designer. The goal of this system is to iteratively reach a particular point of stability where new iterations reproduce the form of the previous iteration. Consequently, the agency of the designer is instrumental in creating the appropriate conditions allowing for this event to occur, and to observe and reflectively interact – as an integral part of the system – until a design solution is reached. The goal here is not to obtain the best solution, since this concept makes little sense within design (Simon 1996), but an adequate solution.

In the design of structures that activate material performance this system of exchange becomes increasingly nuanced. Material, energetic, and external parameters concerning design intention and fabrication can each inform aspects of a digital model, with a continuous system description made from these partial models. Each aspect has a capacity to act independently, tends towards its own optimization, and makes an impact upon other models that are linked to it. We distinguish between three types of model: generative, analytic and decision making (Figure 2).

GENERATIVE MODELS

Generative models include genetic algorithms (Holland 1975); (Bentley 1999), growth algorithms (Runions 2005); (Lindenmayer 1986); (Runions 2005) stochastic models such as the diamond square algorithm (Fournier 1982), and agent based systems (Flake 1998); (Bonabeau 1999); (Carranza and Coates 2000), (Tamke 2010). Generative models possess a degree of autonomy, and after initial parameterization arrive at a solution independent of the designer.

ANALYTIC MODELS

Analytic models are exemplified by structural analysis (Preisinger 2014) and ray tracing for solar analysis (Spencer 1962, Malacara 1978, Wendelin 2003). They generate new information about a known thing. For example, in the case of structural analysis, a pre-given topology is informed about materiality and load for the purpose of predicting behavior.

DECISION MAKING MODELS

Decision making models are characterized as being either internal or external. Decisions include when to operate, or what to do. For example, a model might be triggered into operation or even being by the crossing of a critical threshold through a mechanism as simple as an IF statement in a function. Alternatively, more powerful methods, including optimization models such as simulated annealing (Kirckpatrick 1983) or ant colony algorithms (Colomi 1991), might decide locally that one solution outperforms another, as in region extraction algorithms (Samet 1988), and communicate a temporary best solution back to the larger simulation, or make global decisions regarding the weighting and synthesis of multiple aspects of performance as in multi criteria optimization models (Zionts 1976); (Vierlinger 2013).

FEEDBACK: FROM LINEAR TO NETWORKED MODELS

The integration of multiple sub-models within synthetic computational processes is simultaneously related to states, behaviors and functions. Each sub-model is implicated in performative behaviors that rely upon or inform other models. These complex interrelations challenge the linearity of the procedural modeling paradigm present in current parametric architectural software. In here sub-models are connected in a static way. The processing of information in this model aims at the calculation of a set of results, which can with some efforts be passed into the model again and trigger further iterations of the model. Multiple sub-models with autonomous connections for feedback challenge the current modeling paradigm on a performative and conceptual level. The challenges are caused by the concept of fixed connections of submodels and time that underlies the current models. In here, all sub-models run in the same time interval (Fig. 3) – the run time of the overall model. In reverse, this means that sub-models, which take longer to calculate, are forcing all other models to wait, even those that are not dependent on the output of the calculation. This handling of time decreases the overall performance, while the fixed setup of connections induces constant communication between submodels, even if their interaction might solely be

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2 Examples of three types of models. The black fields show the types of models used in the project Transmissive Assemblies
sporadic in nature. We need to extend upon models that ‘only’ synthesize, and to move to models that also give agency to interdependent parts.

DISCREET EVENT BASED SIMULATION

The simulation community faces similar challenges as the simulation of many distinctly different but interdependent activities has to run simultaneously. Discrete-time systems that change their time synchronously - as present in current parametric modelers – have here been widely replaced by Discrete Event based systems (DEVS) that ease the handling of interaction, as they do not need to understand why and when external actions take place, but can concentrate on the effect that an external action has on the internal system (Gunay 2012). This approach provides benefits and savings due to simplifications within sub-models and the communication between them: it has though potential issues in stability and synchronization (Cellier and Kofman, 2006). DEVS separate the simulation processes and provide a framework for connecting these models, as within the widespread language Open (Åkesson, 2010). Modelica, however, features a non-traditional equation-based modeling approach. The trend today is hence to simply develop simulation libraries which can be called from any language and shift the focus from languages to modeling paradigms (Matloff, 2008). These evolved from frameworks where sub-models interact though waiting in an idle state on input from others (event-oriented paradigm) to those where sub-models are understood as processes that are only started in case of events (process oriented paradigm).

As DEVS inherently support variable time steps, any sub model can possess its own simulation time leading to an asynchronous simulation. The modularity of the DEVS formalism suggests a more organized code structure, which makes models more flexible, transferable, and reusable. Goldstein describes in 2013 further motivations for the agency devised to sub-models in DEVS: the coupling of independently developed models by different domains that allows interdisciplinary collaboration, scalability of systems and the reduction of management of simulation.

STATE OF THE ART

Computational frameworks have recently been proposed for the field of building physic simulation in order to assess the complex energetic behavior and sustainability of a building design in a project specific way. Related initiatives such as sustainability-open (Coenders 2013) propose a modular framework that can hold components for design, analysis and optimization. While sub-models operate here in the same time frame, DesignDEV
(Goldstein 2013) proposes a truly event-based approach towards modeling. Examples exist currently for the field of building physics simulation. The proposed formalism is however domain agnostic.

OUR APPROACH

Within a context of architectural design, a possible implementation of the above ideas has been explored through two case study projects: Transmissive Assemblies and Reflective Growth. Both projects utilize time-based processes in establishing models of exchange across a system for design. Our approach has been to develop systems in which individual computational models operate with distinct local resolutions in time measurement, and where different models are interfacing through event-based triggering as procedural objects. This is contrasted to a situation of continuous simulation and exchange relative to a global measurement of time.

CASE STUDY 1: TRANSMISSIVE ASSEMBLIES

The installation Transmissive Assemblies (Figure 4) concentrates upon two qualities that are particular to fiber-reinforced composites: translucency in a structural element, and the ability to gain stiffness locally through forming and folding. Taking point of departure from preceding experimental architectural practice focused upon these qualities—exemplified by Renzo Piano’s Mobile Sulphur Extraction Facility (1966)—the project asks how a modern composite sandwich might be designed to modulate the transmission of light in a controlled manner through strategic material variation.

Transmissive Assemblies has the broader aim of establishing new methods for designing with synthetic materials. Synthetic materials afford opportunities for specification, simulation, and feedback not available in found materials, through design parameters that relate to different scales and material components. These parameters are often standardized, and the models that surround them have typically concentrated on synthesizing the inter-related behavior of constituent components. However, the same parameters could be opened up to design. In the case of a composite sandwich, structure, core and skin could all be given agency.

The project develops a set of allied models related to structure, core and skin, which is used to introduce variation into a tiling, translucent and geometrically stiffened GFRP panel system. To achieve differentiated light transmission through the composite sandwich, different parts of the whole are strategically activated—the hanging points, which find the best available condition, or the core, which is perforated, or the skin, which folds locally to increase stiffness.

Transmissive Assemblies (Figure 5) is made from an assembly of composite sandwich panels. The foam core is a highly insulative and lightweight PET structural foam, and both thermoplastic and thermoset composite skins have been explored. Before their consolidation into a sandwich, each of these materials undergo working processes specified by the digital model, using tools that include a CNC router and an industrial robotic arm, as well as vacuum bagging. The digital design process links together a number of different Generative models, each related to one of the constituent materials within the sandwich assembly. Over a time-based process, these models trigger one another, and transmit information between themselves, until a stable condition is achieved that satisfies a design intention regarding light conditions as well as structural stability.

DESIGN SYSTEM

The digital design system developed for Transmissive Assemblies is constructed around a number of interconnected computational models:

1. A Boid type simulation (Reynolds 1987) devised as means to use autonomous agency to analyze and transform solutions;
2. A generative system creating height maps describing potential configurations of the material core of the final composite (based on a Diamond Square Algorithm (Fournier 1982))
3. A method of extracting the boundaries of significant areas within the height map (based on a principle of Connected-Component-Labeling (Gonzales and Woods 1992, Ronsen et al. 1984)) as a means to pass information between elements of the computational system;
4. A system of structural analysis (Karamba);
5. A system for optimization—via a genetic algorithm (Octopus²).

These computational models are set in motion by the overall design intent of the project, either directly or indirectly by the propagation of information passing between them. The models themselves individually assume a degree of independence from the specificities of the project. As a result, it is the connections established between models and subsequent interpretational processes of their output that is the means by which concrete design proposals are made.

UTILIZATION

The design system (Figure 6) is set in motion by supplying a desired lighting condition. This establishes an overarching design intent, relative to which the processes of the models are to be directed and evaluated. From here an event-based non-linear system of information exchange is...
The number of agent systems is not known in advance. They become smaller and more numerous as the design system develops towards a solution.
established, directed towards establishing a design solution that modulates specifications for the core and skin of a composite sandwich to meet performance criteria concerning lighting and structure.

INITIATION: GENERATION OF THE HEIGHT MAP

In order to initiate the overall design process the system generates a random height map as starting point. Using the principles of the diamond square algorithm (Fournier 1982), this map represents material conditions within the core of the composite structure. The generated “landscape” is interpreted relative to a threshold value, which simplifies peaks and valleys to be represented as two distinct height levels. These correspond to the two material conditions with which the project operates: perforated and solid. As simulation process develops so do the number of historical states informing the landscape.

REGION EXTRACTION

From this initial map, perforated regions of the core are identified and passed on to other parts of the system as our main model of interfacing. The process of extracting the regions is based on the principles of connected component labeling (Gonzales and Woods 1992) (Ronsen et al. 1984).

AGENT SYSTEM

One instance of using the regions extracted from the height-map model is related to an autonomous agent simulation. Each region represents an area within the structure with a specific qualitative function related to light transmission. One goal directing the system is to attempt matching the regions produced by the height map with the specific light condition initially supplied to the system. In order to do this, each region is passed to an instance of a Boid type simulation (1), which deploys agents within each region. These agents are used to search the space of each region for matches and mismatches between region and design intent and pass appropriate alterations back to the height map via the regions. Alterations either extend or fill in perforated zones. This occurs every time all deployed agents in all regions have plotted a course from the center of a region to its boundary. This is the triggering event for reconfiguring the height-map-model. As simulation process develops, the number and size of the regions and their agent systems alter significantly, with the consequence that neither their number nor the time that they take to run are known in advance (Figure 7).

STRUCTURAL ANALYSIS AND OPTIMIZATION

The composite structure is tiled into panels connected by 3d printed joints. This system offers a series of potential suspension points by which the structure can be attached to a given space. These points have to be positioned outside of the regions since material strength is here diminished due to material perforation. However, the alterations continuously made to the representation of the material core recurrently produce regions that might include one or more suspension points. This is interpreted as a triggering event which activates an optimization process for the overall structure. Here, regions are used to distribute material specification across the structure. Optimization of the structure consists of continuous reconfiguration of the support points via a genetic algorithm optimizing towards the least amount of structural stress.

END POINT

During the system’s runtime, the above processes trigger and inform each other continuously (Figure 8). This process performs an ongoing alteration of the underlying perforation of the material core and the position of the suspension points. As time passes the system will eventually reach a stage where the regions find an acceptable match for the design intent and an optimal position for the suspension points under this condition. At this point the princi-
The surface geometry of each panel includes primary and secondary ribbing that locally stiffens the composite skin to compensate for perforation of the core.

CASE STUDY 2: REFLECTIVE GROWTH

The installation Reflective Growth (Figure 10) intersects two systems informed by physics and traditional crafting technique.

THE FIRST SYSTEM

The first of these relates to light. The reflection of light follows a clear rule: angle of incidence equals angle of reflection. This is the point of departure for an array of mirrors that are programmed to reflect the light of a moving artificial sun to a set of targets. These are pre-defined in the scope of the installation and light coming from a highly directed source shall hit these in pre-defined patterns during selected periods.

THE SECOND SYSTEM

The second system relates to construction, where the use of materials as wood find their limit in matter and fabrication. These are constitutional for the practice of building with wood, where the clear logic and constraints of the structural system informs the making, characterized by a high degree of offsite pre-fabrication. This provides wood industry with a competitive advantage as the evolution of the underlying craft led to rational fabrication and assembly strategies for complex systems, as systems of notations on the wooden elements or the system of traditional massive wood joints. These are self-registering and immediately stable when two pieces are connected. Notations guide the builder. Wood, however, has its limitations in strength on the level of constructions through precision and achievable geometry as the process of fabrication is characterized by its own economies of time and budget. The installation investigates means to capture this knowledge through physical and digital prototypes in order to create a set of constraints that inform
a generation. This produces a solely “buildable” solution and allows the design to make use of the benefits of wood joints in self-jigging and fast assembly. The project investigates means to interface between two highly constrained systems through stochastic search algorithms.

DESIGN SYSTEM

The digital design system developed for Reflective Growth consists of two overall computational models, which negotiate a design solution by means of an optimization process. This process is driven by a genetic algorithm. The two models are:

1. A leaf Venation algorithm (Runions et al. 2005) (Figure 11)
2. A Raytracing analysis.3

The process of designing with the system begins by specifying a desired orchestration of light ray casting from a moving light source to several target points, by way of the mirrors of the structure. Following this setup, the system generates a number of mirror planes at random heights, oriented towards their individual targets (Figure 12).

The calculated mirror planes become the target of a Venation algorithm which attempts to grow a structure capable of supporting the mirrors in their desired height. This process can be evaluated relative to several objectives:

1. The total length of material used for the given solution of the Venation algorithm (cost minimization);
2. The total amount of joints used for the given solution (fabrication speed minimization);
3. The amount of starting positions used by the Venation algorithm (production simplification); and
4. The degree by which mirrors occlude each other relative to their desired reflection.

An additional part checks for solutions in which mirrors or supporting structures intersect so as to make the given solution unproducible.

SYSTEM PROCESS

Relative to the above objectives, the system enters into an iterative process of multi objective optimization. Here, the process of orienting mirror planes and growing the supporting structure towards them occur as continuously repeated event based processes, which allow successful parameter-settings to be recorded so as to inform future generations of design solutions.
VENATION

Based upon the leaf Venation algorithm (Runions et al. 2005) and as a further development of the tailored Venation algorithm described in (Tamke et al. 2013), a more generic Venation algorithm was developed for Reflective Growth. This Venation algorithm is set up as a hierarchical object oriented algorithm, where each object contains a number of properties and information about its position in the system hierarchy. The system contains three objects from higher hierarchical level to lower – branch, seed and auxin. The branch functions as a container for seeds and auxins, as well as information regarding naming conventions and interrelations. The seed consists of a plane with semantic information on growth properties and constraints from timber construction. And the auxin is constructed as a plane with semantic information about position and activeness in the system.

For this project the algorithm is set up to function within the physical nature of the specific construction system. The seed carries information about the four sided profile of the wooden building elements constraining splits and kinks to these sides, and five allowable angles derived from the timber production constraining the growth steps to (Figure 13) and (Figure 14).

RAYTRACING

Raytracing is used to calculate the position of a mirror so as to transmit a ray of light from one position in space to another. Each mirror is uniquely attached to one position of the light source which is movable. In addition, the ray-tracing is also used to test for the degree by which mirrors occlude light transmitted from each other. The ray-tracer measures to which degree the reflected light hits the target areas.

END POINT

A genetic algorithm is employed to generate and iterate on candidate solutions from the process. That is, a population of different structures is created. Multiple objectives are provided that represent the overarching aims for the construction system (minimal amount of kinks and wood used) and the reflective system (light hits targets). By the end of the optimization process the designer is supplied with a collection of acceptable and producible solutions from which to choose the final design, thus supplying the designer with the final agency in deciding the final expression of the structure, while making sure that it complies with the quantitative objectives set up for the system. Information flows within the process are described in (Figure 15).
DISCUSSION AND CONCLUSION

The projects Transmissive Assemblies and Reflective Growth implement an event-based modeling methodology for generative and performance-oriented design. While drawing on conceptualizations and implementations outside the architectural domain, our approach has been developed within standard architectural software. Partly, this relates to the complex three-dimensional geometries developed in the projects, and partly to the growing capacity for architectural software to host many different simulation tools. The approach aims to increase the agency of the model by distributing description and decision-making.

In Reflective Growth, decisions are taken at one level, whereas decisions are taken at three levels in Transmissive Assemblies. However, it is a battle to escape from inbuilt linear assumptions which complicate the non-linear exchanges that the use of discrete event simulation, as a framework for a digital design system, allows access to. We find that the linearity within the systems is strongly dependent on the types of generative models employed, and that those that are able to continuously adapt to change in the environment, such as the agent-based models used in Transmissive Assemblies, are seemingly better at supporting an event-based simulation system.

Both projects demonstrate that event-based modeling methodologies provide a viable means to allocate design agency to models. This is increasingly necessary in order to handle the growing complexity of the architectural design domain, where the development and communication of design intent and information can no longer be assumed a linear process. It is particularly in the pursuit of reflexive or reactive methods, and multiple interdependent optimizations, that an event-based approach seems most suited. In this context, as well as affording novel opportunities for design, these models offer a method for overcoming the rigidity and overly deterministic behavior of our present models.
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NOTES
2. http://www.food4rhino.com/project/octopus developed by Robert Vierlinger in cooperation with Christoph Zimmel, karamba3d.com and Bollinger Grohmann Schneider ZT GmbH Vienna.

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