Parametric Sankey: Interactive Mapping of Complex Material Flows for Urban and Architectural Design

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Abstract. The mapping of flows in a city is essential for understanding urban systems and enabling the transition of the city into a circular economy. However, while tools for the virtual representations of physical *volumes* and *spaces* in urban environments have proliferated, effective tools for modeling the underlying *flows* are still missing. This paper discusses the development of Parametric Sankey, a tool for the trans-scalar representation of flows, and demonstrates its instrumentation in a research design process. The proposed Parametric Sankey tool overlays different flow categories (material, energy, labor, customer, waste, etc.) into one dynamic trans-scalar system, enabling interactive processes between analysis and intervention, and providing thereby an experimental interface to envision future circular cities and architectures.

Keywords: Parametric Sankey · Material flows · Trans-scalar · Circular cities · Grasshopper

1 Architecture of Flows

The circular economy promises to change how society produces goods, how they are procured and delivered, and how waste is collected and re-entered into the value chain. Flows are fundamental aspects of the circular economy that are both spatial and temporal, yet the interaction between flows and space, in which the seamless organization of flows that plays primary roles in defining the situation of the site, are often left unexamined (Holmes et al. 2021; Korhonen et al. 2018; Hesse 2010). In this research, we examine architecture's and the city's role in developing a circular economy through the lens of flows.

A proper understanding of flows is the key to the comprehensive use of resources toward circular processes, which demand the application of systems thinking (Chen 2009). Material flow analysis (MFA) is a central methodology for quantifying the aggregate resources used, reused, and lost (Graedel 2019). Visualization plays an essential role in comprehending the pattern of material flows, allowing detailed analysis and refinement of the intervention (Iacovidou et al. 2017). Sankey diagrams are the most common representation strategy to visualize the results, showing the interlinkages in

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systems while retaining the holistic display of their complexity (Schmidt 2008). The representation is numerical and diagrammatic, allowing simultaneous qualitative and quantitative observations.

There were attempts in architecture and urban design to represent and incorporate flows in the design processes concerning flows of people, information, and urban transport (Ballantyne and Smith 2012; Delalex 2006). One example is Louis Kahn's study of Philadelphia, where he visualizes the movement of cars to propose a new traffic pattern to untangle congestion (Kahn 1952). Several strategies have been developed to map pedestrian, private, and public transport flows on an urban scale (Dovey and Ristic 2017). The notion of flows is closely correlated with the performative aspects of architecture, where the formal and material configurations will dictate and be shaped by how the building's heat, energy, water, and wind flow (Cody 2017). Flows of people are also studied as the objective is to improve building safety and optimize the architectural experience (Derix 2014; Schaumann et al. 2019).

The interface between flows and architecture/urban context can be conceptualized as a 'space of flows,' where the 'purposeful, repetitive, programmable sequences of exchange and interaction between different physically disjointed positions' are happening (Castells 2010, p. 442). The flows, while dynamic, have inherent predictability and manifest as the city's infrastructures, networks, and architecture (Mangelsdorf 2013; Weinstock 2013). To understand the city's multi-scalar interactions with flows, we re-contextualize the Sankey diagram, a scientific representation of flows, into a parametric modeling environment in an urban and architectural context. By finding the intersection between architecture, urbanism, and environmental science, this paper showcases the development of Parametric Sankey tools for addressing different flows in a design process and demonstrates its instrumentation in a research design studio. The Parametric Sankey tool aims to understand flows in the urban and architectural context and identify potential interventions contributing to the transition to a circular economy.

2 Parametric Sankey for Mapping Complex Flows

Our research explores how flows can be represented interactively in different scales and situations, from pure diagrammatic processes to urban and architectural scales. We investigate the mapping and intervention of flows using a unified parametric Sankey tool in Grasshopper to facilitate trans-scalar flow analysis and development. Parametric modeling allows interactive exploration by establishing the association between sets of different parameters in which the changes of the parameters will reflect on the reconfiguration of the model outcome (Oxman 2017). This paper discusses the development of Parametric Sankey for addressing different flows in a design process and demonstrates its instrumentation in a research design studio. Figure 1 shows the proposed methods for the Parametric Sankey, which includes (a) collecting data to understand the processes of material transformation, (b) interactive flow modeling with different nodes of identified processes, (c) contextualization of flows in the neighborhood, and (d) architecturalization of flows in the building.

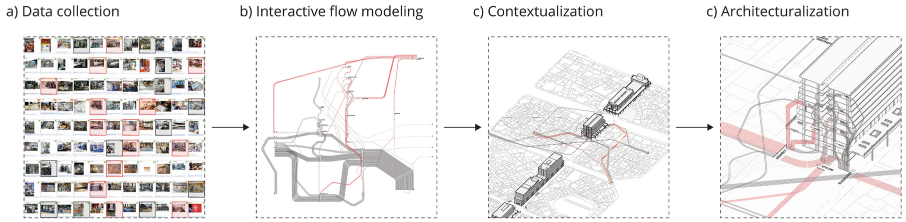

Fig. 1. Parametric Sankey, the proposed method for flow-driven urban and architectural design.

2.1 Case Study: Mapping Sewoon Sangga Flows

We use Sewoon Sangga as the case study to demonstrate the application of the interactive Sankey flow mapping tools in the design process. The objective was to examine how the Sewoon Sangga building complex, a 1 km long brutalist architectural relic of the 1960s in Seoul, could be revitalized and act as a catalyst for the transitioning of the surrounding district into an exemplary circular economy through the understanding of dynamic flows. This urban manufacturing and distributing neighborhood became the platform for understanding the current ecosystem and investigating the potential of Sewoon Sangga to participate in imagined circular manufacturing processes as a program for architectural interventions.

Over time, a bottom-up culture has emerged in this mixed-use commercial and residential complex, with artisans and entrepreneurs appropriating the megastructure. The uniqueness of Sewoon Sangga has been in creating an urban ecosystem with the Euljiro neighborhood that merges the manufacturing, material distribution, product, and repair culture. The diverse range of small scaled artisans with various skills and shop owners co-exist in cooperation along the organic alleyways as an urban structure to create specialized clusters such as printing, publishing, metalworking, tool manufacturing, jewelry making, electronics, precision machinery, and more (Baeumler 2016). The character of Sewoon Sangga and Euljiro is rapidly changing, and the injection of new capital is in the process to transform the city.

The mapping is started by investigating different materials flowing in and out of the market, from plastics, garments, plants, foods, electronics, and all of the derivatives. From these observations, preliminary material flows were created based on MFA principles by representing processes as collections of nodes where the flows of different materials pass through the process as the material turns into products and waste (Graedel 2019). The collected data identified the multiplicity of flows involving the flow of materials, waste, and energy (Fig. 2).

The identified processes provided a baseline for modeling the Parametric Sankey in which the interactivity between these processes could be explored and intervened. The parametric flows are juxtaposed with the existing system through a trans-scalar approach from processes, cities, and architecture towards a circular design.

2.2 Parametric Sankey Tool

The Parametric Sankey tool represents flows as a collection of nodes as processes and directed edges as material flows. We developed Grasshopper components to allow the

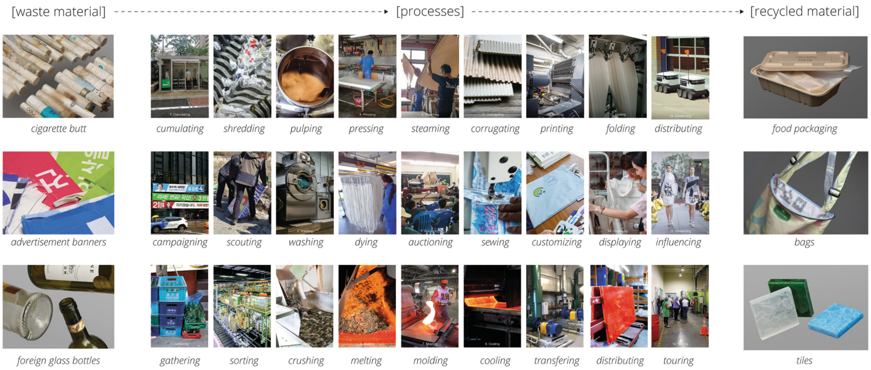

Fig. 2. Investigation examines the processes of waste's material transformation into new products.

parametric modeling of flows using input, output, and loop components (Fig. 3a). The input component receives information about the flow from the output component and draws the visualization flows in Rhino's model space. The flows are parameterized by flow properties such as name, volume, and color and geometrical properties such as node's location, direction, and working plane. A utility component facilitates feedback loops since Grasshopper does not support a recursive data stream. The developed components are designed to work in 2D and 3D modes using single or multiple working planes, allowing the multidimensional adaptation of parametric Sankey.

A process is represented by a node, defined by a cluster consisting of multiple input components and an output component (Fig. 3b). Multiple input flows are handled by cascading input components which accumulate the information to the output component. The output component receives parameters to define the distribution of flows to different channels. The flow is created and managed by connecting the node's output with the other node's input and defining the channel and distribution parameters (Fig. 3c). The looping flow information is fed back to the previous node using the loop component. The parametric model allows us to interactively explore different distributive and connectivity patterns through Rhino's modeling space (Fig. 3d). The modeling of the flows should follow the law of conservation of matter (Brunner and Rechberger 2004). The process node represents the transformation of materials from the input to the output. The processes are linked by flows that are measured in mass per time. The used units depend on the spatial and temporal scale of the described system, tons per year are commonly used in practice.

3 Results: Trans-Scalar Flows

We model the flows in diagrammatic, urban and architectural scale in the design process. The modalities of Parametric Sankey for each representational mode are described below.

3.1 Flows as Interactive Diagrams

The Parametric Sankey overlays different materials and waste flow with other resource flows, such as energy, heat, and water (Fig. 4). The diagram is composed of processes

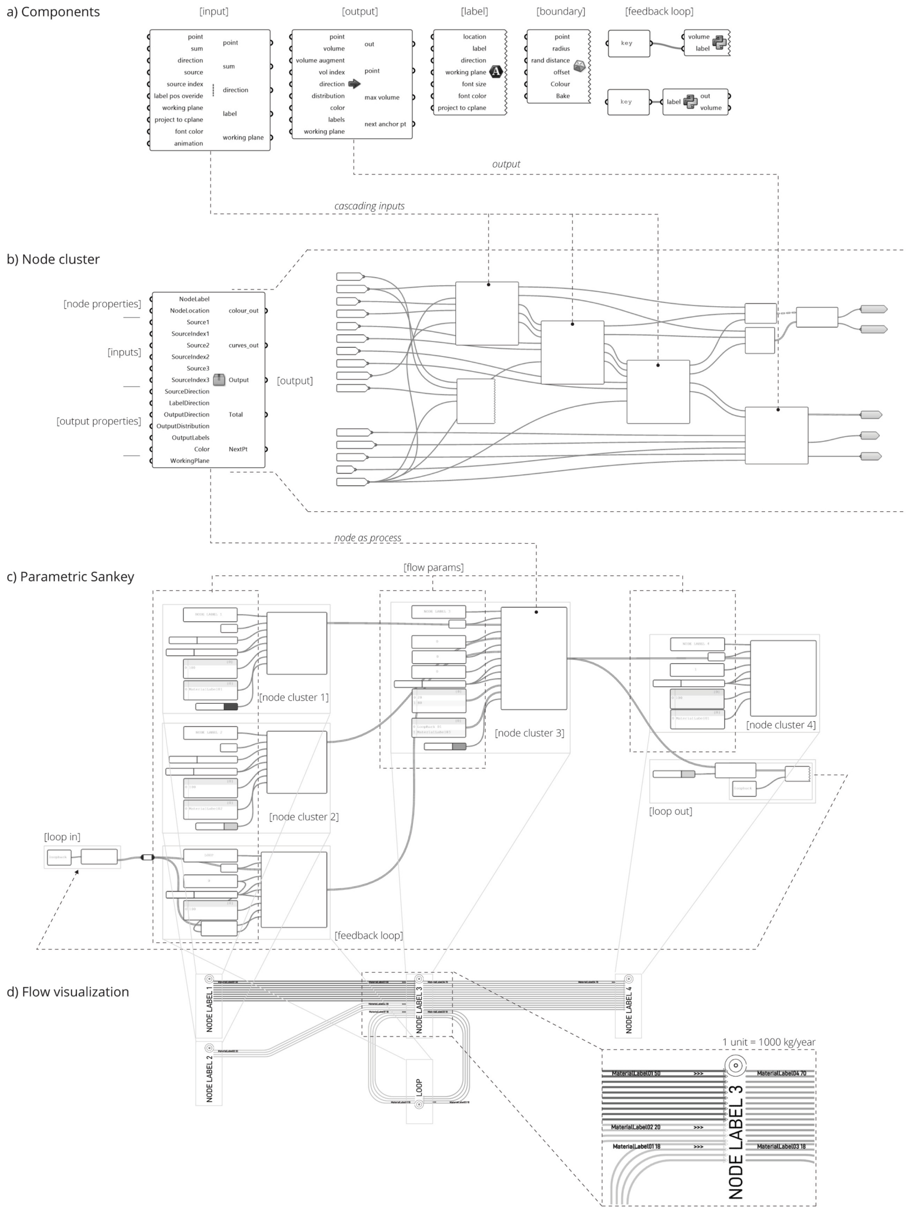

Fig. 3. Parametric Sankey component diagrams.

as nodes that transform the materials from one to another, as directed edges represent the flows. The color represents the layering, differentiation, or categorization of flows. The edges' size and color gradients reflect the flow's quantitative dimension. The node's position and the flow direction are reconfigurable, allowing the different formal configurations of flows to be explored, thus offering a way to disentangle complex flow into different typologies, such as merging, splitting, looping, and overlaying. Some nodes serve in a specific line of flow, whereas some nodes combine and intersect different flows altogether.

In architecture, one of the utilities of the diagram is to anticipate new organization possibilities (Allen 1998). Parametric Sankey allows architectural thinking to map complex material flows and explore the spatial relationship. The 2-dimensional constellation of distributed nodes gives an anti-hierarchical relationship in the material processes, decoupled from the physical manufacturing or logistical spaces. The resulting map visualizes the relative proportion of the flow. Any additions or modifications to the current flows will cause changes in the subsequent flows. It enables an intuitive understanding of the complex flows and interactive processes between analysis and intervention, providing experimental ground to envision a circular system. The parametric diagram recalls the idea of diagrams as proliferation instead of reductive machines (van Berkel and Bos 1998), departing from the conventional use of the Sankey diagrams as static representational tools.

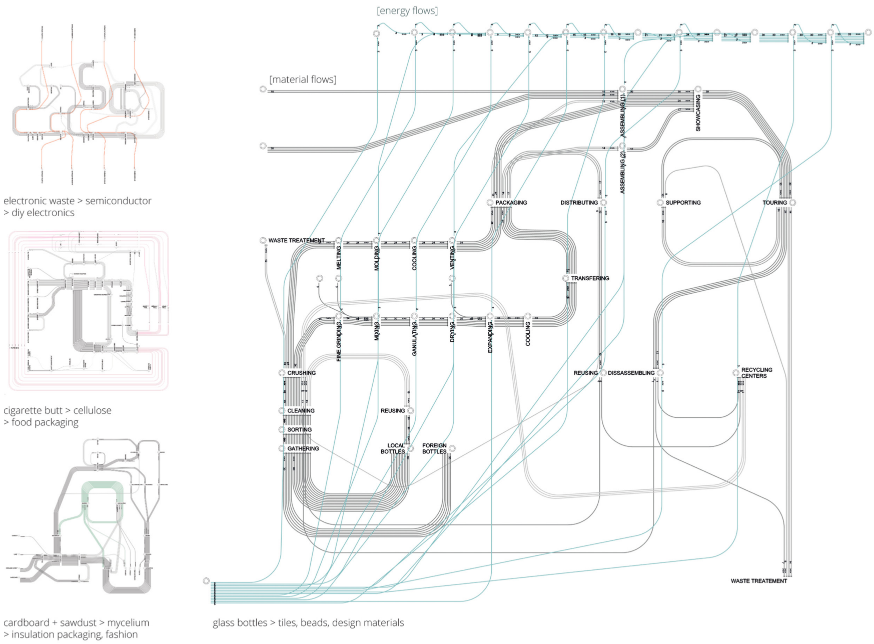

Fig. 4. Parametric Sankey from the various material processes shows flows' layering, branching, merging, and looping. Work by Auguste Pachoud, Alexandros Trivizas, Mikaël Rey, Lorenzo Simontacchi, Anna Hausel, Isabelle Nguyen, Amélie Gaillet and Laura Guerreiro.

3.2 Flows as Urban Assemblages

Incorporating Parametric Sankey into an urban environment proposes an alternative view of urbanism as it favors the representation of behavior, situation, and interrelation over areas, locations, and territory (Batty and Cheshire 2011; Hesse 2010). The tool makes the analyzed processes tangible by depicting the city as a collection of flows where the places, buildings, and neighborhoods are the emergent of the productive processes (Dovey et al. 2017). The abstract processes are given spatial and material realities, giving a different reading to the overall flows. Sometimes, one process is distributed to different sites, and the logic of geographical proximity is now taking part. The resulting maps show the capacity of the Sewoon Sangga as a catalyst of a circular economy where waste and recycled materials are sourced and distributed around the neighborhood (Fig. 5). The flows show the interconnectivity between different places concerning a particular process and situate Sewoon Sangga as a strategic structure for future transformation.

Fig. 5. Parametric Sankey recontextualizes flows in the urban fabric. Work by Auguste Pachoud, Alexandros Trivizas, Flavio Nogueira Pereira, Bryan Marques Soares, Lucile Charamel, Léa Guillotin, Ilayda Makas and Ecenaz Ozkorkut.

3.3 Flows as Architecture

The urban flows are folded from the ground to the section plane of the building, engaging the flow entering and exiting the building, connecting the flow from the larger urban context to the architectural scale (Fig. 6). Representing flow in architecture brings forward the capacity of diagrams as 'contingent descriptions of possible formal configurations' (Allen 1998, p. 16), showcasing the dialogue between architecture and the other fields. The parametric Sankey graft the flows into the building's spatial realities, mapping the tensions and possible design interventions. The interactive framework allows the exploration of different configurations while maintaining the topological connectivity of the flows.

The interface between building typology and the flow's topology manifests into various architectural apparatus such as corridors, stairs, elevators, ramps, shafts, and chimneys, reconfiguring and revitalizing the obsolete typology. The flows challenge the existing condition of the Sewoon Sangga building. The transformative vertical of Sewoon Sangga into an automated-populated circular manufacturing and distribution results from careful spatial surgery of the building sections informed by the flows of waste, material, people, and other resources. These sectional interventions result from the architectural thickening of the flows to create formal acupuncture within the building.

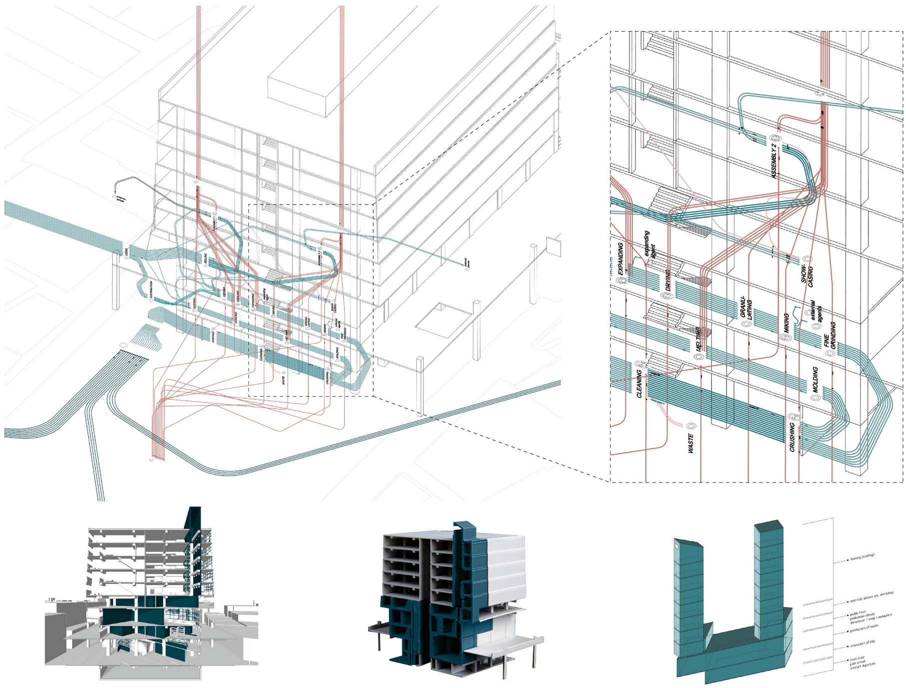

Fig. 6. The architecturalization of parametric Sankey into building section. Work by Amélie Gaillet and Laura Guerreiro.

4 Discussion and Future Developments

We developed a parametric modeling framework that allows the trans-scalar representation of flows. Flow diagrams can be intuitively developed and explored. Using case studies, we tested the capacity and limit of the tool and critically explored the potential future development to address circular cities. The interactive diagram allows the flows to be spatialized to make sense and reconfigure their pattern. The recontextualization of flows into urban fabric enables the reading of site interrelation, revealing the potential new nodes for circular processes. The architecturalization of flows confronts the obsolete typology with the need for new dynamics, which drives the reprogramming and revitalization of the building.

Parametric Sankey situates itself in the intersection of material flow analysis, urbanism, and architecture as an attempt to incorporate circular principles into design processes. By observing, analyzing, conceptualizing, and constructing with the flows through parametric Sankey diagrams, we better understand the city as a dynamic state in contrast to the static typological views. The flows are actively engaged in the architectural representational system as interactive diagrams in either abstract, urban, or architectural contexts. The tool lets the designer actively study, experiment, and discover various patterns of flow as sites of potential new relations and architectural inventions. The flows are represented as spatial and topological entities with which the architecture and urban design can engage. As a result, we get a unique perspective of investigating the urban manufacturing district in Seoul through the lens of material and energy flows from a linear to a circular economy. The formalization of these flows helps the conceptualization of the preliminary design stage.

Our framework is still in the early stage of development, which opens the diverging path of improvement to further explore its potential for architectural translation (Fig. 7). One possible future development is incorporating a parametric optimization process in the workflow by coupling the Parametric Sankey to particular objectives. For example, specific flows could be optimized to achieve different degrees of proximity with the other flows by strategically placing and orienting the nodes within the solution space. The current tool still uses explicitly defined parameters to model the flows, requiring manual iterative reconfigurations. An exciting direction to tackle this is incorporating graph-based modeling into the framework, where the flows can be formulated as an adaptive system reacting to certain conditions. Moreover, the current system can only represent flows on a specific static temporal scale. Further development is needed to represent the rich temporal aspects of flows.

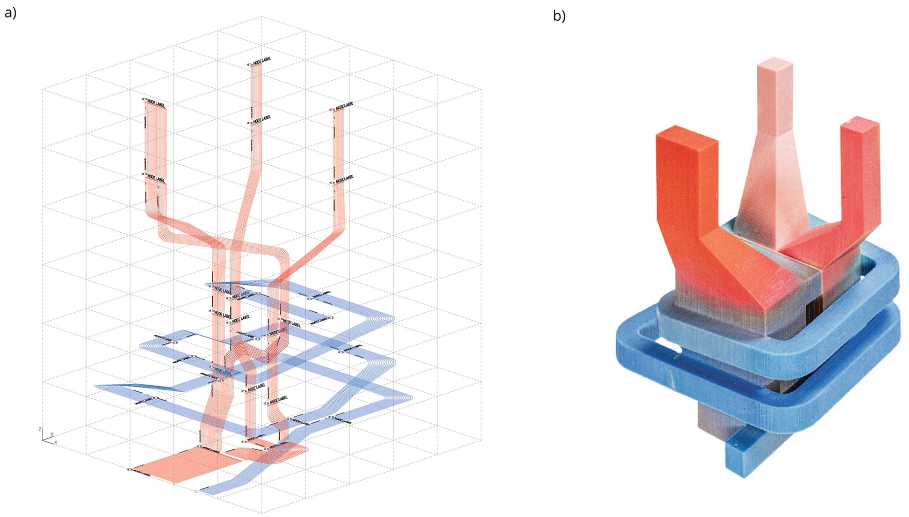

Fig. 7. 3D Parametric Sankey in multiple working planes creates spatial 3d flows (**a**), and the volumeterized flows are printed with ColorJet Printing (**b**).

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