Urban Mining: Visualizing the Availability of Construction Materials for Re-Use in Future Cities

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Abstract

This paper presents a method and case study to visualize the urban stock of materials and its availability for use in building future cities.

Re-using material from existing buildings for new buildings can be seen as a source for construction materials in times of depleting natural resources. The authors explain the concept of "urban mining" and the challenges, such as "How much resources are available in a city? Today? In the near future?" We explore what data is needed to answer the questions, and then discuss how to best visualize the data in an effective and intuitive way. We apply the concept to an exemplary real-world district in Singapore that is in transformation. Then, we discuss features of a visual tool prototype and explain the thinking behind the design, e.g., how the spatial and temporal dimensions can be presented. Lastly, we conclude the paper with an outlook of future challenges.

The paper presents a multi-disciplinary approach with researchers from computer science, architecture, graphic design and material science, and contributes to the discussion of how to visualize knowledge and plan sustainable future cities.

Keywords--- **Urban Mining, Visual Analytics, Knowledge Visualization, Information Visualization, Future Cities, Sustainable Cities**.

1. Introduction

Over the past decades, the rise of Information Visualization has produced a diverse range of exploratory tools that make use of dynamic and highly interactive visual environments. They enable a domain expert to investigate, try out scenarios and search the information and visual space to generate better implement and develop a better understanding of the underlying information. We deliberately use the word domain expert since we found out that most tools were not designed for users lacking the domain expertise.

Therefore, we aim at starting from the view of a real need and a societal challenge and add the visualization to the problem. The starting point is the need of today's cities for material to meet the expected future growth: stone, sand, steel and many more limited resources. In the age of fast growing cities, the need for resources is a challenge for environment, society and cities. At the same time cities are in a constant transformation. Buildings are constantly being renovated, retrofitted, replaced or rebuilt. A logical result is that a lot of materials become available for a second or third use—a paradigm shift for the building industry introduced by Hebel et al. [1]. A building or city can therefore also be seen as a "mine of resources for future buildings and built structures", we use the term "urban mine" for that. The question will then be on how large such an urban mine actually is, in other words, which resources would be available in which quantities and when.

This paper conceptually looks first at a location to test this question and we have identified Singapore as the place for this study. We then look into identifying the relevant data and have chosen a particular city district where a large transformation will soon happen. This allows us to identify data and to discuss in an interdisciplinary team on what should be visualized. This contextualization aims at addressing concrete challenge and opportunity.

Having identified the relevant data, we then look at the relevant literature and methods to visualize spatial and temporal data for the above-mentioned purposes, to make the urban mine visually understandable, measurable and quantifiable over time. We then put together the best methods to build on previous research.

We then sketch, design and implement the tool as a software prototype and add our collected data to a first mock-up version for discussion. Our prototype is meant for visualization experts and planners who are researching in the area of knowledge visualization and exploratory data analysis, such that to lead to a discussion of applying state-of-the-art concepts to a great current and future opportunities in creating more sustainable future cities.

2. Case Study

This section explains the site of where we collect the data, which will then be visualized in the tool.

2.1. Country: Singapore

Singapore is an island with very small territory and even more limited natural material resources. The contributions of material and energy flow accounting to urban ecosystems analysis for Singapore have been studied by Schulz [2]. Almost all construction materials have been imported over the past decades. Sand and other mineral materials play a particular role as these are also used for land reclamation [3]. The sheer quantity of imports has, in the past, even lead to diplomatic problems and export-bans from neighboring countries. This calls for innovative up-cycling approaches of existing materials as demonstrated by Hebel and von Richthofen [4] with respects to sand alternatives derived from reclaimed construction materials.

Over the last fifty years, fueled by rapid economic and demographic growth following fast urbanization Singapore has accumulated a significant stock of material bound in the present buildings and structures of the city. Many of these edifices already reached their half-life time and many more will in the near future. This will either require substantial renovation or demolition. Both processes will unlock the material stock. Presently, 99% of this construction and demolition debris is used for land-reclamation in Singapore. Once the debris has been dumped in the ocean, contamination with water and other refuse may make it unsuitable for future use as construction material. While this is called “recycling” of building debris, it is in fact a non-recoverable “down-cycling” of material that could be used as for new buildings instead.

2.2. Site: Jalan Besar

We have chosen the site Jalan Besar north of the central business district of Singapore. This site features a good range of building types and building ages starting from pre-independence heritage buildings (1965 and before) throughout all decades of the late 20th century as well as contemporary building. The site features three generations of so called Housing Development Board (HDB) estates from the 1970s, 80s and 90s. These massive housing blocks are often redeveloped *en block* into residential units and condominiums of higher standard. The site also contains larger multi-story shopping malls, some of which will be renovated soon. The site is therefore representative of the many parts of Singapore that undergo rapid urban renewal.

3. Data Collection

This section describes the challenges and method related to identify the data, that is needed and can be obtained to achieve the goal of how to visualize the urban building stock of a city district or whole city.

3.1 Challenges

A major challenge for re-using building debris is knowing the quality, quantity and temporal availability of demolition material. Such databases do currently not exist. Since storage and logistics around demolition sites is a cost driving factor the current practice is to simply dispose of the problem and not to collect, store and reuse the material. On the other side the demand for building materials is constantly rising and the prices justify a close examination of where, when and how much material will be available.

Since 2015 Singapore requires Building Information Modelling (BIM) which includes detailed information on the materials used in a building, see [5]. BIM databases are oriented towards the future. Unfortunately, the existing building stock has not been quantified yet for Singapore. Furthermore, a complete BIM set of a building contains vast amounts of detailed data that can be helpful, but is not necessarily needed to estimate material stock at urban scale. Comparison, harmonisation and aggregation of different BIM dataset pose an additional problem which is why we decided to propose our own data structure. This simple data structure can, in return be used for future BIM datasets.

3.2 Approach

The building materials used in particular building types and for particular building periods are well researched. This brought us to our indirect approach to answer this question of quantifying the building stock before 2015. Thoma et al. [6] identified the building periods and building types for Zurich, Switzerland to derive material composition and energy transmission factors. The same classification was applied to Singapore by linking the knowledge from building history research to these types to achieve a first approximation.

Let us illustrate this with an example: A Singapore shop-house for example was typically made of bricks and wood as it was built in colonial times without the use of modern building technology, while the residential housing blocks HDBs from 1960–80 were made of reinforced concrete and bricks, and later HDBs were made of reinforced concrete alone [7]. Since building technology, typology and material evolved together it is possible to correlate them.

This approach seemed a workable approximation for the missing data, which is needed to visualize the “urban mine” of our research site.

3.3 Data Collection

The existing building stock has already been modelled with 3D shapes giving the building footprint, volume and envelope. These basic building geometries allow to establish more precise material volumes for floors, facades and roofs which are different from the sheer volume of a building envelope. Each building is then visually inspected on the ground and categorised according to the building type and approximate building age. This allows to infer material composition (concrete, steel, glass, bricks and wood) and material life-span based on comparison with representative contemporary buildings studied in Singapore. Building geometry and material composition are then stored in a database.

4. Visualization Tool: Prototype

This section describes our prototype to visualize the urban building stock of a city district or whole city. We find that this problem calls for utilizing different views of the same data, so the user understands the information from different perspectives. To facilitate multi-perspective investigation and exploration, we consider a tight coupling of views important.

4.1 Structuring the data

We first structure the data of buildings into two categories: building geometry and material attributes. The geometry of a building is represented in *.obj* format, where the shape and position are stored. The attributes of a building consist of building volume, year of construction, estimated material composition (concrete, steel, glass, bricks and wood) and material life-span. The geometry and attributes of buildings are stored in a database, and linked with unique building IDs.

4.2 Functionalities

From discussions with domain experts, we collected the following functional requirements for the tool:

- Present the year of construction
- Present an approximation of material composition
- Show it in three-dimensions
- Visualize the time aspect on the availability of the material
- Color-coded building map based on the parameters above (quantity, ripeness and composition). Finally, determined half-life and full-life times of buildings (in ranges of forty to eighty years) will demonstrate the availability of material at a given time in the future.
- Invent a “temporal pyramid” of aging building material stocks. This pyramid could be as detailed as the underlying data (e.g. the more materials entered, the more detailed the pyramid).

We then extended the requirements of this tool to include state-of-the-art researches in information and knowledge visualization:

- Multiple view techniques
- Data transformation for exploratory visualization
- Coordinated views, tight coupling and linked views
- Exploratory visualization methods, tools and algorithms
- User-centered design
- Aesthetic and appealing user interface

4.3 Related Literature

In scientific literature, we find various frameworks and taxonomies to conceptualize the problem that are developed by proponents related to Information Visualization. Their main interest is to classify visualization methods in the field of information visualization. The research is known to the reader in this conference and topics that we studied were tasked by data type taxonomy of information visualization with seven data types (one-, two-, three-dimensional data, temporal and multi-dimensional data, and tree and network data) and seven tasks (overview, zoom, filter, details-on-demand, relate, history and extracts) [8]. We find that the Information Visualization angle is not sufficient and extended it for our discussion with research in the field of Knowledge Visualization which was introduced by Burkhard [9], and Eppler and Burkhard [10, 11]. They added the idea of knowledge management and communication with the audience as well as the inclusion of a framework of seven visualization types: Sketch, Diagram, Image, Map, Object, Interactive Visualization and Stories.

In order to design the best possible interface we have looked at works from Information Architecture and Information Design such as the works from Tufte [12, 13, 14] and Bertin [15], cornerstones in the documentation of the history of information design, both concentrate more on printed media. In contrast, information architects focus more on digital technologies [16, 17]. Tufte pointed to the limitations of displaying complex information on digital screens. As a consequence, Tufte offered only few strategies and examples for exploiting novel digital technologies to make information clearer. This is not solely but still the territory of information architects and information visualization researchers, but also increasingly for researchers from architecture. Halatsch [18] discussed how planning of urban systems can be supported by combining dynamic, complimentary visualization software.

Specifically, visualization systems have shown the efficiencies in assisting transportation researchers to develop data-driven intelligent transportation systems, where a structured survey can be found in [19]. In Singapore, Zeng et al. have developed various visualization works to study public transportation system (PTS), including the PTS mobility [20], waypoints-constrained origin-destination [21] and PTS movements relationship with social media usage [22]. Besides, Singapore A*STAR has developed an interactive visualization system to detect home and work places [23].

In conclusion, there is a lot of related research; yet a publication that proposes a concept for exactly our task was not found by us.

4.4 Design Mockup

Figure 1 shows the prototype featuring one city district in Singapore: Jalan Besar. As shown in Figure 1, the user interface (UI) contains two major views: 3D visualization of building ages of the district and a horizontal dashboard for analyzing material supply and demand. The dashboard is divided into three units: the first left one shows the legends to building ages and materials, the second one indicates the geographical location of the area and the third one functions as a material explorer that allows users to gain ideas of future supply and demand for each material. This UI is made for full size HD display (1920×1080).

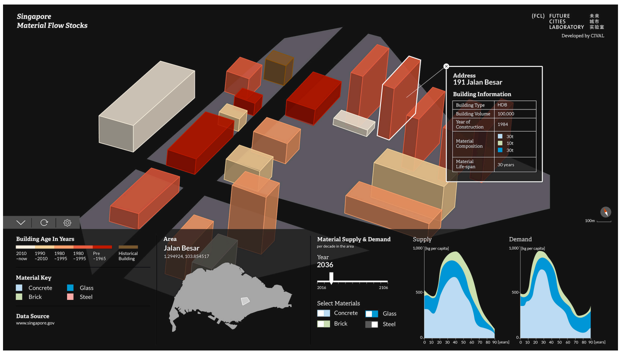

Figure 1: Visual prototype of the UI—3D building visualization and an overlay dashboard

4.5 Implementation

Our system is implemented entirely in Java. Currently, the system is tested on an Intel Core i7 2 2.8 GHz MacBook Pro with 16 GB memory and an AMD Radeon R9 M370X graphics board.

It is always a challenge to develop a vivid visualization system that supports interactive exploration for a complex dataset. In this work, the data to be explored can be categorized into spatial (building positions), temporal (material life-span) and multi-dimensional (material types). To address these challenges, we build our system on an open-source 3D rendering framework, namely ether[1], and implement a family of user interactions, including map navigation, direct selection of buildings, and filtering buildings in an area. The system achieves interactive frame rates with over 60 fps to support interactive data exploration.

4.6 Discussion

The following part will highlight specific design decisions.

[1] https://github.com/arisona/ether

4.6.1. The UI is divided into one large background image and an overlay dashboard with three units for multiple views. The dashboard can be closed with an arrow. This UI was also tested on large visual displays such as the Value Lab as proposed in [18].

4.6.2. The Colors The challenge for color mapping is how to best indicate building ages and simultaneously illustrate the materials. Here the best combination is achieved through user tests with students and non-experts who give their preferences in the design iterations.

Two color mapping schemes are employed in the system, see Figure 2. First, a multi-hued sequential scheme with warm yet distinct colors is chosen to best show the ages of buildings in years. Specifically, a dark brown color is separated from the sequential scheme for indicating historical buildings where materials cannot be recycled. Second, a qualitative scheme with light colors is chosen to best show the building material types.

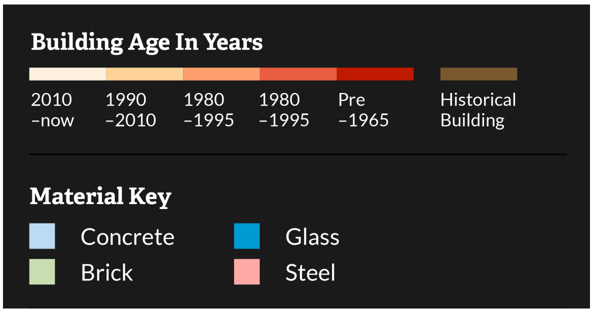

Figure 2: Colors for building ages and materials

4.6.3. Spatial Correlation To indicate the exact site location, we extract the essence of the area and plot it on a map of Singapore as in Figure 3. We anticipate multiple sites will be integrated in the system in the near future. Hence, a visual correlation for spatial information is important for facilitating the exploration process.

Figure 3: Spatial correlation—the chosen area is highlighted.

4.6.4. Temporal pyramid of materials The central piece to analyze the urban mine can be found in Figure 4. This unit adds a time slider to dynamically browse through the data on material supply and demand in an urban area. It also includes four toggles to filter data, by showing or hiding materials, such as concrete, bricks, glass and steel. Finally, the information is organized in a ThemeRiver style [24], which advances the typical bar chart as it is able to show continuous changes over time.

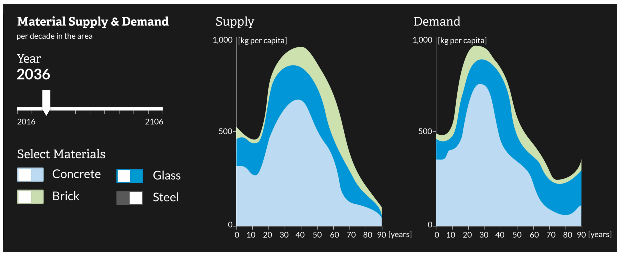

Figure 4: Material explorer—the two graphs show material supply and demand and they correspond to the time slider.

4.6.5. Details on buildings become visible as a pop-up text box once a user selects a building as can be seen in Figure 5. The text box shows an address of a building and its information including building type, building volume, a year of construction, material composition and material life-span.

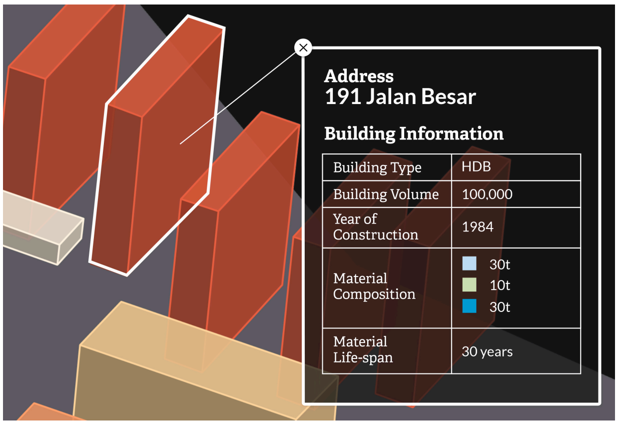

Figure 5: Building detail—this is shown as a pop-up text box.

5. Challenges

The first challenge is scalability. How does such a model scale up for a whole city? In our example to do it for the whole of Singapore.

The second challenge will be to link our method to available digital 3D models of cities. Software companies and cities currently develop 3D models of their cities. Some are derived from aerial images or LIDAR data, some are generated from digital 3D models and the question will be how to link the knowledge of the typologies and building year to a trustable source of information to automate the generation of such models.

The third challenge will be the visualization of material flow analysis (MFA) and scenarios that could underline policies on material economies—in our context for Singapore. A possible scenario could be to compile the vast number of HDBs reaching a half-life time (for instance thirty years = renovation) and a full-life time (sixty years = demolition) in material quantities and to compare this volume to the future need of construction materials.

The forth challenge of course is related to the proposed direction of using an urban mine as source for future buildings and the societal and economic/industrial implementation of the paradigm shift from building a house with new material towards building a house from re-used material resources.

Conclusion

This paper presents a method and case study to visualize the urban stock of materials for building future cities. Urban Mining is introduced as a way of re-using material from existing buildings for new buildings in times of depleting natural resources. A prototype is developed based on collected data of a site in Singapore and eminent features are discussed. Finally, the paper presents different challenges to build on this research, which inspire the community to take this direction as a focus for studies by others.

The paper presents a multi-disciplinary approach and case study with authors from computer science, architecture, graphic design, communication, finance, urban development and material research and contributes to the current discussion of how to visualize knowledge and plan sustainable future cities.

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