Constructability of districts: capabilities of productivity and logistics big data for machine learning prediction

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2019-09-19
AIM OF THIS STUDY

Devise a conceptual framework for the exploitation of district development big data (esp. quantitative + qualitative productivity-related indicators, and elements related to construction logistics + supply chain), in order to build a machine learning model as a decision-making and action-taking helper for high-level construction management within the new contextual framework of district constructability.
CONSTRUCTION MANAGEMENT

Time of delivery

Cost of deliverable

Quality of deliverable
CONSTRUCTION MANAGEMENT

- Time of delivery
- Cost of deliverable
- Quality of deliverable
DATA USE FOR CONSTRUCTION MANAGEMENT IN WHOLE DISTRICT DEVELOPMENT

• Aiding and enhancing construction managers’ decision-making and action-taking on project performance assessment

• Also important during large-scale construction activities within whole districts → big data obtained mainly associated to productivity (e.g. productivity rates), and construction logistics and supply chain

• Such data can be exploited by machine learning (ML): development of a ML system that predicts the performance of whole district development
CONSTRUCTION INFORMATICS (Turk, 2006)

Among others...

Data mining
Machine learning (ML)
Building Information Models (BIM)

Supervised (SML)
Unsupervised (UML)
Hybrid (HML)
CONTEXT: DISTRICT CONSTRUCTABILITY

- Constructability: “The optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives” (CII, 1986)

- Implemented through project initiation, execution, and delivery

- Important constructability aspects:
  - Holistic view on logistics (e.g. supply chain integration, on-site resources flow management, close actor cooperation)
  - Optimization of project lifecycle productivity (esp. on-site operations)

- District level: overall performance of construction activities can be appraised in terms of optimized productivity and smooth logistics operations
CONTEXT: DISTRICT CONSTRUCTABILITY

• Proposed concept: district constructability

“District constructability extends constructability from individual projects to an overall, collective metric for the facilitation of construction knowledge and experience implementation when undertaking large-scale construction activities (e.g. the erection of numerous buildings) for the development of entire districts, thus acting as a qualitative performance indicator for urban development”

• Indicators for district constructability appraisal: metrics connected to on-site district construction productivity and logistics
BIG DATA FOR DISTRICT CONSTRUCTABILITY APPRAISAL


• **Input**: relevant conditions (i.e. the performance of the project organization); then the production process takes place

• **Output**: productivity rates & logistics issues

• Productivity calculated in cost- (SEK) and work-hours/m² of total gross area

• Logistics issues qualitatively appraised with 5-point Likert scales
Identified main productivity and logistics issues:
- On-site congestion
- Challenges in material and equipment transportation due to on-site narrow spaces
- Storage bottlenecks
- Difficult cooperation of the project group regarding on-site supply chain tasks
- Disturbances in material and economic flows
- Difficulties in keeping the delivery timetable
- Limitations in the construction production and logistics preparation
- Limited available staffing for the construction works
- Non-informed selection of material and equipment suppliers
BIG DATA FOR DISTRICT CONSTRUCTABILITY APPRAISAL

• Further potential variables:
  o Production flow inventories
  o Descriptions of construction site spatial and schedule clashes
  o Number of reworks
  o Material quantity problems
  o Optimal vehicle rounds
  o District disturbances
  o Existence and proper function of buffer facilities for vehicles and goods
Exemplary independent and dependent variables for district constructability appraisal, as derived from Koch & Lundholm (2018):

<table>
<thead>
<tr>
<th>INDEPENDENT VARIABLES</th>
<th>Type</th>
<th>Example of value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity rate</td>
<td>Continuous</td>
<td>0.1 (%)</td>
</tr>
<tr>
<td>Level of project group cooperation for on-site supply chain tasks</td>
<td>Discrete multinomial</td>
<td>{1,...,5}</td>
</tr>
<tr>
<td>Flow disturbance</td>
<td>Discrete multinomial</td>
<td>{1,...,5}</td>
</tr>
<tr>
<td>On-site congestion</td>
<td>Discrete multinomial</td>
<td>{1,...,5}</td>
</tr>
<tr>
<td>Keeping of delivery timetable</td>
<td>Discrete multinomial</td>
<td>{1,...,5}</td>
</tr>
<tr>
<td>Difficulties in material and equipment transportation and storage</td>
<td>Discrete multinomial</td>
<td>{1,...,5}</td>
</tr>
<tr>
<td>Limited construction production and logistics processes preparation</td>
<td>Discrete multinomial</td>
<td>{1,...,5}</td>
</tr>
<tr>
<td>Enough workforce for optimal undertaking of construction tasks</td>
<td>Discrete multinomial</td>
<td>{1,...,5}</td>
</tr>
<tr>
<td>Informed selection of material and equipment suppliers</td>
<td>Discrete multinomial</td>
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MODELLING ASPECTS OF THE CONCEPTUAL MACHINE LEARNING FRAMEWORK

**Data collection:**
- Quantitative & qualitative construction productivity + logistics data
- Qualitative district constructability labelling

**Variable formulation:**
- Independent variables connected to productivity + logistics data → formulated via unsupervised ML and/or expert input
- Dependent variables connected to district constructability labelling

**Formulation of supervised ML system (algorithm testing, training and validation)**

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Integration of results and production of a working prototype

YES

Satisfactory observed accuracy and error metrics?

NO
SYSTEM CONCEPTUALIZATION

DATA COLLECTION  VARIABLE FORMULATION  SYSTEM FORMULATION  INTEGRATION OF RESULTS
Productivity and logistics data of a large number of developed or developing districts encompassing a large number of projects

Quantitative, e.g.:
- Site productivity rates
- Material quantity problems

Qualitative, e.g.:
- Production flow inventories
- Descriptions of construction site spatial and schedule clashes

Material and equipment transport routes and bottlenecks
- Indicators about buffer facilities

Data will reveal district constructability problems (input variables of the ML system)
- Extracted and exported into suitable file formats
- For the districts, expert input on the qualitative labelling of the district constructability metric (e.g. on a 5-point Likert scale)
• Independent variables
  o E.g. number of reworks
  o Measured through values of collected data
  o Produced through UML (e.g. vector quantization, linguistic clustering) OR qualitative techniques relying on expert input (e.g. brainstorming sessions)

• Dependent variables
  o “District constructability achievement level”
  o Discrete or continuous → used for classification or regression
• Supervised machine learning
  o Training and validation depending on data form and amount, and variables’ type and number
  o Multiple experiments with numerous SML schemes
  o E.g. support vector machines (SVM) for binominal classification
  o E.g. support vector regression (SVR) for regression
  o E.g. variations of random forest for multinomial cases
• Use of auxiliary mathematical, methodological and software tools
  o Non-negative matrix factorization for data normalization and pre-processing (steps 1-2)
  o Multi-input Analytical Hierarchy Process (AHP), for variable labelling (step 2)
  o “Kernel trick”, to aid in the non-linear function of e.g. SVM or SVR (step 3)
  o N-fold cross-validation, for simultaneous SML training and validation (step 3)
  o WEKA (step 3)
  o Surprise Scikit (steps 2-3)
  o Python (steps 2-3)
SYSTEM CONCEPTUALIZATION

• Integration as a working prototype
  o Verification of its predicting results: district constructability rating of new districts, in relation to the detected district constructability problems (related to productivity and logistics)
  • Integration through programming routines and/or GUIs (e.g. PyQt)

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CONCLUSIONS

• District development big data: mainly metrics related to on-site productivity and logistics / supply chain management

• Suitable utilization of this big data through properly contextualized ML can provide construction managers with a better overview of the district development process, enhancing informed decision-making and action-taking

• District constructability: extension of constructability from individual projects to an overall metric for facilitating construction knowledge and experience implementation in the level of districts

• Further research: access to databases and realization of Steps 1 and 2 of the conceptual framework; experimentation with various ML algorithms for the realization of Step 3
THANK YOU FOR YOUR ATTENTION!

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