CHALMERS & ARISTOTLE UNIVERSITY OF THESSALONIKI

Northumbria University NEWCASTLE

36th CIB W78 2019 Conference

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

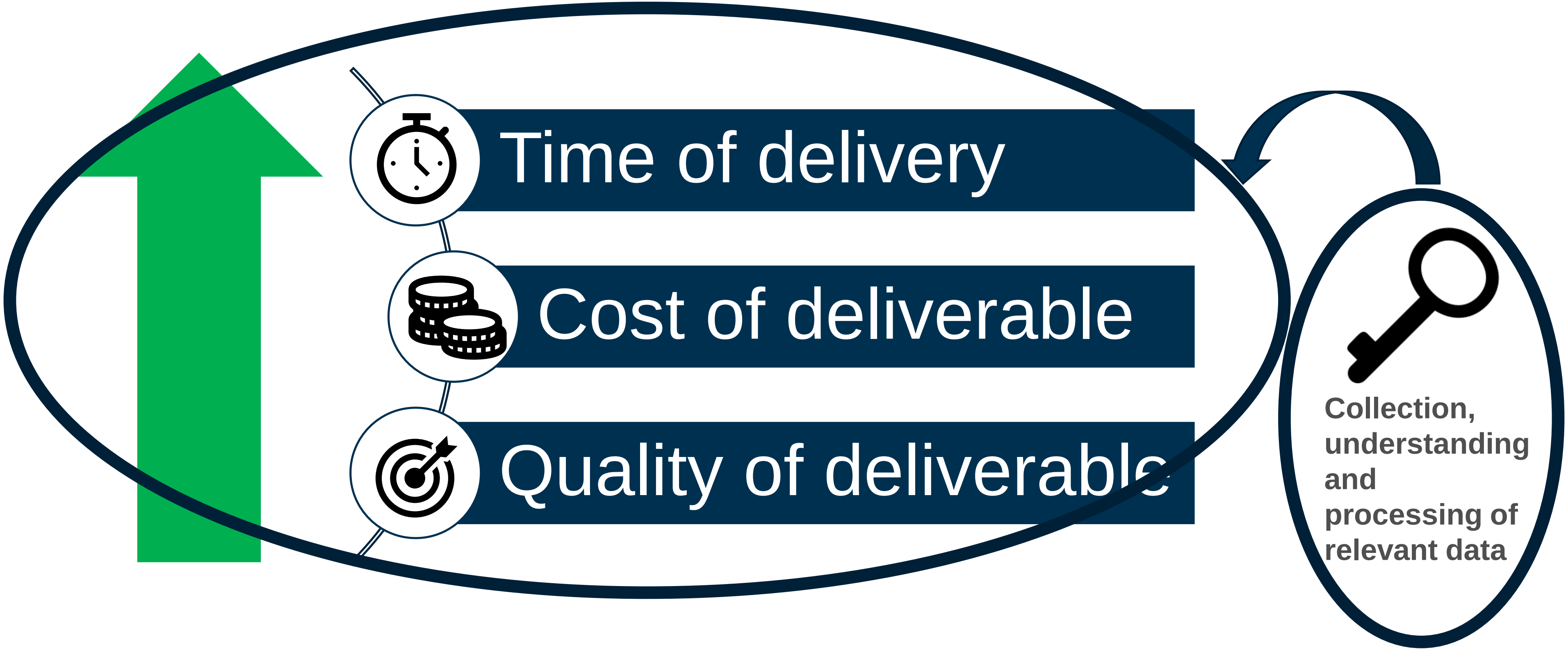
for the exploitation of **district development big data** (esp. **quantitative + qualitative productivity-related indicators**, and elements related to **construction logistics + supply chain**), in order to build a **machine learning model** as a **decision-making** and **action-taking** helper for 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



DATA USE FOR CONSTRUCTION MANAGEMENT IN WHOLE DISTRICT DEVELOPMENT

- Aiding and enhaning 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…

- Construction informatics
  - Data mining
  - Machine learning (ML)
    - Supervised (SML)
    - Unsupervised (UML)
    - Hybrid (HML)
  - Building Information Models (BIM)

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

- Investigated case: district development data in the productivity report “Produktivitetsläget i svenskt byggande 2014” [Productivity status in Swedish construction 2014] (Koch & Lundholm, 2018)
- **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/m^2 of total gross area
- Logistics issues qualitatively appraised with 5-point Likert scales

BIG DATA FOR DISTRICT CONSTRUCTABILITY APPRAISAL

- 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

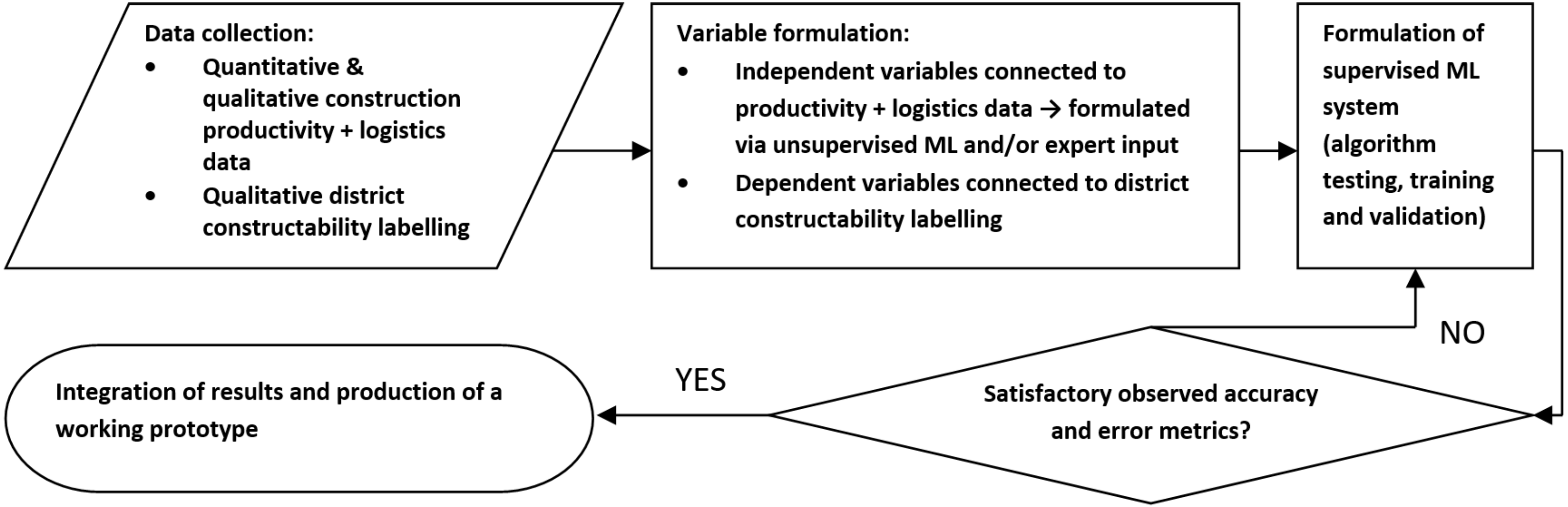
- Further potential variables:
  - Production flow inventories
  - Descriptions of construction site spatial and schedule clashes
  - Number of reworks
  - Material quantity problems
  - Optimal vehicle rounds
  - District disturbances
  - Existence and proper function of buffer facilities for vehicles and goods

BIG DATA FOR DISTRICT CONSTRUCTABILITY APPRAISAL

INDEPENDENT VARIABLES	Type	Example of value
Productivity rate	Continuous	0,1 (%)
Level of project group cooperation for on-site supply chain tasks	Discrete multinomial	{1,…,5}
Flow disturbance	Discrete multinomial	{1,…,5}
On-site congestion	Discrete multinomial	{1,…,5}
Keeping of delivery timetable	Discrete multinomial	{1,…,5}
Difficulties in material and equipment transportation and storage	Discrete multinomial	{1,…,5}
Limited construction production and logistics processes preparation	Discrete multinomial	{1,…,5}
Enough workforce for optimal undertaking of construction tasks	Discrete multinomial	{1,…,5}
Informed selection of material and equipment suppliers	Discrete multinomial	{1,…,5}
DEPENDENT VARIABLE	**Type**	**Example of value**
District constructability	**Discrete multinomial**	**{1,…,5}**

Exemplary independent and dependent variables for district constructability appraisal, as derived from Koch & Lundholm (2018)

MODELLING ASPECTS OF THE CONCEPTUAL MACHINE LEARNING FRAMEWORK



SYSTEM CONCEPTUALIZATION

- DATA COLLECTION
- VARIABLE FORMULATION
- SYSTEM FORMULATION
- INTEGRATION OF RESULTS

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)**

SYSTEM CONCEPTUALIZATION

DATA COLLECTION → VARIABLE FORMULATION → SYSTEM FORMULATION → INTEGRATION OF RESULTS

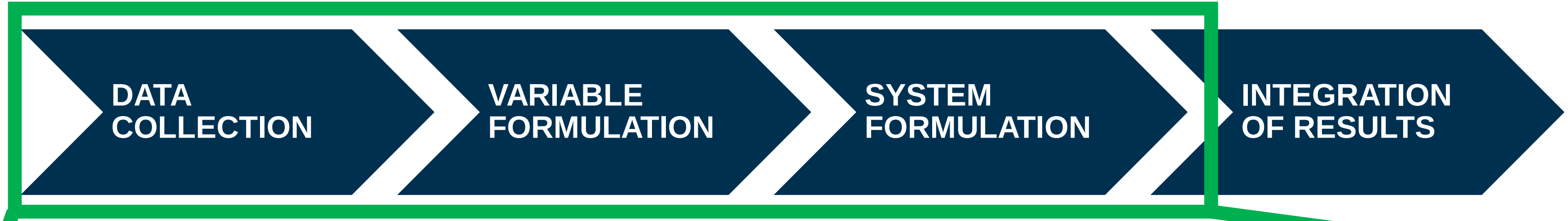
- **Independent variables**
  - E.g. number of reworks
  - Measured through values of collected data
  - Produced through UML (e.g. vector quantization, linguistic clustering) **OR** qualitative techniques relying on expert input (e.g. brainstorming sessions)
- **Dependent variables**
  - “District constructability achievement level”
  - Discrete or continuous → used for classification or regression

SYSTEM CONCEPTUALIZATION

DATA COLLECTION → VARIABLE FORMULATION → SYSTEM FORMULATION → INTEGRATION OF RESULTS

- **Supervised machine learning**
  - Training and validation depending on data form and amount, and variables’ type and number
  - Multiple experiments with numerous SML schemes
  - E.g. support vector machines (SVM) for binomial classification
  - E.g. support vector regression (SVR) for regression
  - E.g. variations of random forest for multinomial cases

SYSTEM CONCEPTUALIZATION



- **Use of auxiliary mathematical, methodological and software tools**
  - Non-negative matrix factorization for data normalization and pre-processing (steps 1-2)
  - Multi-input Analytical Hierarchy Process (AHP), for variable labelling (step 2)
  - “Kernel trick”, to aid in the non-linear function of e.g. SVM or SVR (step 3)
  - N-fold cross-validation, for simultaneous SML training and validation (step 3)
  - WEKA (step 3)
  - Surprise Scikit (steps 2-3)
  - Python (steps 2-3)

SYSTEM CONCEPTUALIZATION

DATA COLLECTION → VARIABLE FORMULATION → SYSTEM FORMULATION → INTEGRATION OF RESULTS

- **Integration as a working prototype**
  - 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)

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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