

PROCESS BASED SIMULATION MODELS USING BPMN FOR CONSTRUCTION MANAGEMENT AT RUN-TIME

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MOTIVATION

Currently, about 50% or more of the effort required to deliver a built environment is non-value added effort, or waste in the eyes of the customer.

In addition, the effectiveness of a labour hour has not improved in the last 50 years, while other industries have seen significant advances.

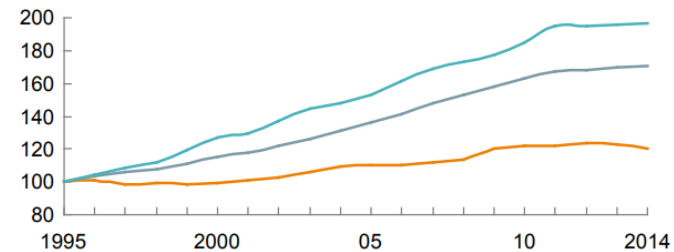
Globally, labor-productivity growth lags behind that of manufacturing and the total economy

Global productivity growth trends¹

Construction Total economy Manufacturing

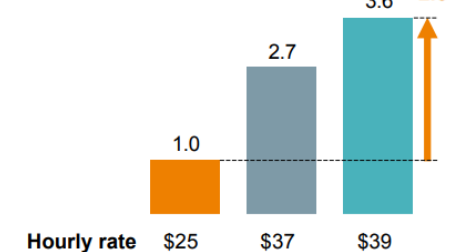
Real gross value added per hour worked by persons engaged, 2005 \$

Index: 100 = 1995



Compound annual growth rate, 1995–2014

%



¹ Based on a sample of 41 countries that generate 96% of global GDP.

SOURCE: OECD; WIOD; GGCD-10, World Bank; BEA; BLS; national statistical agencies of Turkey, Malaysia, and Singapore; Rosstat; McKinsey Global Institute analysis

COMPLEXITY

Traditional methods perform activity-based planning, which does not model the cause-effect relationships among project variables.

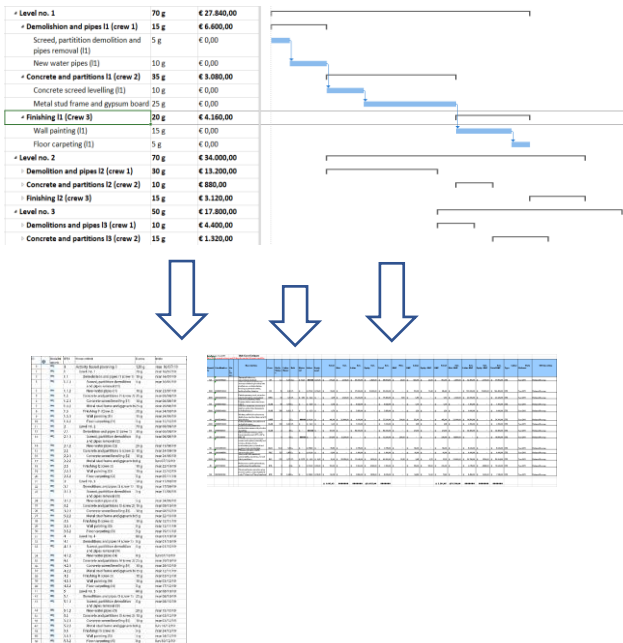
Rather, the dynamics of a construction site can be studied as an emergent property from interactions between resources on-site and the environment.

LEAN CONSTRUCTION

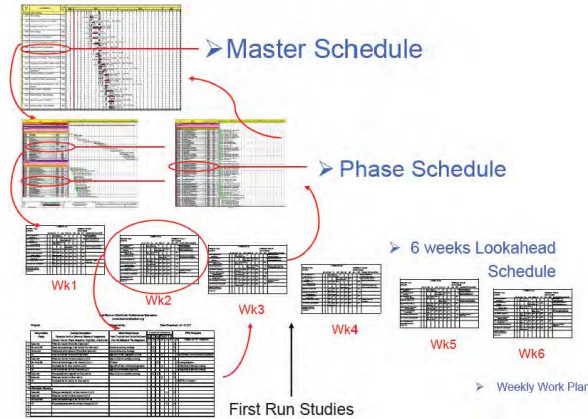
Respect- and relationship-oriented production management-based approach to project delivery.

DEALING WITH EMERGENT BEHAVIOUR

Activity-based planning

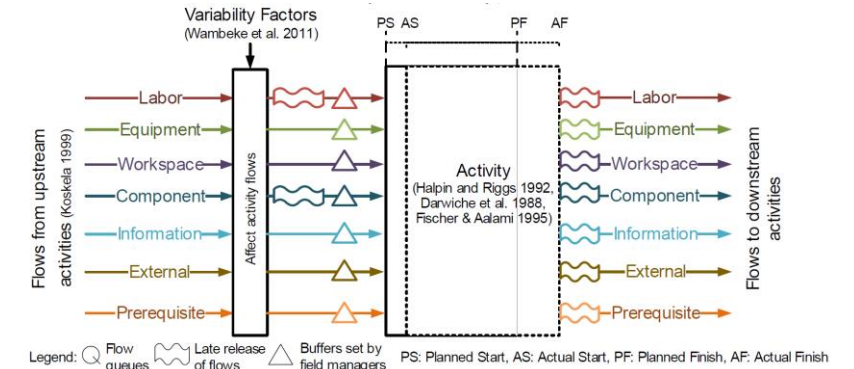


Lean Construction (e.g., LPS)



Ref.:
 Lean Construction Institute, *THE LAST PLANNER PRODUCTION SYSTEM WORKBOOK, version 2.0, March 2007.*

Analysis of workflow variability

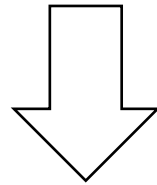


Ref.:
 Nelly P. Garcia-Lopez and Martin Fischer, *A Construction Workflow Model for Analyzing the Impact of In-Project Variability, Construction Research Congress 2016*

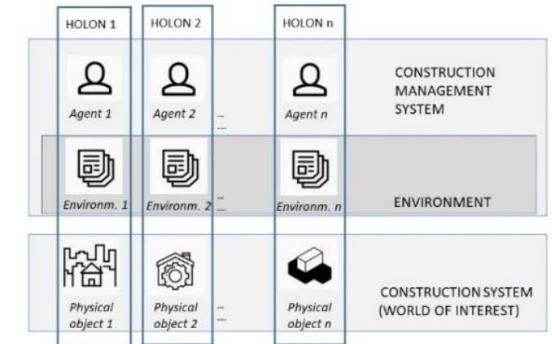
Initial work planning must be limited to the short term and must continuously be updated as a consequence of the feedback of the actual status of resources and processes.

THE HOLONIC APPROACH

It imitates real world process of systems, where **the global behaviour emerges as a result of interaction between agents**. It can take advantage of BIM-based structured information.

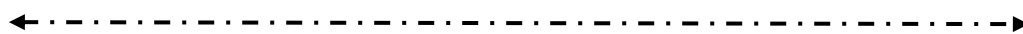


HOLONIC EXECUTION SYSTEMS



Holons = autonomous self-reliant units. Having a degree of independence, which can handle contingencies without asking higher authority for permission.

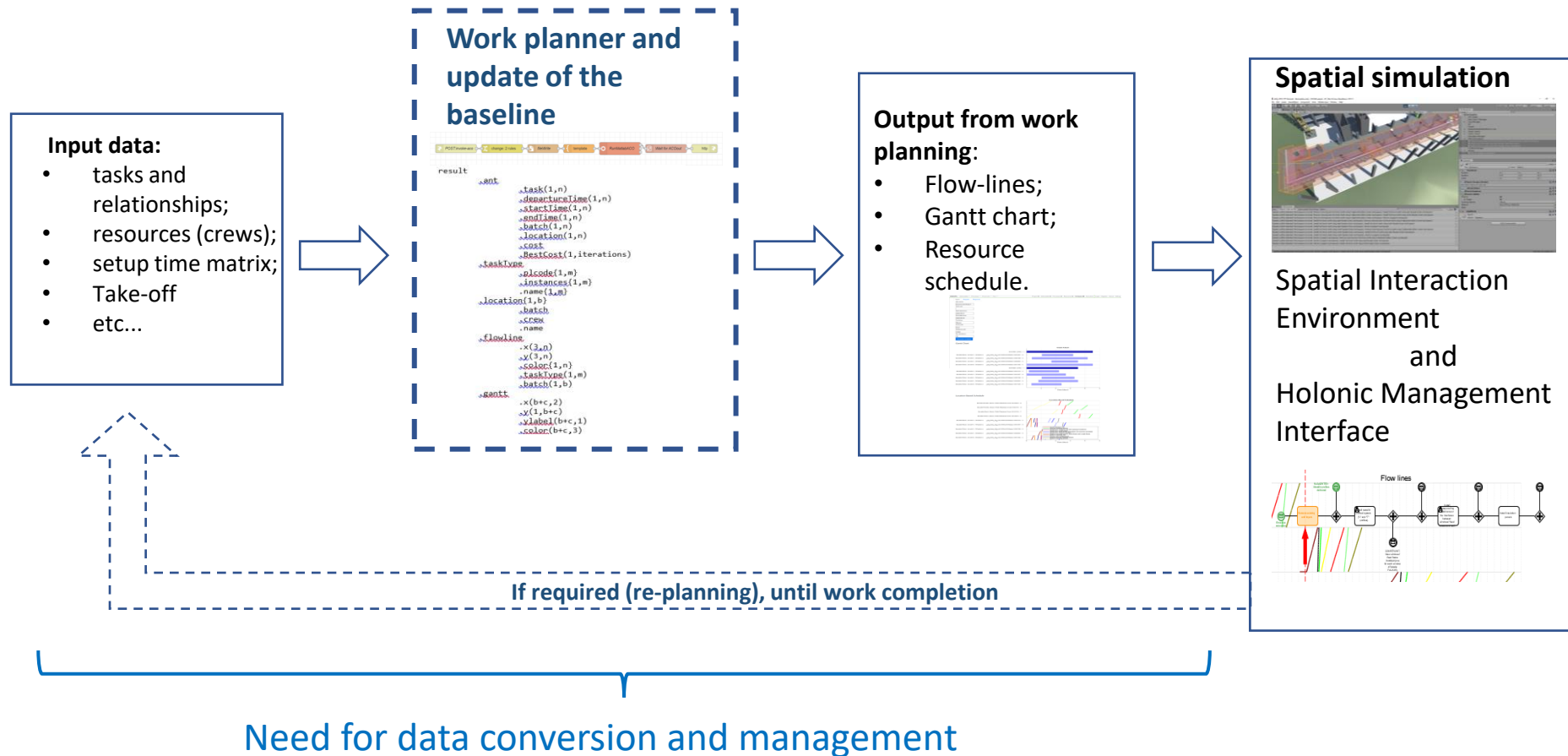
Hierarchical
↓
Accurate



Holarchy

Heterarchical
↓
Robust

OUR APPROACH



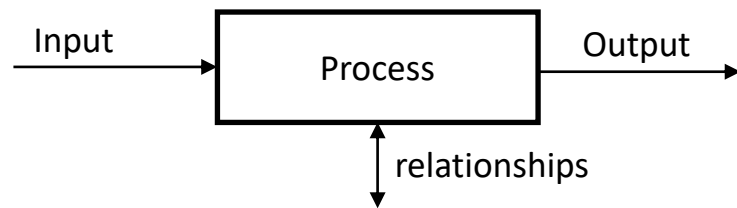
Ref.: EU Project Encore (Grant agreement number: 820434), <https://encorebim.eu/> , An Energy-aware and cost-effective BIM Cloud Platform for Building Renovation.

TURNING BIM MODELS INTO PROCESS MODELS

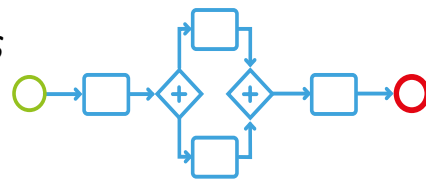
BUISNESS PROCESS MODELLING NOTATION

Example of tool: Construction Simulation Toolkit – CST (Ismail and Scherer 2014)

It uses BPMN to capture and arrange the domain expert knowledge and transform it into simulation processes, coupling logistics and production in one environment



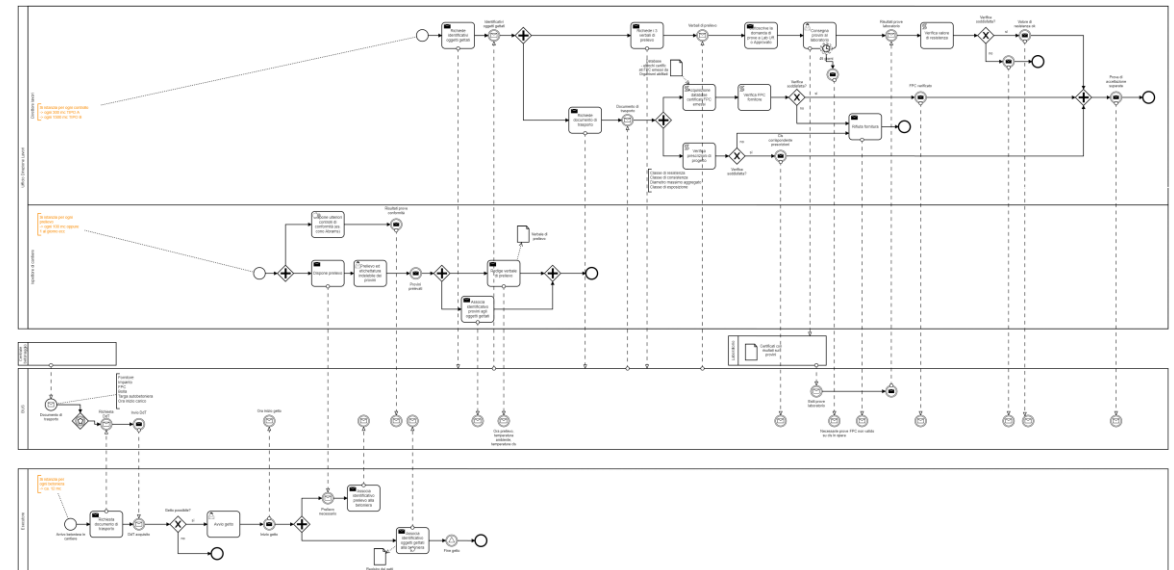
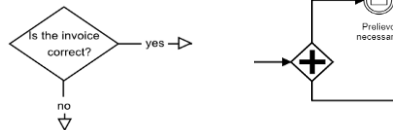
- Representation of *workflows*
- Standardization of notation



Documents



Decisions and gateways

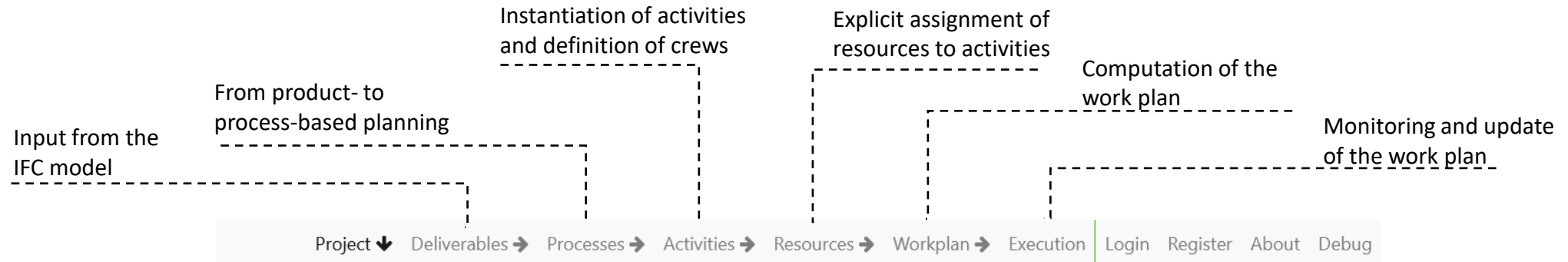


BPMNs INTEGRATED IN PLANNING

Advantages provided by BPMN:

- The schema of **resource combination** defined prior to simulation and scheduling, is **flexible**;
- It can **dynamically** calculate the duration of activities, as a consequence of the real combination of resources;
- It supports the application of **corrective** actions, due to the unexpected during work progress;
- It **combines information** deriving from diverse sources, in terms of types and origins;
- The graphical representation of BPMN make the models **easy to understand** and communicate.

DATA INTEGRATION THROUGHOUT THE PLANNING PHASE



AWOPS Project ▾ Price Lists ▾ Run ▾

ENCORE projects

Choose: Case Study 3 Choose Edit Save Delete

Project metadata

_key	939b3a1d6b06b42c09b694cca44c1437f06b24c5
id	PRJ003
name	Case Study 3
company	ACME ltd
created	25/06/2021
updated	
startDateTime	01/09/2021
dueDateTime	31/10/2021
storage	/resources/case_study_3/

IFC resources

Search:

ID	URL	Author	MVD	Created	Updated	LOIN	Tags
IFC1	Caceres Existing.ifc	Mario Rossi	IFC2x3 TC1 - coordination view	25/6/2021, 10:46:39			Existing
IFC2	Caceres New Construction.ifc	Mario Rossi	IFC2x3 TC1 - coordination view	25/6/2021, 10:46:49			Finished

Showing 1 to 2 of 2 entries

Remove

Deliverables

Search:

ID	URL	Name	Author	Created	Updated	Tags
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Progress input through RESTful API from construction sites

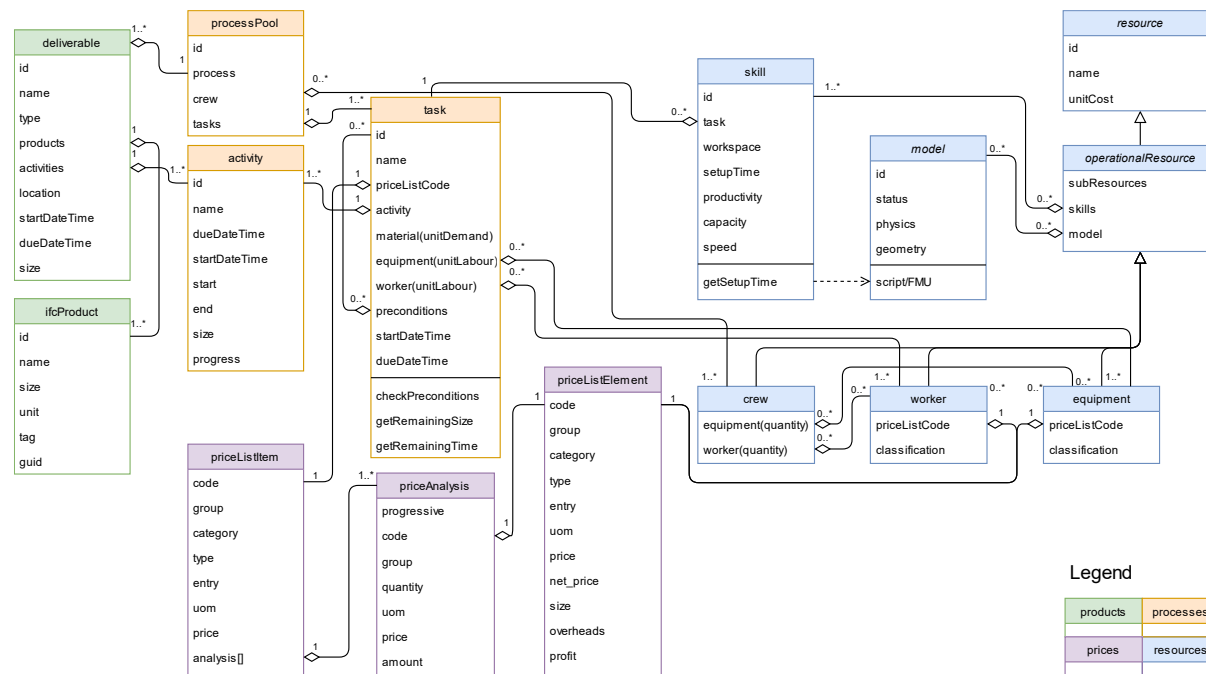
COMBINATION OF PROCESSES, RESOURCES, COST ANALYSES

Product: the product model has been assumed as broke-down according to the IFC standard

Price list: every record is uniquely identifiable over the Internet (URLs identified and stored as JSON documents of a graph DB).

Operational resources: the minimum set of required resources is specified by the price list items associated with tasks

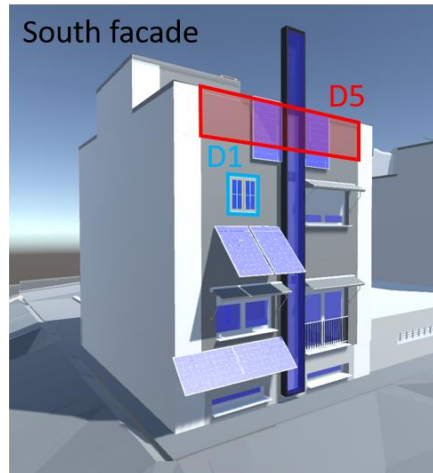
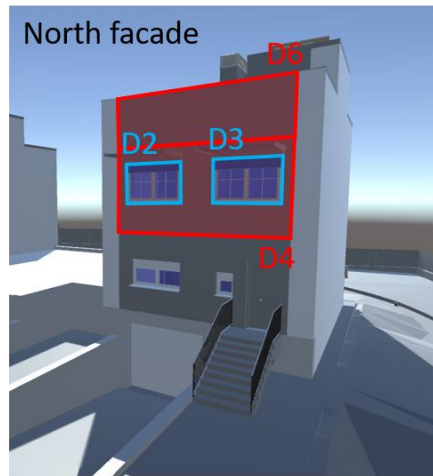
Processes: they are described by BPMN, represented as XML-based notation.



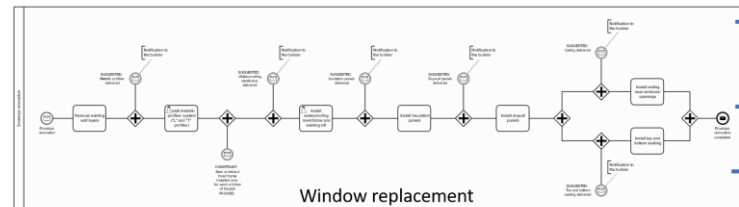
UML class diagram of the information model

CASE STUDY: RETROFIT

Pilot of ENCORE Project (H2020) - <https://encorebim.eu/> .

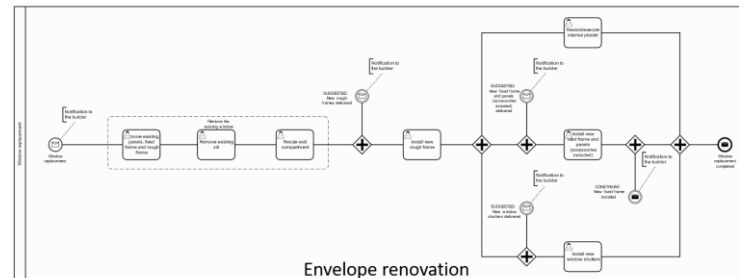


Concerning D1, D2, and D3

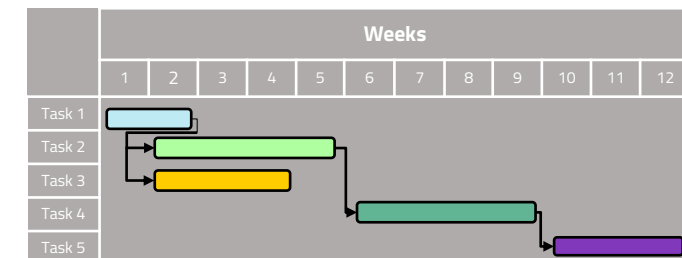


Same process, several deliverables

Concerning D4, D5, and D6



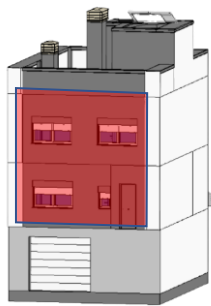
In fact, the user is unable to optimize the sequence of tasks into a definite job logic.



DEVELOPMENT OF THE JOB LOGIC

AWOPS (tool of ENCORE Portal): Automated Work Planning Service

1. Import of models and definition of groups of deliverables



AWOPS Deliverable - Processes - Price Lists - Run

Import Encore project

Project metadata

Processes

IC resources

Price lists

Input popular format: .csv

Price list format: .xml

Grouping ...

AWOPS Deliverable - Processes - Price Lists - Run

Project - Deliverable - Processes - Resources - Workplan - Execution

Deliverable grouping

ID	Type	Size	Unit	Start date/time	Due date/time	Process	Facade	Level	tag	globalId	Name
1	Renovation	2	m2							'1031597'	'3A470cpEfnRlUjC7P6zVv'
1	Renovation	2	m2							'1024008'	'03U0vc6P1r95OlnR6sq4F'
1	Renovation	2	m2							'1031584'	'3A470cpEfnRlUjC7P6zVv'
1	Renovation	2	m2							'1024169'	'03U0vc6P1r95OlnR6sq4F'
6	Renovation	2	m2							'1046922'	'24ZjYhbCKRz4cnlgTf'
6	Renovation	2	m2							'1023433'	'03U0vc6P1r95OlnR6sq4F'
7	Demolition									'1023912'	'03U0vc6P1r95OlnR6sq4F'
8	Construction					Installation of thermal coat	North			'1032728'	'25ocqHCHBZOEsw0_3'
9	Construction					Installation of thermal coat	South			'1032650'	'25ocqHCHBZOEsw0Hf'
10	Construction					Installation of thermal coat	East			'1032620'	'25ocqHCHBZOEsw0Hf'
11	Demolition					Installation of thermal coat	West			'1011844'	'2VwZQz0hCnK4H5d8V'
12	Construction									'1032431'	'25ocqHCHBZOEsw0Hf'

2. Process modelling and association with price lists

AWOPS Deliverable - Processes - Price Lists - Run

Activity: tptstuf

Activity: tptstuf

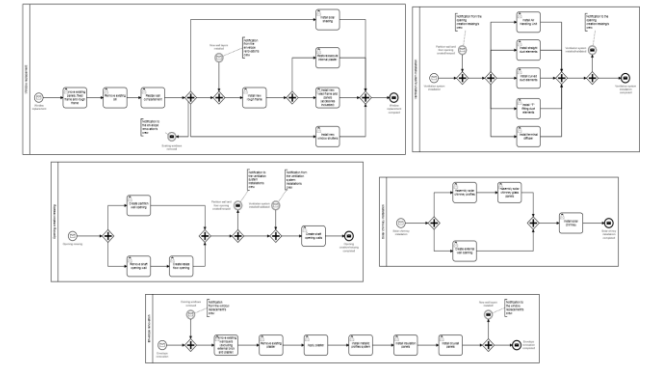
Definition of crew and resource types per task is included in the price list

REST API

Link

Price List

codice	Descrizione di analisi	Unità di misura	Quantità	Prezzo unitario	Prezzo totale	Importo
T0202_22.407.021.001	Scarcamento dei materiali di risulta in cantiere di cantiere per 2400h - da addebitare al subappalto di cantiere generale	m³	1	€ 33.71200	€ 33.71200	€ 33.71200
T0202_AT.008.020.000	Manovalita in cantiere: manovalita con capacità in cantiere, 200 kg, 1000 m³	ora	0,5	€ 8.20000	€ 4.10000	€ 4.10000
T0202_AT.002.020.000	Manovalita: manovalita in cantiere (max 100 kg)	ora	4	€ 1.20000	€ 4.80000	€ 4.80000
T0202_AT.002.020.000	Manovalita: manovalita in cantiere (max 100 kg) (max 100 kg)	ora	0,02	€ 18.00000	€ 0,36000	€ 0,36000
T0202_RU.MG3.001.002	Copertura antivegetazione	ora	9	€ 28.70000	€ 258.30000	€ 258.30000
T0202_RU.MG3.001.002	Copertura antivegetazione	ora	1	€ 28.70000	€ 28.70000	€ 28.70000
T0202_RU.MG3.001.002	Copertura antivegetazione	ora	0,5	€ 28.70000	€ 14.35000	€ 14.35000
T0202_RU.MG3.001.004	Copertura antivegetazione	ora	5,8	€ 24.00000	€ 139.20000	€ 139.20000
Totale T0202_001						
Totale generale						
IA	Spese generali		15% di IVA		€ 72.12000	€ 72.12000
IB	Spese generali		20% di IVA		€ 2.84000	€ 2.84000
IC	Spese generali		10% di IVA		€ 10.22000	€ 10.22000
IE	Spese generali		10% di IVA		€ 658.54800	€ 658.54800
Incidenza manovalita						
						78,11%



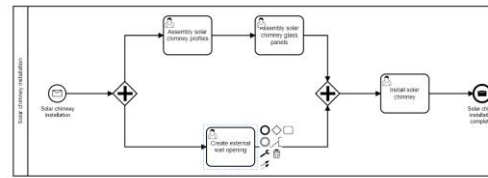
DEVELOPMENT OF THE JOB LOGIC

3. Crews and resource types are associated automatically

Activities associated with a Deliverable.

Process	Deliverable ID	Type	Price List Code	Size	Unit	Start date/Time	Due date/Time
PROCC	1	Renovation	T0G20_01.E04.201.002	0.1	m	2021/10/15	2022/1/31
PROCC	1	Renovation	T0G20_01.E04.003.002	0.72	m ²	2021/10/15	2022/1/31
PROCC	1	Renovation	T0G20_01.E04.003.003	0	m ²	2021/10/15	2022/1/31
PROCC	1	Renovation	T0G20_01.E04.003.004	0	m ²	2021/10/15	2022/1/31
PROCC	1	Renovation	T0G20_02.A03.003.002	0.72	m ²	2021/10/15	2022/1/31
PROCC	1	Renovation	T0G20_02.A03.003.001	0.52	m ²	2021/10/15	2022/1/31
PROCC	1	Renovation	T0G20_02.C01.002.002	0	m ²	2021/10/15	2022/1/31
PROCC	1	Renovation	T0G20_02.E06.006.003	0.2	m ²	2021/10/15	2022/1/31

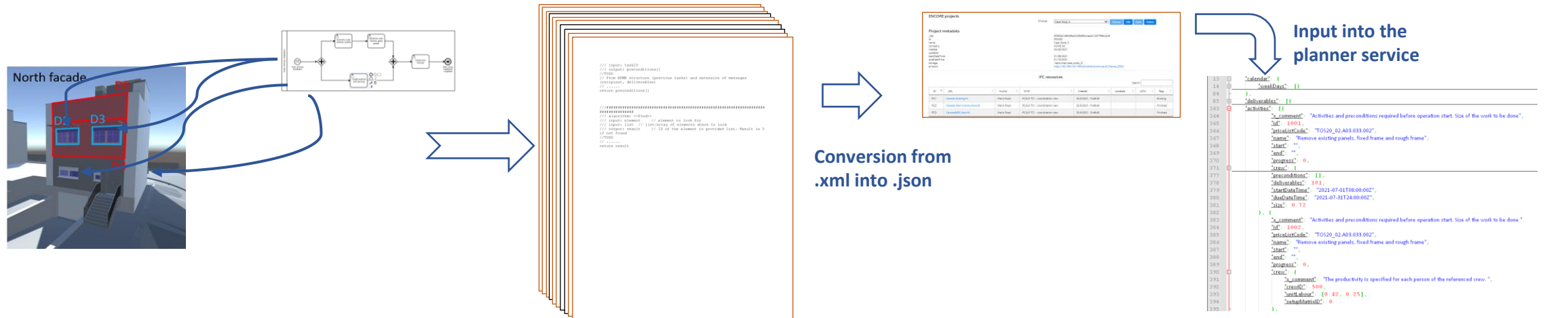
The process containing those tasks.



Resource list associated with a task.

Code	Item	Price/Unit (€)	Selected	Shared
TOS20_AZ.N06.016.006	Grù a torre - braccio 40-41 m, portata in punta 1000 kg. Nolo da 8 a 12 mesi	3.75	true	true
TOS20_AZ.N06.020.002	Montacarichi elettrico - scorrevole con cavalletto in acciaio, portata 300 kg, nolo mensile.	0.26	true	true
TOS20_AZ.N10.025.001	Puntelli, noleggio mensile - metallici a croce h max m 4.00	1.3	true	false
TOS20_AZ.N10.025.002	Puntelli, noleggio mensile - in legname d'abete	19	true	false
TOS20_RU.M10.001.000	Operaio edile - Specializzato	28.76	true	false
TOS20_RU.M10.001.003	Operaio edile - Qualificato	26.71	true	false
TOS20_RU.M10.001.004	Operaio edile - Comune	24.08	true	false
TOS20_RU.M11.001.001	Installatore/Operaio metalmeccanico - 5ª categoria di livello superiore	25.1	true	false
TOS20_RU.M11.001.004	Installatore/Operaio metalmeccanico - 3ª categoria	21	true	false

4. Every process will be instantiated into as many instances (i.e. activities) as the number of associated Deliverables



DEVELOPMENT OF THE JOB LOGIC

5. The ACO stigmergic algorithm finds a feasible solution optimized with respect to a cost function

The planning algorithm is based on the multiple ant colony system for vehicle routing problems with time windows (MACS-VRPTW).

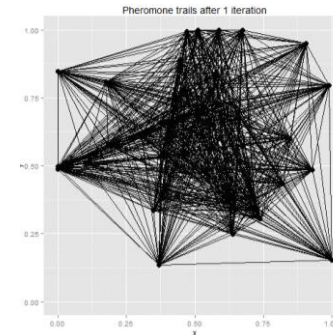
```

"deliverables": [ {
  "x_comment": "Data about each deliverable of production.",
  "id": 101,
  "name": "M_Window-Casement-Triple:0.395 x 1.83 m:1390997",
  "size": {
    "x_comment": "Main size of the object.",
    "value": 0.72,
    "unit": "m^2"
  }
} ]

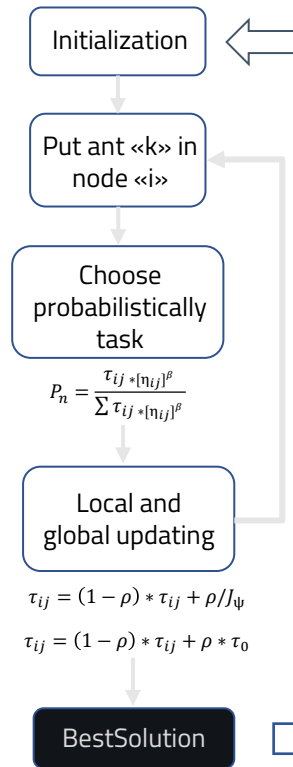
"activities": [ {
  "x_comment": "Activities and preconditions required before operation start. Size of the work to be done",
  "id": 1001,
  "pricelistCode": "TOS20_02.A03.033.002",
  "name": "Remove existing panels, fixed frame and rough frame",
  "start": "",
  "end": "",
  "progress": 0,
  "crew": [
    "x_comment": "The productivity is specified for each person of the referenced crew.",
    "crewID": 500,
    "unit_cost": [0.42, 0.25],
    "siteMatrixID": 0
  ]
} ]

"operationalResources": [ {
  "workers": [ {
    "x_comment": "unitCost has unity of measure as specified in site.currency and site.timeUnit",
    "id": 300,
    "pricelistCode": "TOS20_RU.M10.001.004",
    "name": "Operato edile - Comune",
    "unitCost": 24.08
  } ]
} ]
    
```

Planning phase supported by the ACO algorithm



Time window
Attractiveness
Feasibility



$$P_n = \frac{\tau_{ij} * [\eta_{ij}]^\beta}{\sum \tau_{ij} * [\eta_{ij}]^\beta}$$

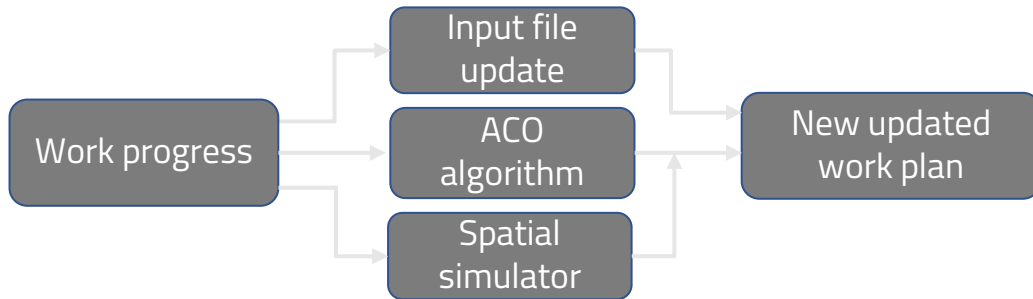
$$\tau_{ij} = (1 - \rho) * \tau_{ij} + \rho / J_\psi$$

$$\tau_{ij} = (1 - \rho) * \tau_{ij} + \rho * \tau_0$$

Tour cost = TourTime * model.HourlyCost (crew cost)
 OverheadCost = endTime * model.jobSiteCost
 antCost = TourCost + OverheadCost

FIRST WORK PLAN AND UPDATE NO. 1

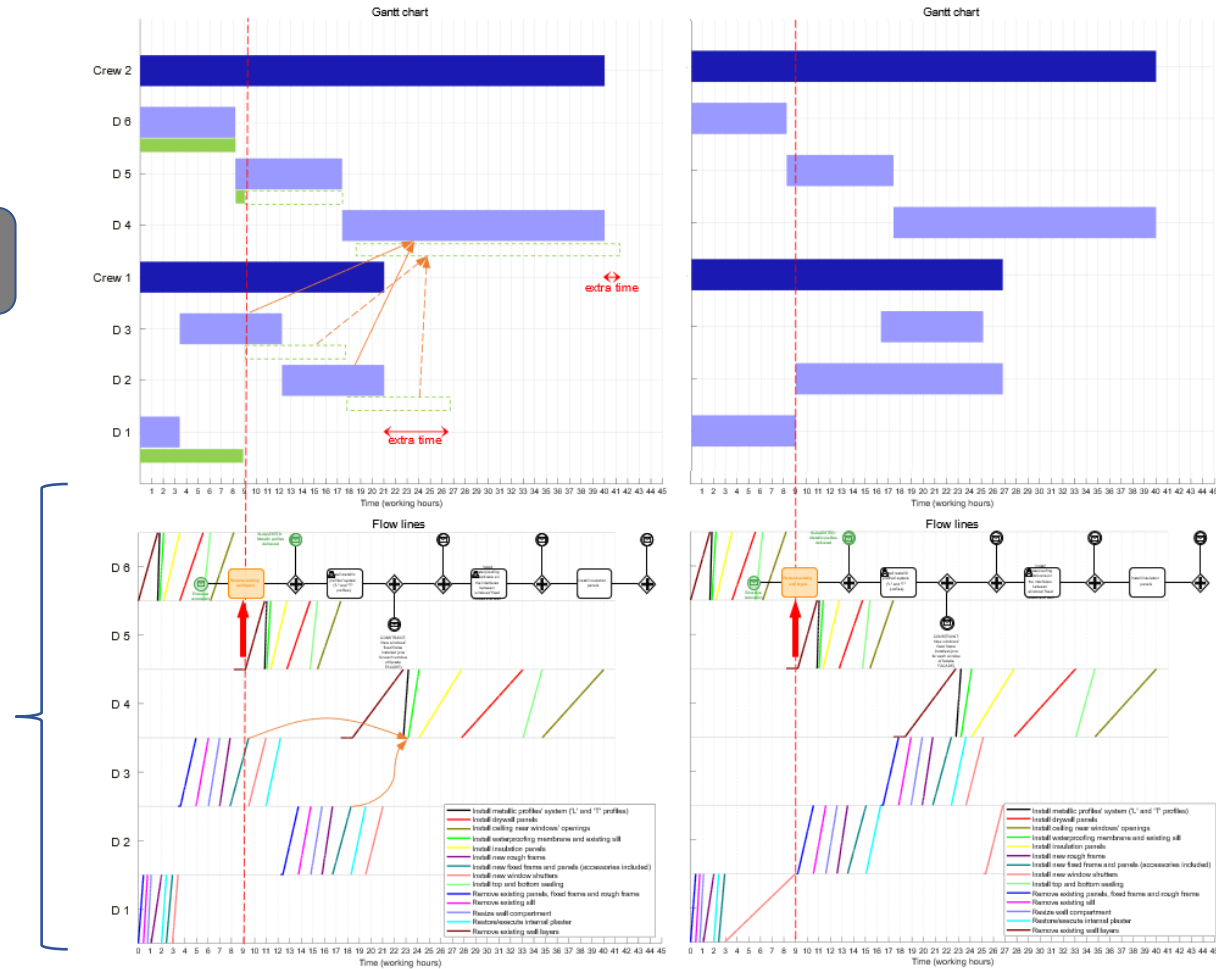
Generalized procedure



In this scenario D1 has run late.

The expected consequence is that D2 and D3 be delayed, which would impact D4 (crew no. 2).

However, the planner reassigns Crew no. 1 involved in D2 and then D3, which does not delay the work of Crew no. 2 at all.



CONCLUSIONS

- Some algorithms, such as stigmergic ones, can support work planning at runtime, however they require the use of a notation that models process and not products
- BPMN is a good notation to define processes
- BPMN can arrange information properly and integrate information about work progress, and can trigger planning algorithms to update work plans continuously
- The job logic and duration of activities is the result of the combination of involved resources, hence this is able to cope with the complexity of construction projects

THANKS FOR YOUR ATTENTION!

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