KRDB

Summer Online Seminars

19/06/2020

Construction Process Modelling

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Joint work with Werner Nutt and Matthias Perktold

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Construction Projects are “Rarely” On-Time/On-Budget

- Wembley National Stadium
    - Commenced: 2002
    - Planned Completion: Early 2006
    - Open: March 2007
    - *Delay: 1 year*
    - Planned Cost: £757m
    - Final Cost (approx.): £1bn
    - *Increased cost: 32%*

http://www.globalconstructionreview.com/

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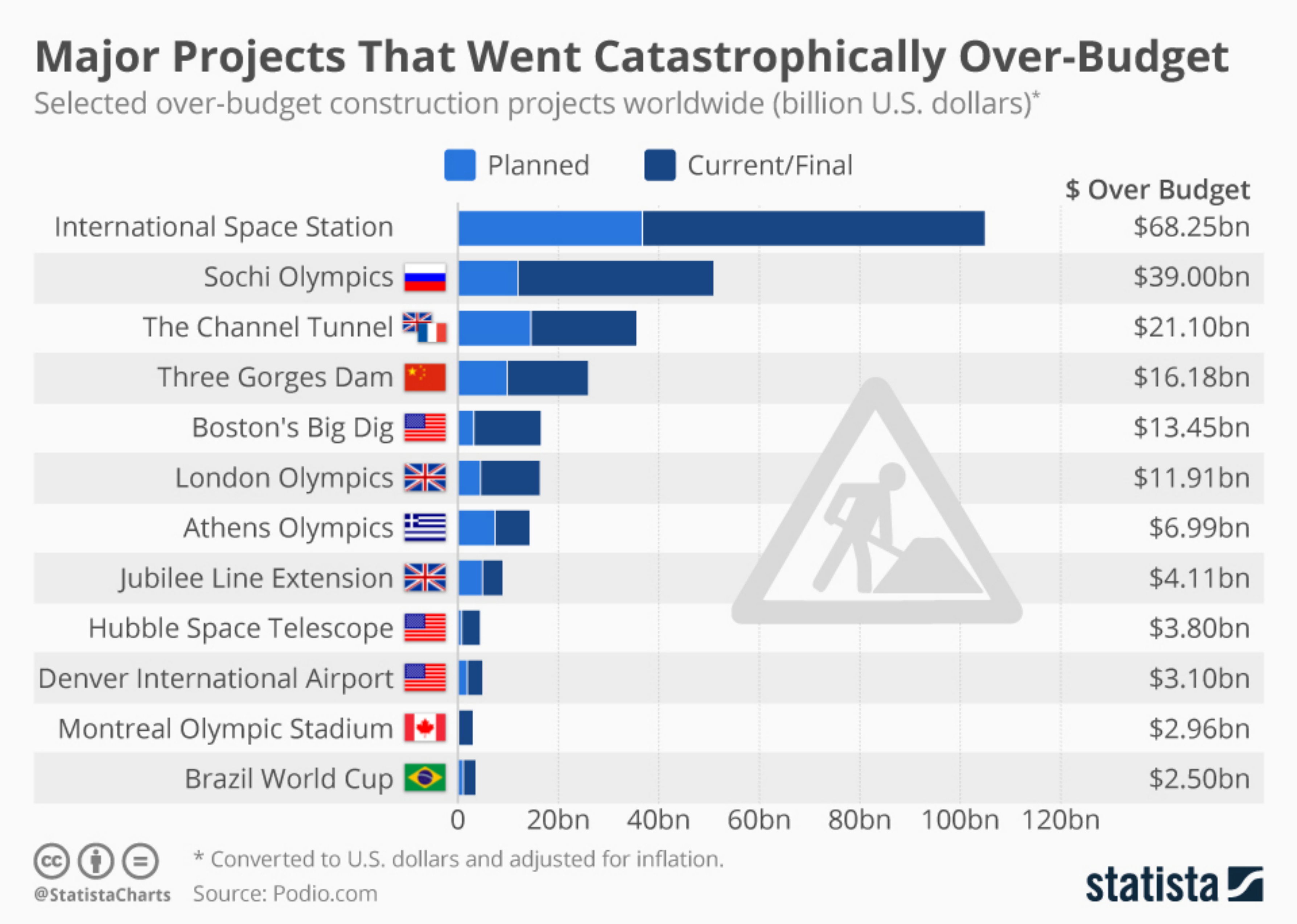
Construction Projects are “Rarely” On-Time/On-Budget

- Berlin Airport
  - Commenced: 2006
  - Planned Completion: ~~2011~~ ~~2012~~ ~~2013~~
  - Open: Oct 2020 ???
  - *Delay: 9 Years*
  - Planned cost: €2bn
  - Current Cost: €7bn
  - *Increased cost: 200%*

https://www.economist.com/the-economist-explains/

...and Many More



Major Projects That Went Catastrophically Over-Budget

Selected over-budget construction projects worldwide (billion U.S. dollars)*

* Converted to U.S. dollars and adjusted for inflation.

Source: Podio.com

What are the challenges

- Coordination
  - Between SMEs
  - With the Supply Chain

- ≠ Manufacturing
- ≠ Admin Proc.

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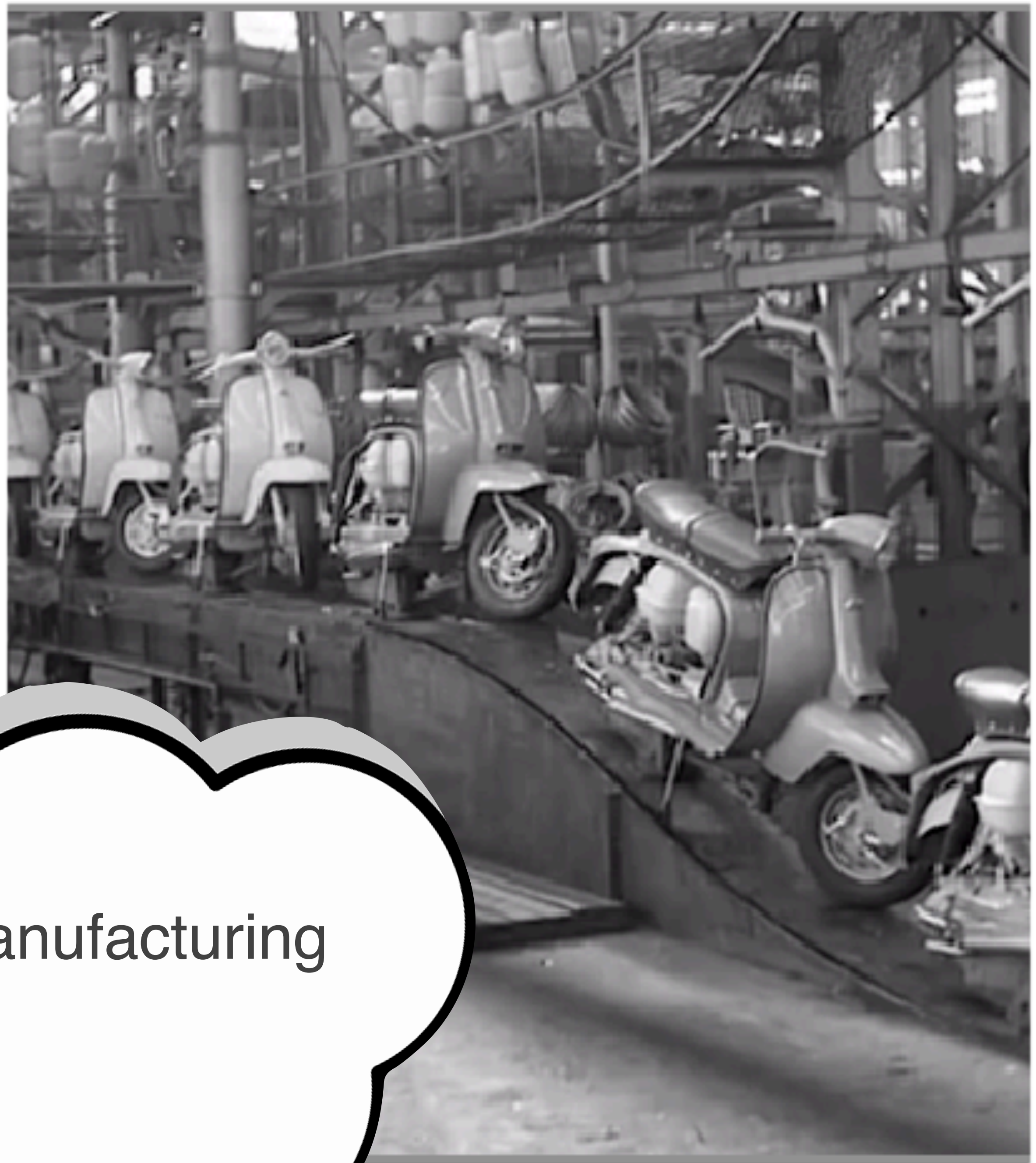
DI BOLZANO
ALTO ADIGE

What are the challenges

- Coordination
  - Between SMEs
  - With the Supply Chain
- Low Standardisation
  - Each project is one of a kind



- SMEs Consortium
- Technically

- ≠ Manufacturing

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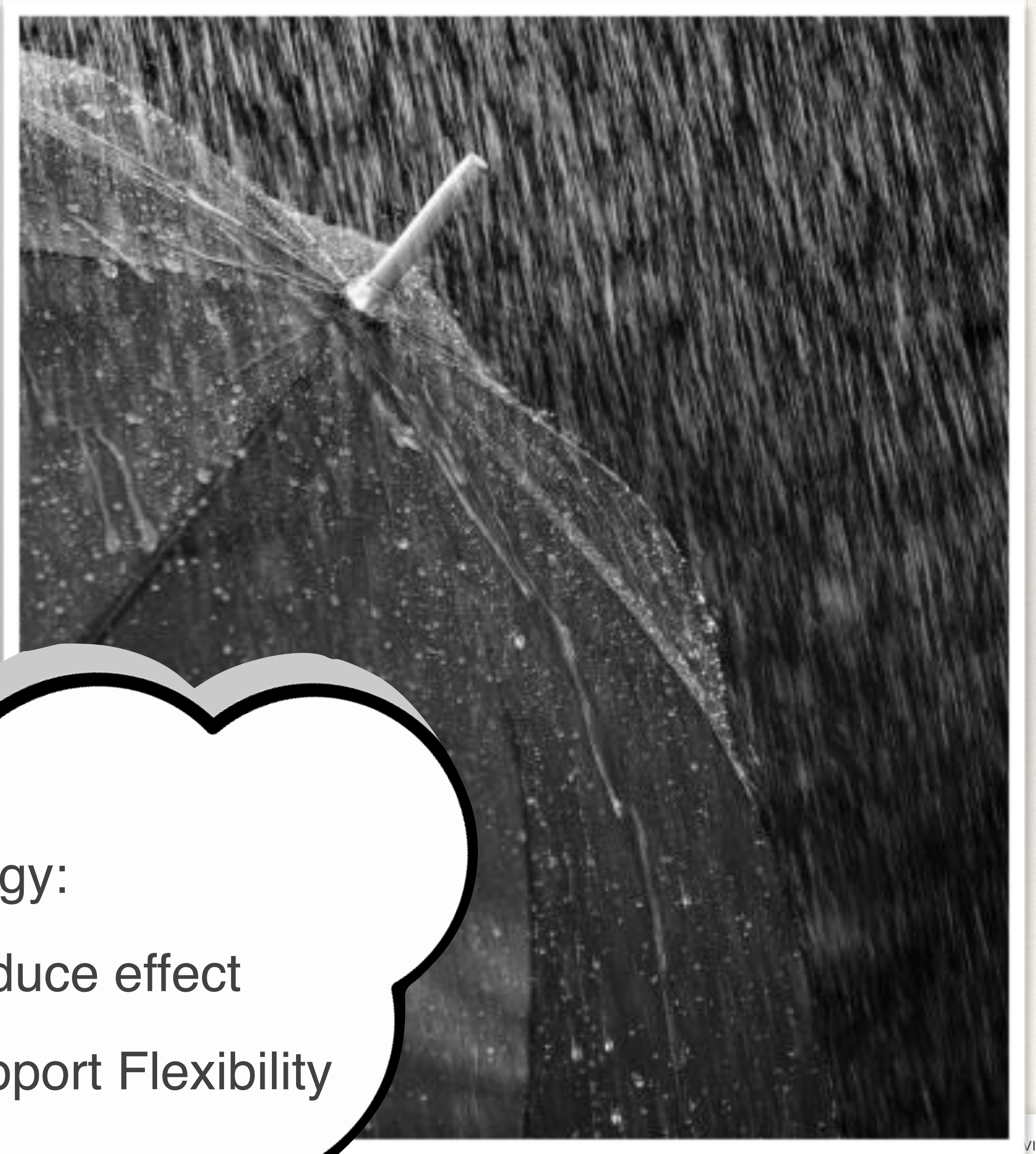
What are the challenges

- Coordination
  - Between SMEs
  - With the Supply Chain
- Low Standardisation
  - Each project is one of a kind
- Imponderabilities
  - E.g., weather conditions, changing requirements
  - Unavoidable



Strategy:

- Reduce effect
- Support Flexibility

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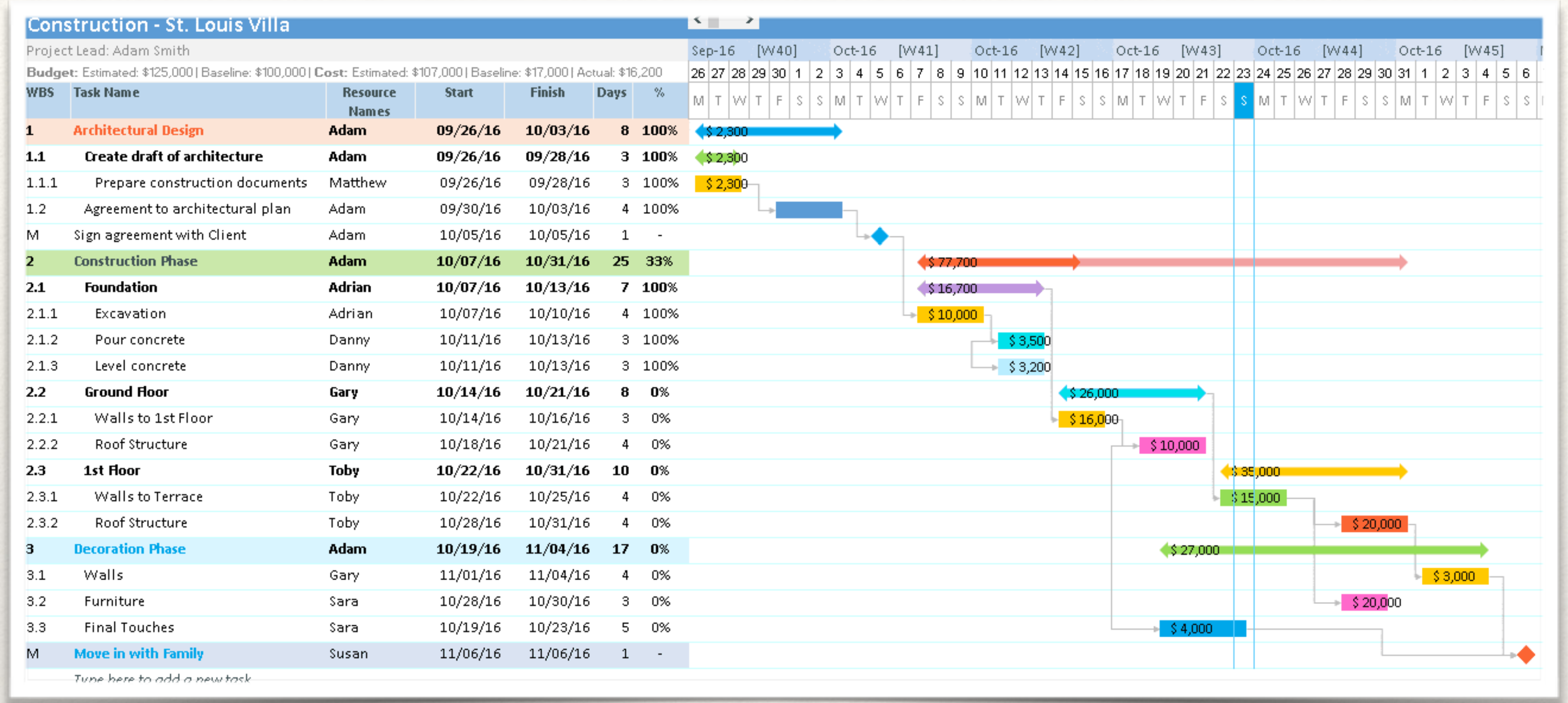
Current Approach



Construction - St. Louis Villa

Project Lead: Adam Smith

Budget: Estimated: $125,000 | Baseline: $100,000 | **Cost:** Estimated: $107,000 | Baseline: $17,000 | Actual: $16,200

WBS	Task Name	Resource Names	Start	Finish	Days	%
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2	Construction Phase	Adam	10/07/16	10/31/16	25	33%
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3.3	Final Touches	Sara	10/19/16	10/23/16	5	0%
M	Move in with Family	Susan	11/06/16	11/06/16	1	-

Type here to add a new task

- Execution Process Management: Gantt Charts
- Defined by the Project Manager
- Tools: MS Project / MS Excel

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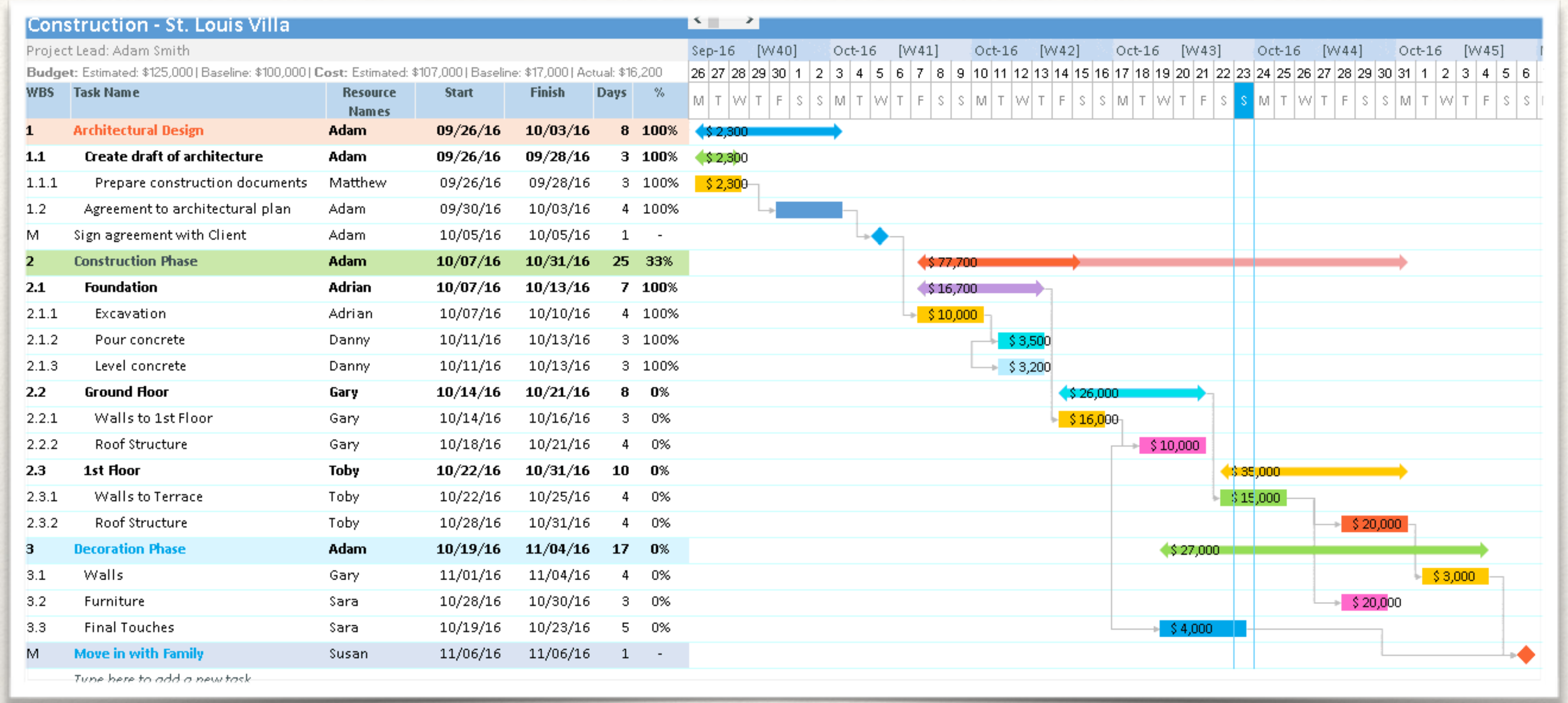
Gantt Charts: Pros



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Type here to add a new task

- For the entire duration of the project
- Show alternation of companies on-site
- Show milestones
- Support communication with the customer

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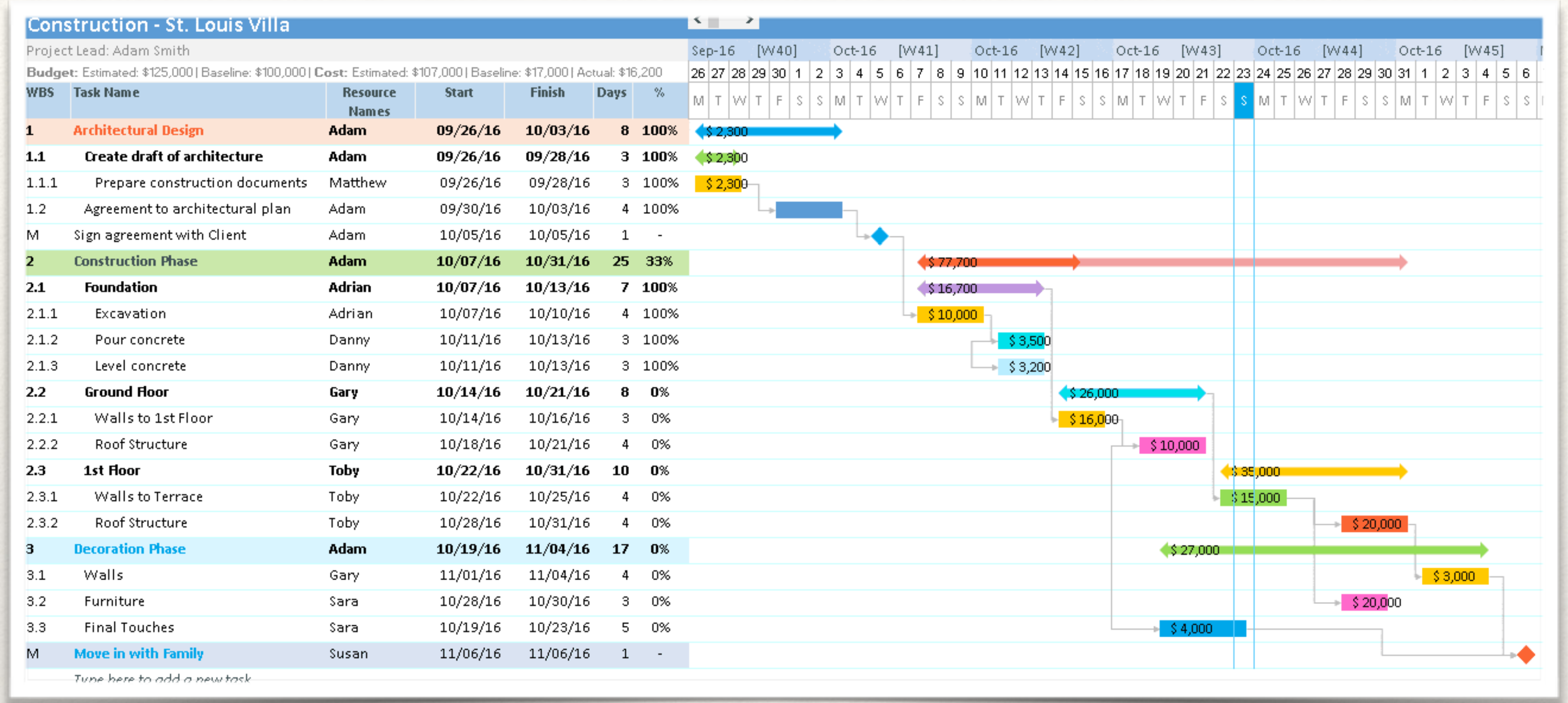
Gantt Charts: Cons



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Type here to add a new task

- General purpose: no proper abstractions (e.g., Locations, Precedences)
- Difficult to update
- Not detailed for a daily / weekly schedule
- They already represent a (long-term) commitment

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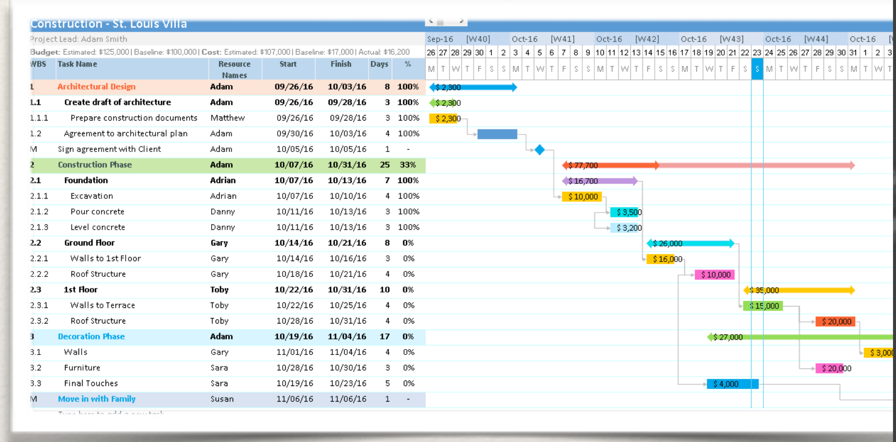
Management with Gantt Charts (1)



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- There is no clear definition of the process requirements:
  - Single point of failure: PM / Foreman
  - Alternative plans? Optimisation? Automation?

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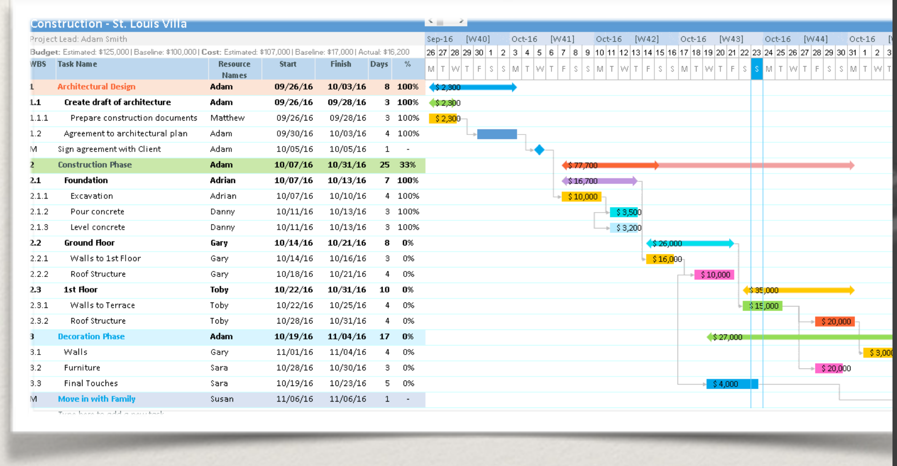
Management with Gantt Charts (2)



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- Daily / Weekly schedule defined “on the fly”
  - No short- and medium-term planning
  - Synch with supply chain and between companies

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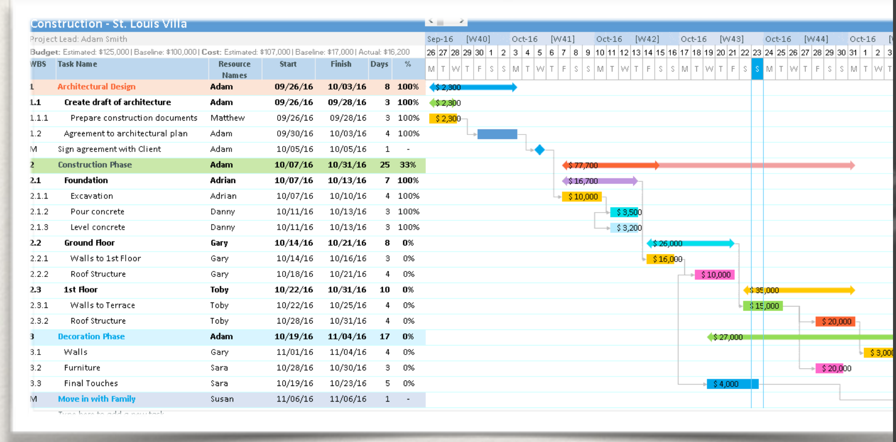
Management with Gantt Charts (3)



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Type here to add a new task

- Do not support report on the actual progress
  - Progress estimated based on indirect measures
  - Are used for tendering purposes only (no updates)

COCkPiT

- COCkPiT
  Collaborative Construction Process Management
- Applied research project
- European Regional Development Fund
  (ERDF -EFRE - FESR1008) of the
  Autonomous Province of Bolzano-South Tyrol

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Scientific Team

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Facoltà di Scienze e Tecnologie informatiche
Faculty of Computer Science

Werner Nutt

Elisa Marengo

Mehtab Alam

Peng Cheng

Hebatallah Mohamed

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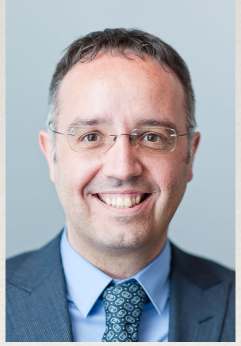
Fakultät für Naturwissenschaften und Technik
Facoltà di Scienze e Tecnologie
Faculty of Science and Technology

Patrick Dallasega


Dominik Matt

Andrea Revolti

Fraunhofer
ITALIA

Carmen Marcher

Christoph Schimanski

Camilla Follini

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Companies

ATZWANGER

Interior

- Environmental engineering
- Water technology
- Energy engineering
- Building services

FRENER REIFER
FASSADEN

Envelope

- Engineering
- Production
- Installation of facades

UNIONBAU

Skeleton

- Competences as bricklayers, carpenters and metalworkers
- Acting also as General Contractors

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COCkPiT: What is it?

- Objective:
  Improve Execution Process Management in Construction by
  - Developing Methodologies
  - Increasing Digitalisation

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COCkPiT: What is it?

- Objective:
  Improve Execution Process Management in Construction by
  - Developing Methodologies
  - Increasing Digitalisation
- This would allow:
  - reduce delays
  - reduce cost overruns
  - better synchronisation with the supply chain
  - better usage of the resources
  - …

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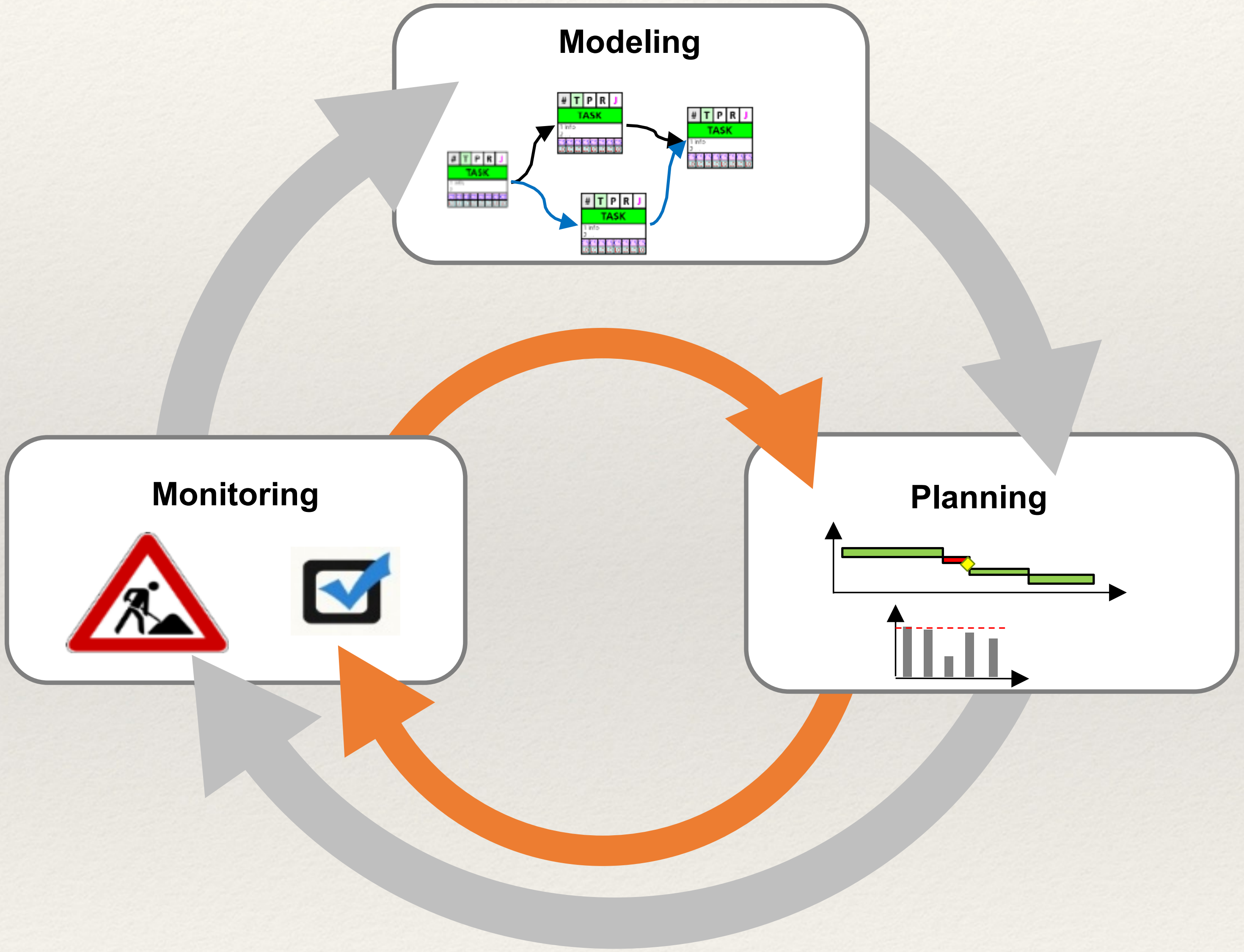
How To Do That



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Topic of Today: Modelling

- Objective: Explicit representation of the process requirements
  - No more single point of failure
  - Identification of alternative plans
  - Automation / Optimisation
  - Flexibility in handling imponderabilities

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Topic of Today: Modelling

- Objective: Explicit representation of the process requirements
  - > No more single point of failure
  - > Identification of alternative plans
  - > Automation / Optimisation
  - > Flexibility in handling imponderabilities
- Requirements:
  - Proper abstractions
  - Formal approach

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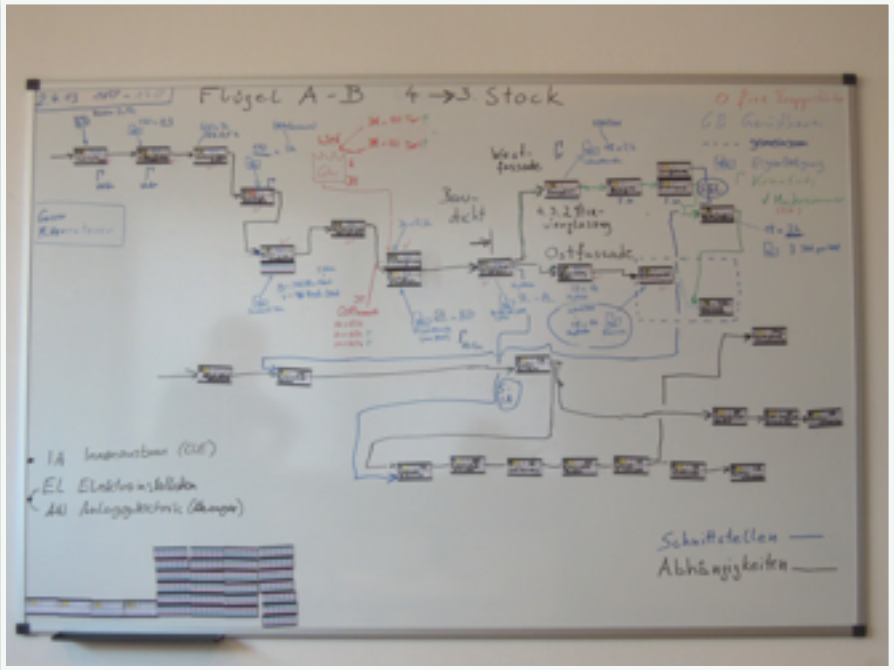
First Approach

- Expansion of the Bolzano Hospital
- Modeling
  - Decoupled from scheduling
  - Define **What** and **Where** (not yet when)
  - Collaborative modelling



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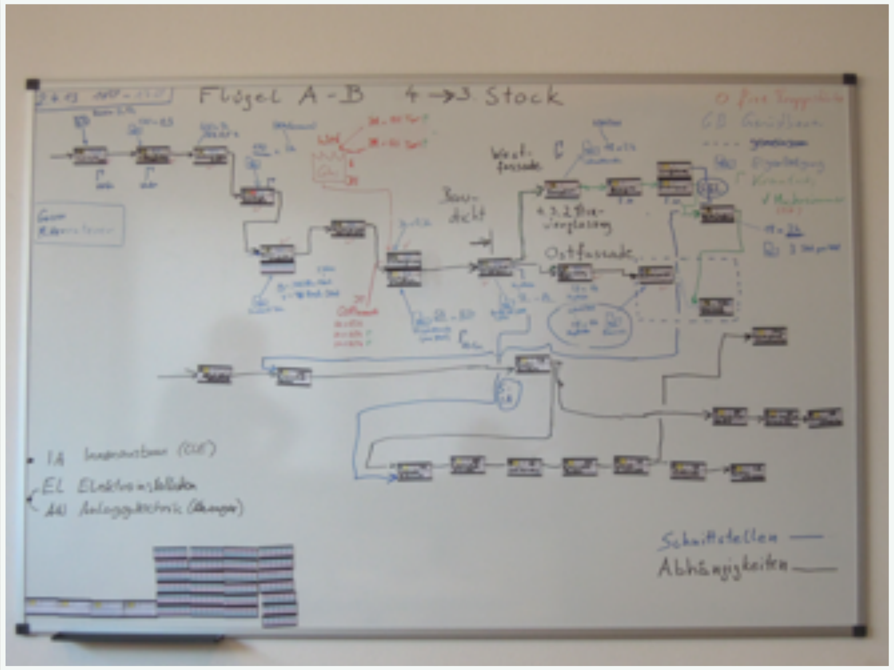
First Approach

- Expansion of the Bolzano Hospital
- Modeling
  - Decoupled from scheduling
  - Define **What** and **Where** (not yet when)
  - Collaborative modelling
- Scheduling
  - Define **How** and **When**



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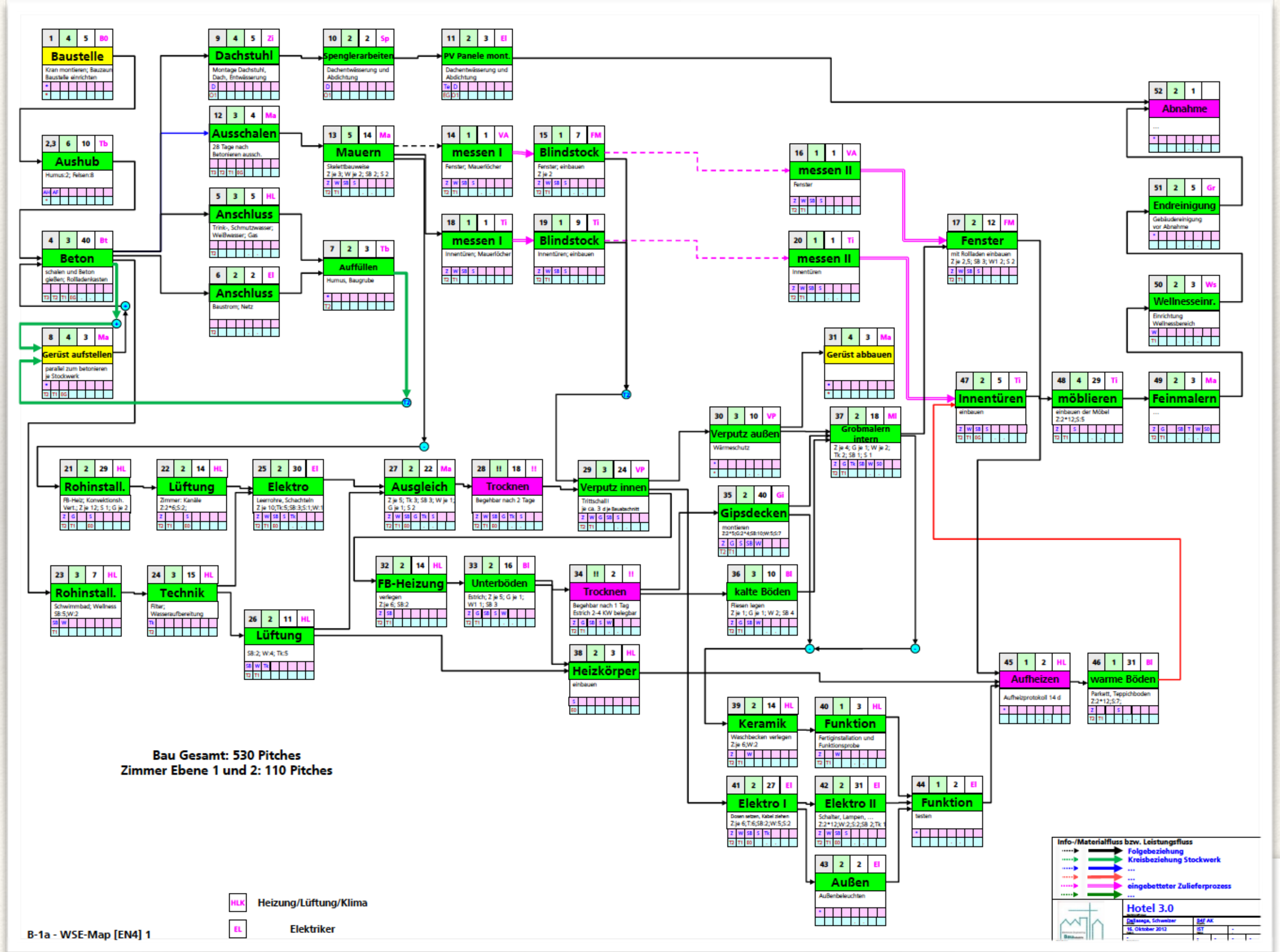
Bolzano Hospital



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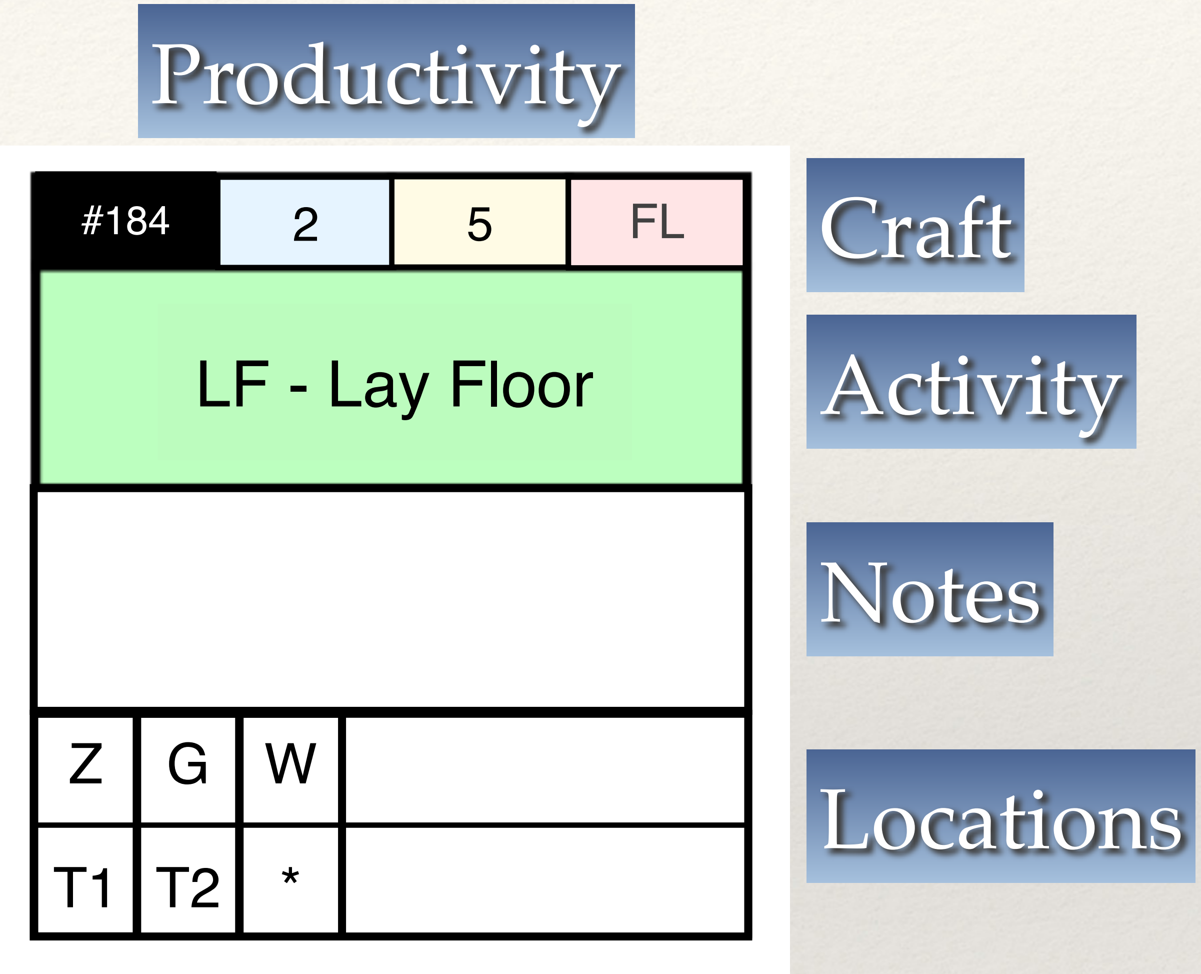
Elements in the model

- Tasks
  - What: Activity
  - Who: Craft
  - Where: Locations
  - How long: Productivity
  - Notes



Productivity

#184	2	5	FL

LF - Lay Floor

Z	G	W	
T1	T2	*	

Craft

Activity

Notes

Locations

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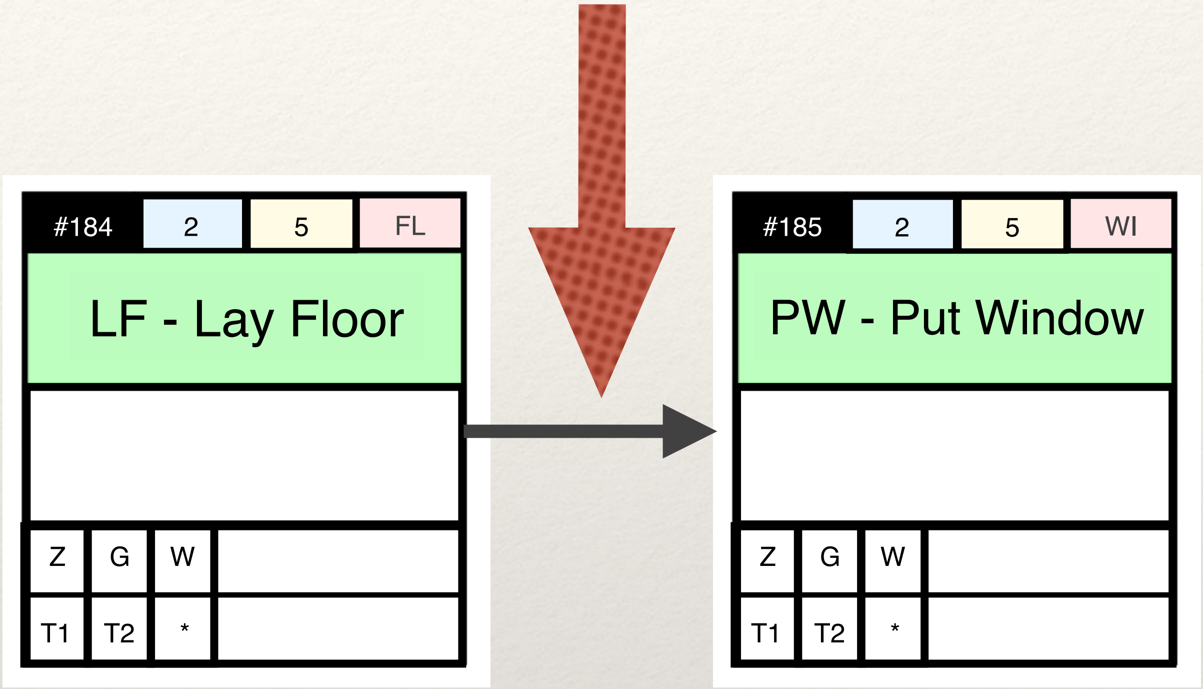
Elements in the model

- Tasks
  - What: Activity
  - Who: Craft
  - Where: Locations
  - How long: Productivity
  - Notes
- Synchronisation
  - Declarative precedences



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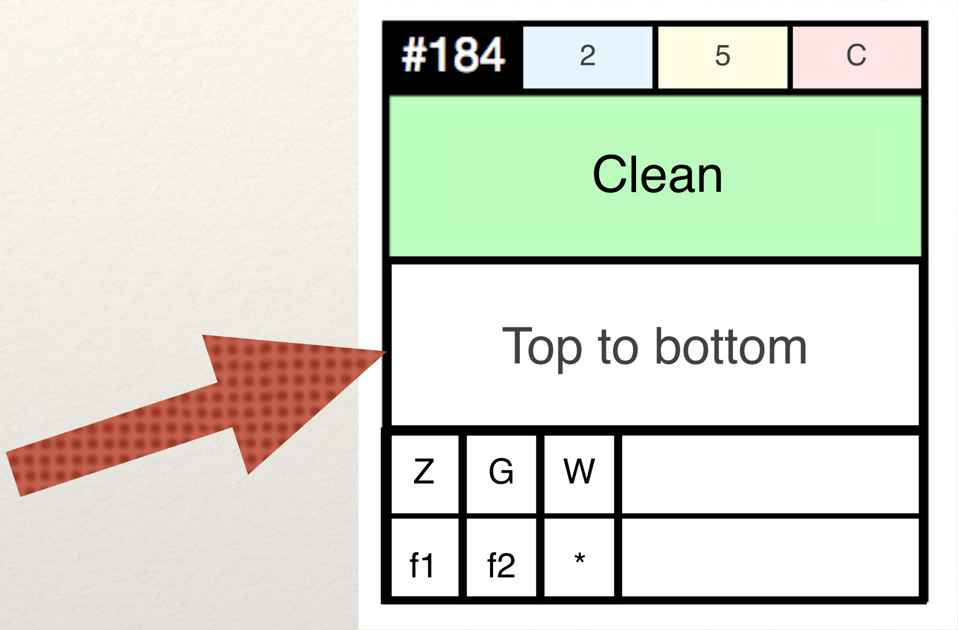
Hidden Knowledge and Ambiguities

- **Orderings**
  among the locations
  (bottom to top, top to bottom)



#184	2	5	C
Clean			
Top to bottom			
Z	G	W	
f1	f2	*	

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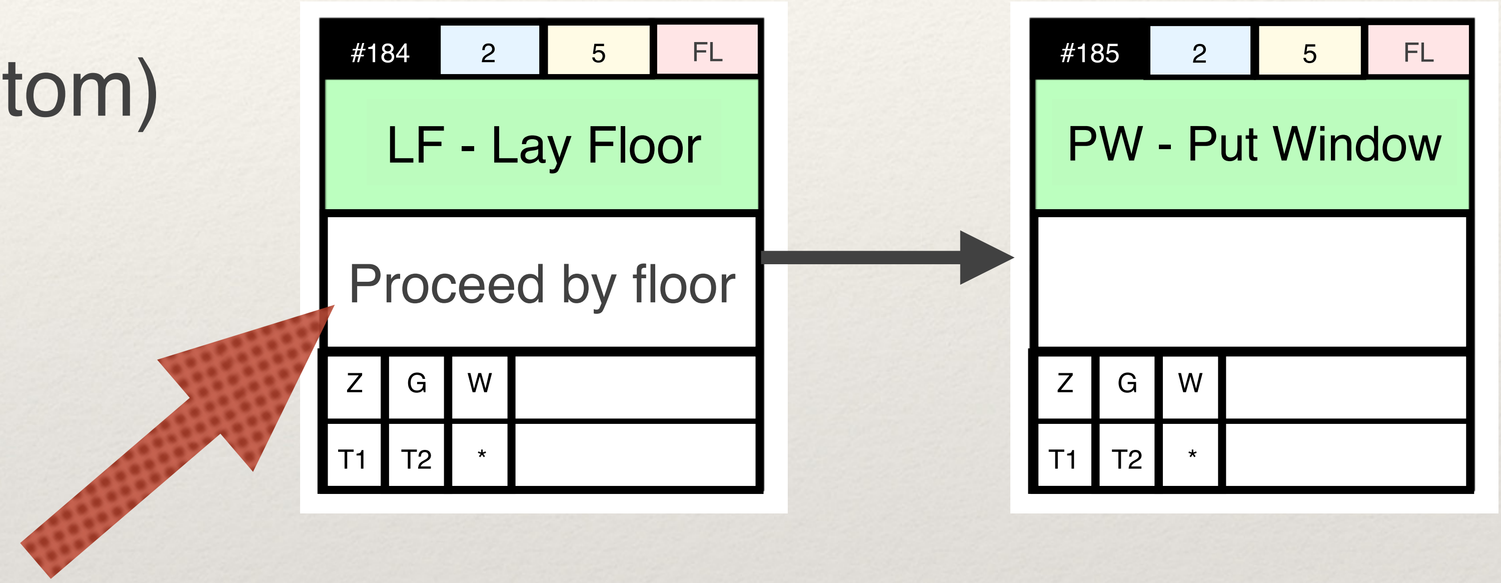
Hidden Knowledge and Ambiguities

- **Orderings**
  among the locations
  (bottom to top, top to bottom)

- Precedence **Scope**
  (floor, activity, building)



#184 2 5 FL

LF - Lay Floor

Proceed by floor

Z G W

T1 T2 *

#185 2 5 FL

PW - Put Window

Z G W

T1 T2 *

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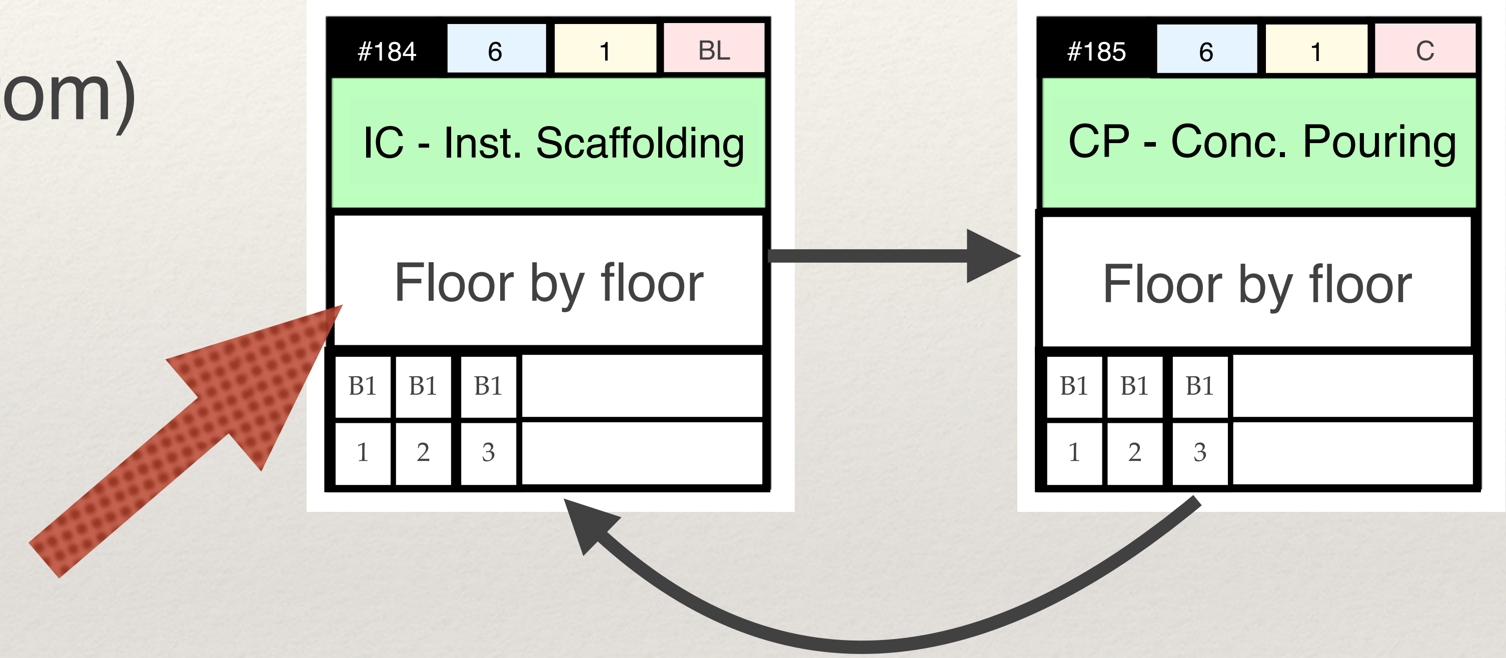
Hidden Knowledge and Ambiguities

- **Orderings**
  among the locations
  (bottom to top, top to bottom)

- Precedence **Scope**
  (floor, activity, building)

- How to perform **Loops**



#184 | 6 | 1 | BL

IC - Inst. Scaffolding

Floor by floor

B1 B1 B1

1 2 3

#185 | 6 | 1 | C

CP - Conc. Pouring

Floor by floor

B1 B1 B1

1 2 3

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Topic of Today: Modelling

- Objective process requirements
  - No n
- F
  - F
  - Formal

CoPMod: Construction Process Modeling

- We extended the language (inspired by Declare)
- Provide a logic-based (LTLf) semantics

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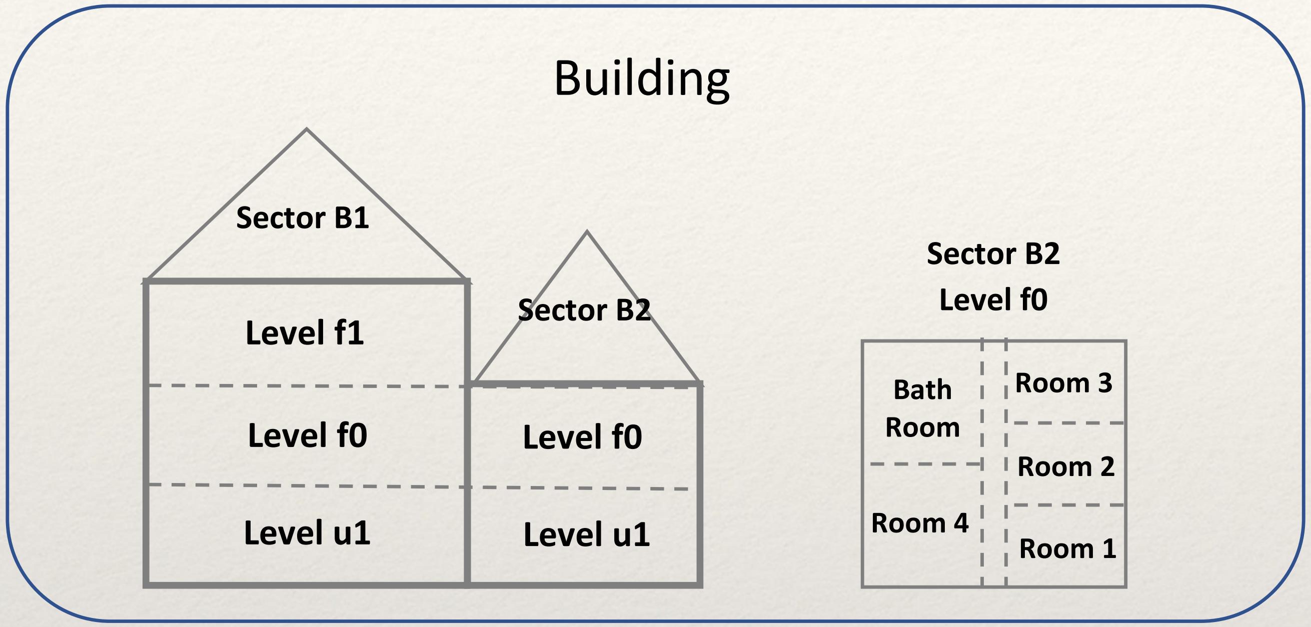
Customisable Building Representation



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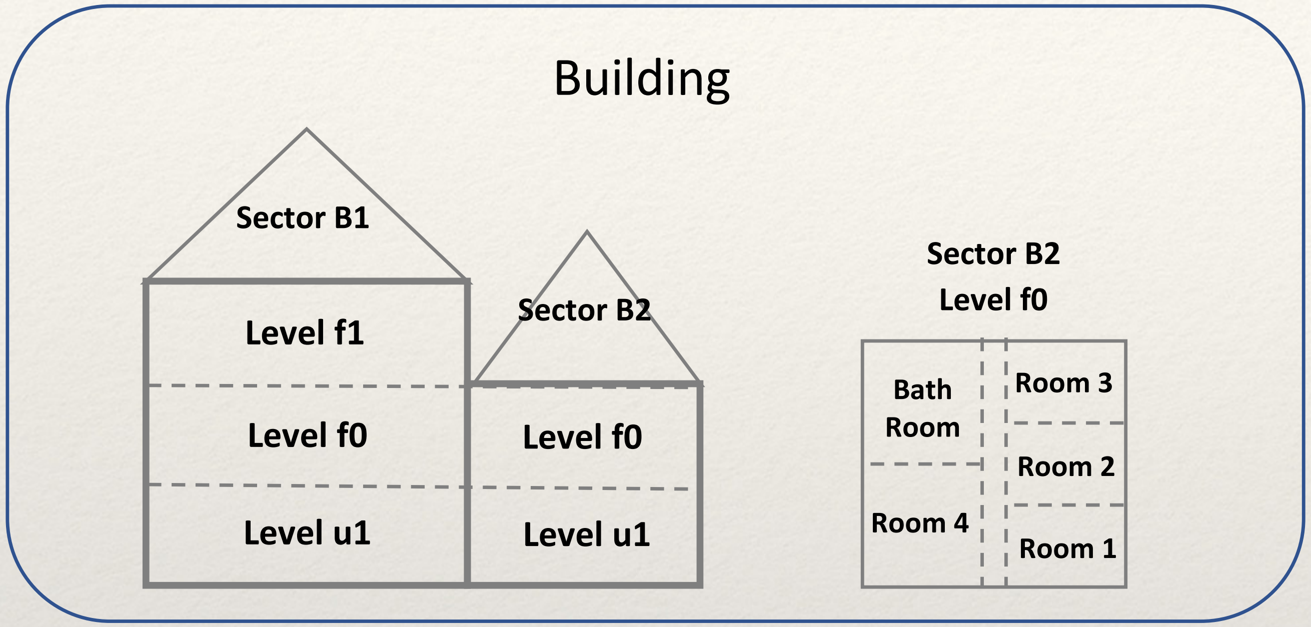
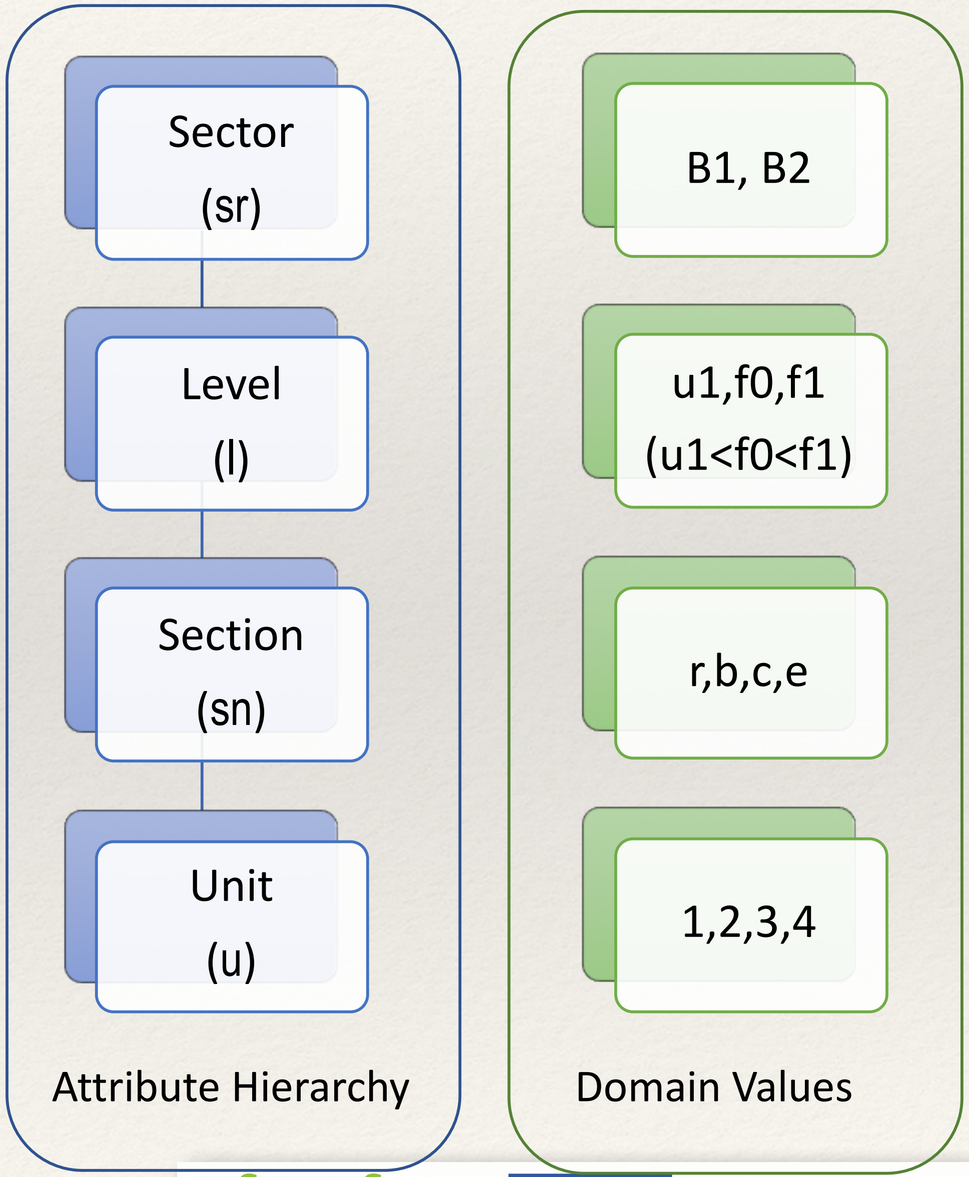
Customisable Building Representation





Sector (sr) | B1, B2

Level (l) | u1,f0,f1 (u1<f0<f1)

Section (sn) | r,b,c,e

Unit (u) | 1,2,3,4

Attribute Hierarchy

Domain Values

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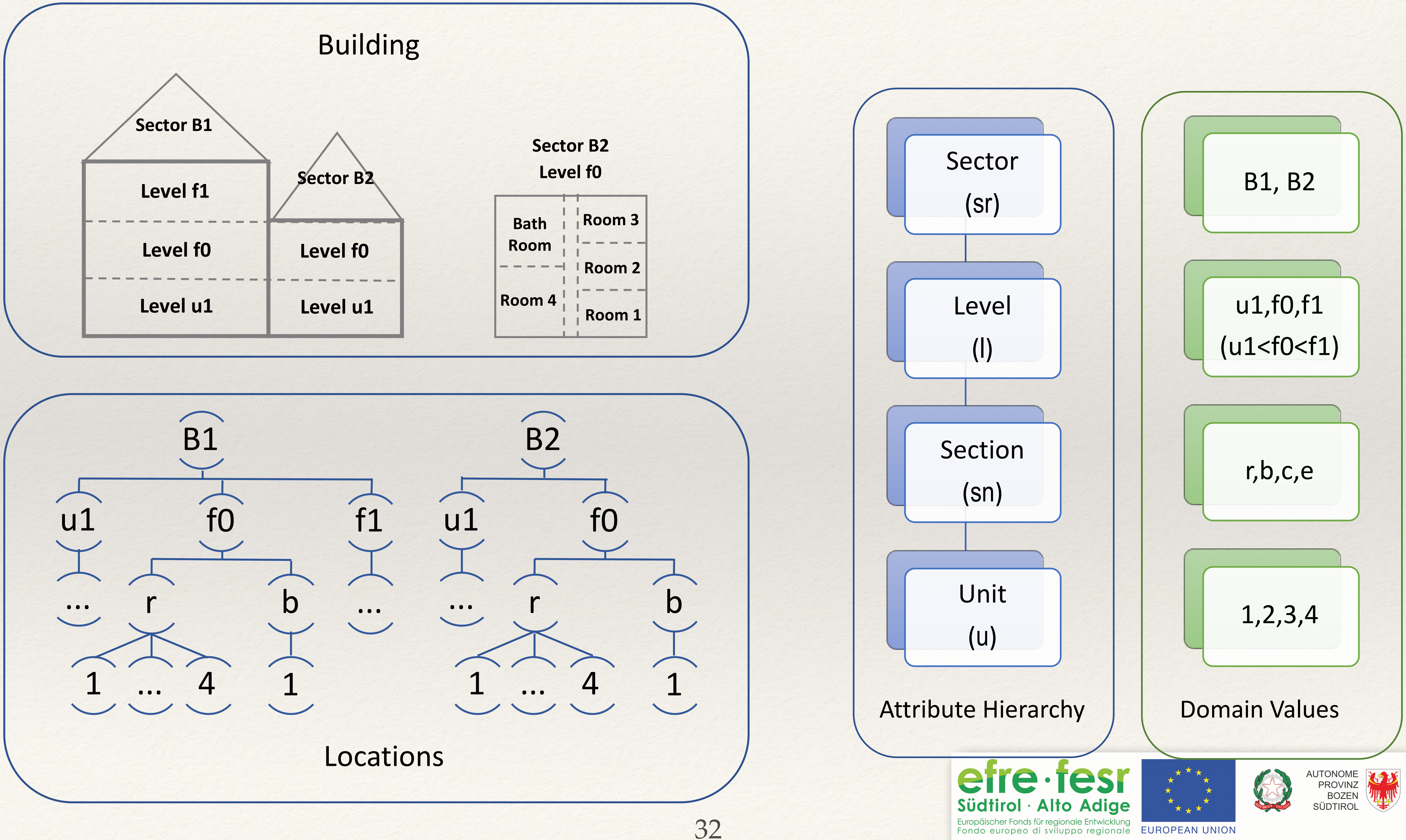
Customisable Building Representation



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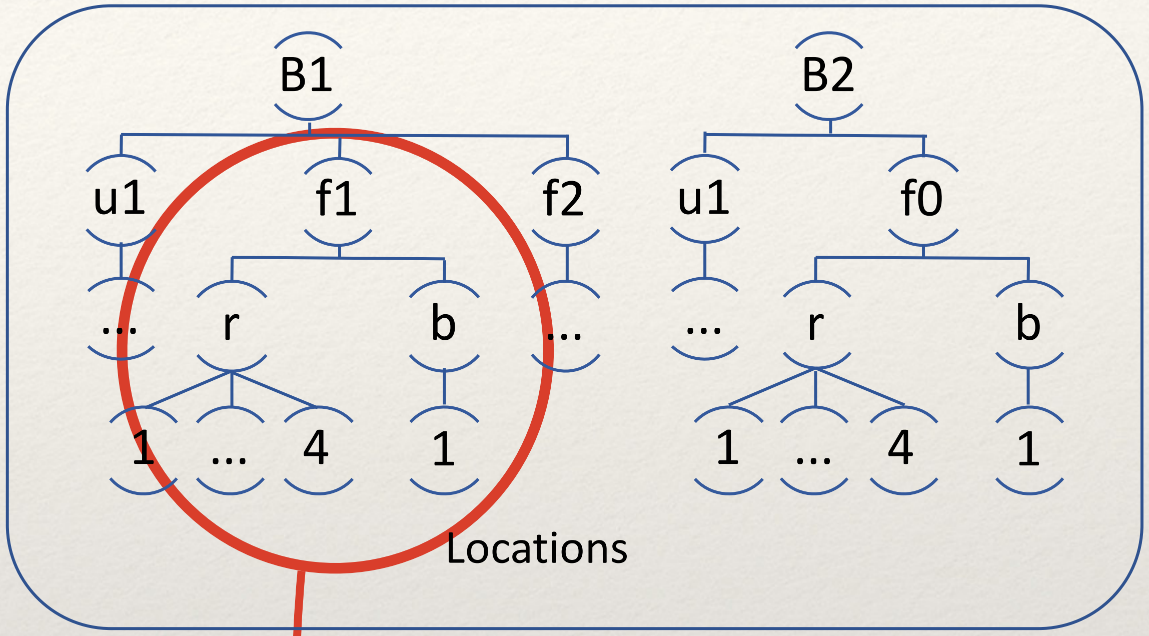
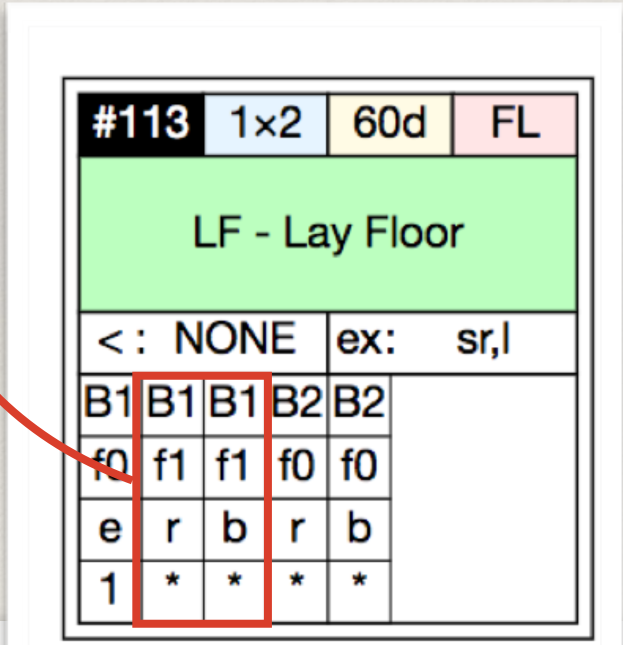
Representation of Locations

- A building is abstractly represented as a tree
- Locations in the tasks are **subtrees**



<B1,f1,r,*>
<B1,f1,b,*>



#113	1×2	60d	FL

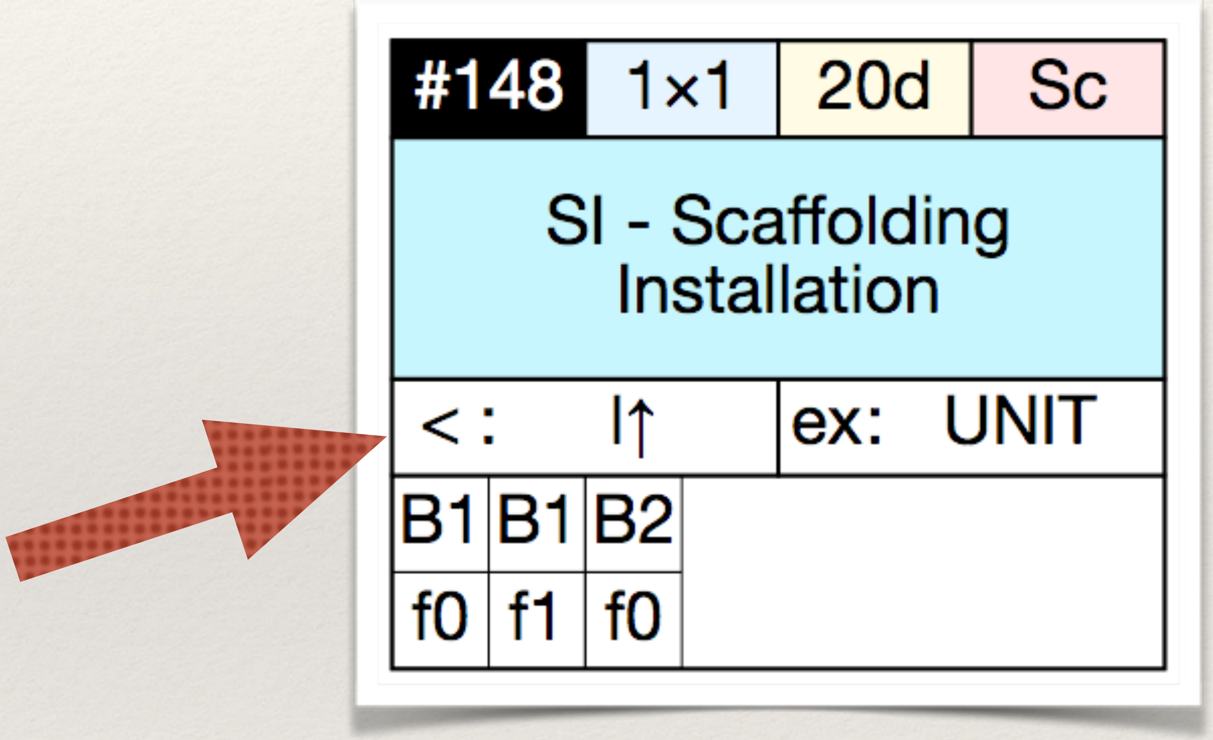
LF - Lay Floor

<: NONE | ex: sr,l

B1	B1	B1	B2	B2
f0	f1	f1	f0	f0
e	r	b	r	b
1	*	*	*	*

Ordering Constraints

- Attribute domain values can be ordered
- **Ascending** and **descending** ordering constraints



#148 1×1 20d Sc

SI - Scaffolding Installation

<: I↑ ex: UNIT

B1 B1 B2

f0 f1 f0

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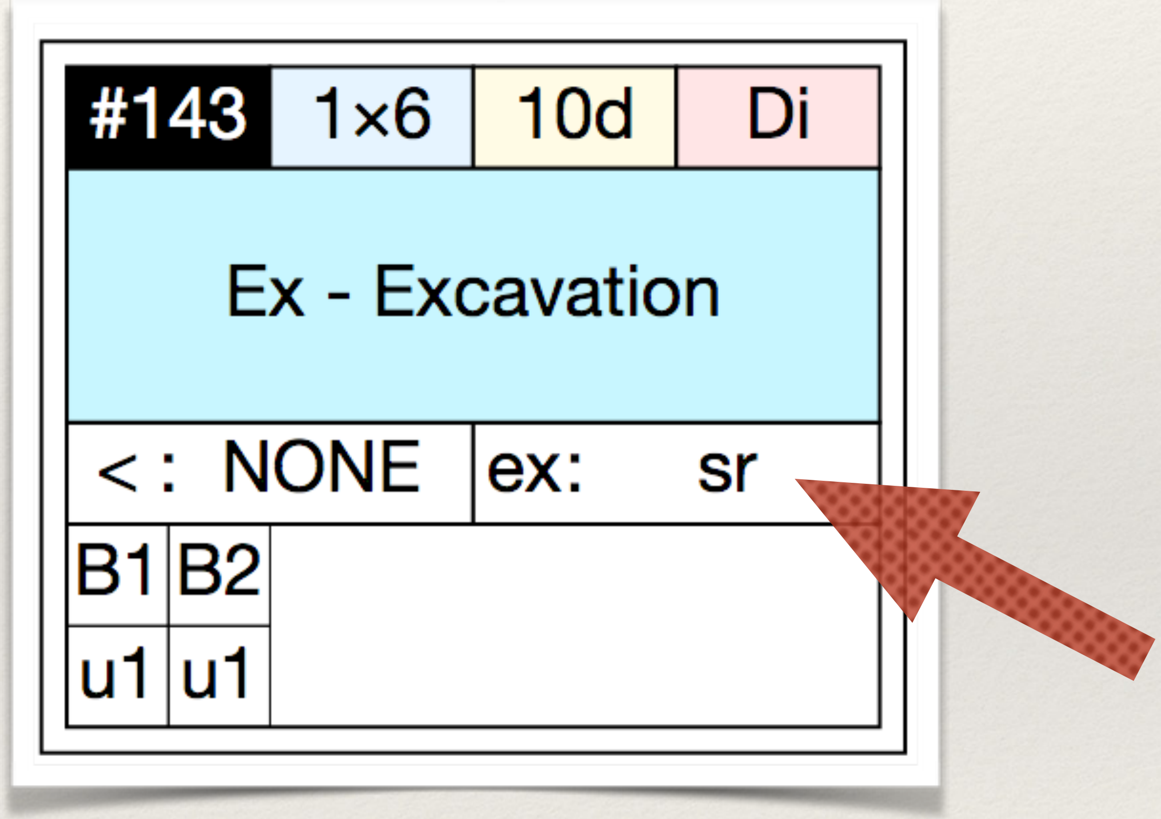
Exclusivity Constraints

- Once the task is started, **no other task** can be performed there
- By default: exclusivity at the **unit level**



#143 1×6 10d Di

Ex - Excavation

< : NONE ex: sr

B1 B2

u1 u1

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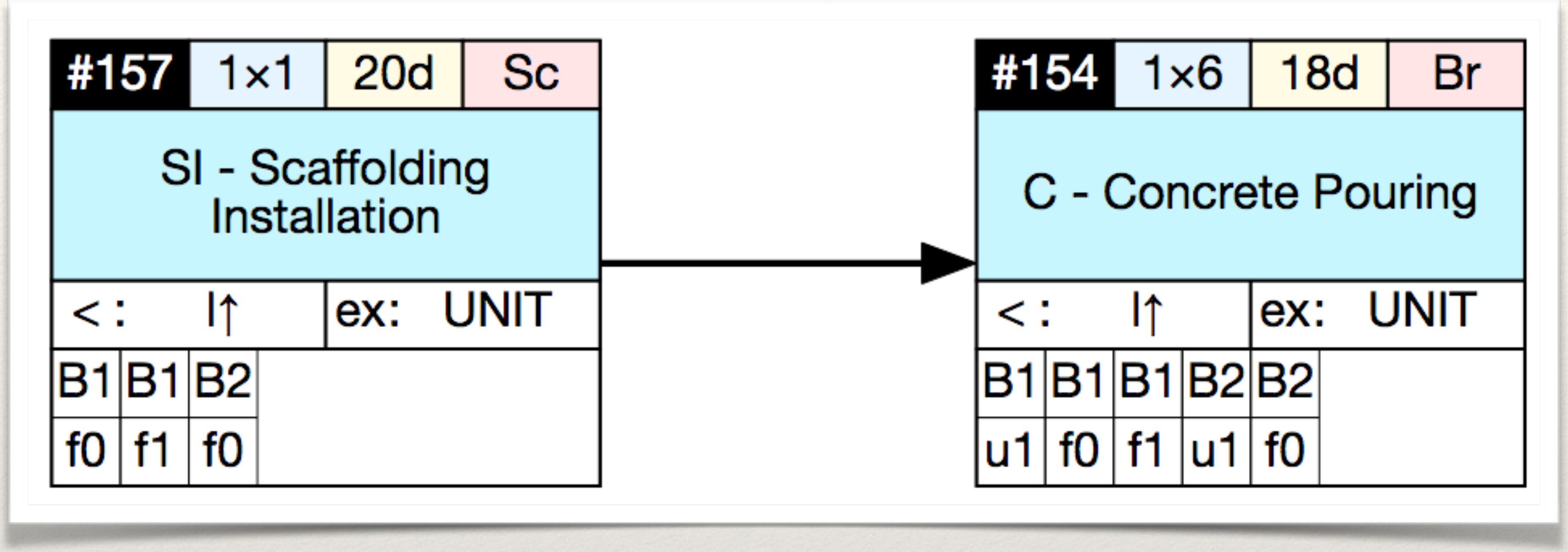
Precedences



#157 | 1×1 | 20d | Sc

SI - Scaffolding Installation

<: I↑ | ex: UNIT

B1 | B1 | B2

f0 | f1 | f0

#154 | 1×6 | 18d | Br

C - Concrete Pouring

<: I↑ | ex: UNIT

B1 | B1 | B1 | B2 | B2

u1 | f0 | f1 | u1 | f0

- Precedences between activities

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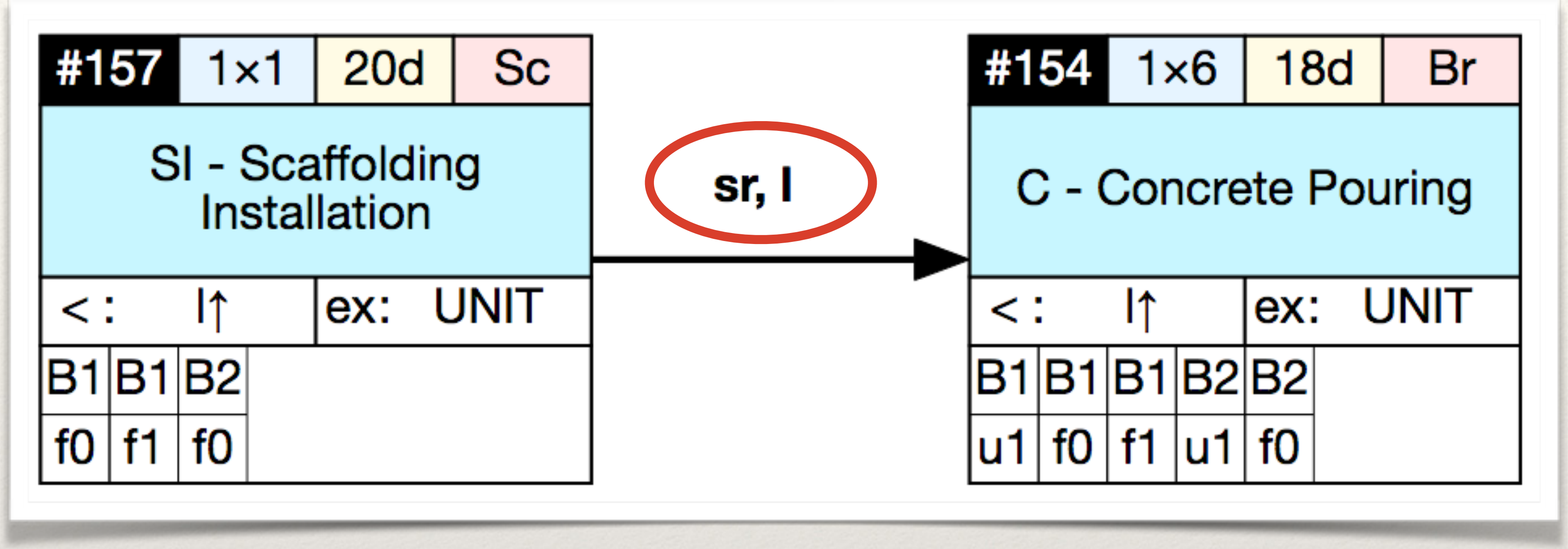
Precedences: Scope



#157 1×1 20d Sc

SI - Scaffolding Installation

<: l↑ ex: UNIT

B1	B1	B2
f0	f1	f0

sr, l

#154 1×6 18d Br

C - Concrete Pouring

<: l↑ ex: UNIT

B1	B1	B1	B2	B2
u1	f0	f1	u1	f0

- The **Scope** specialises the precedence (e.g., precedence by <sector, level>)
- By default: **Activity level**

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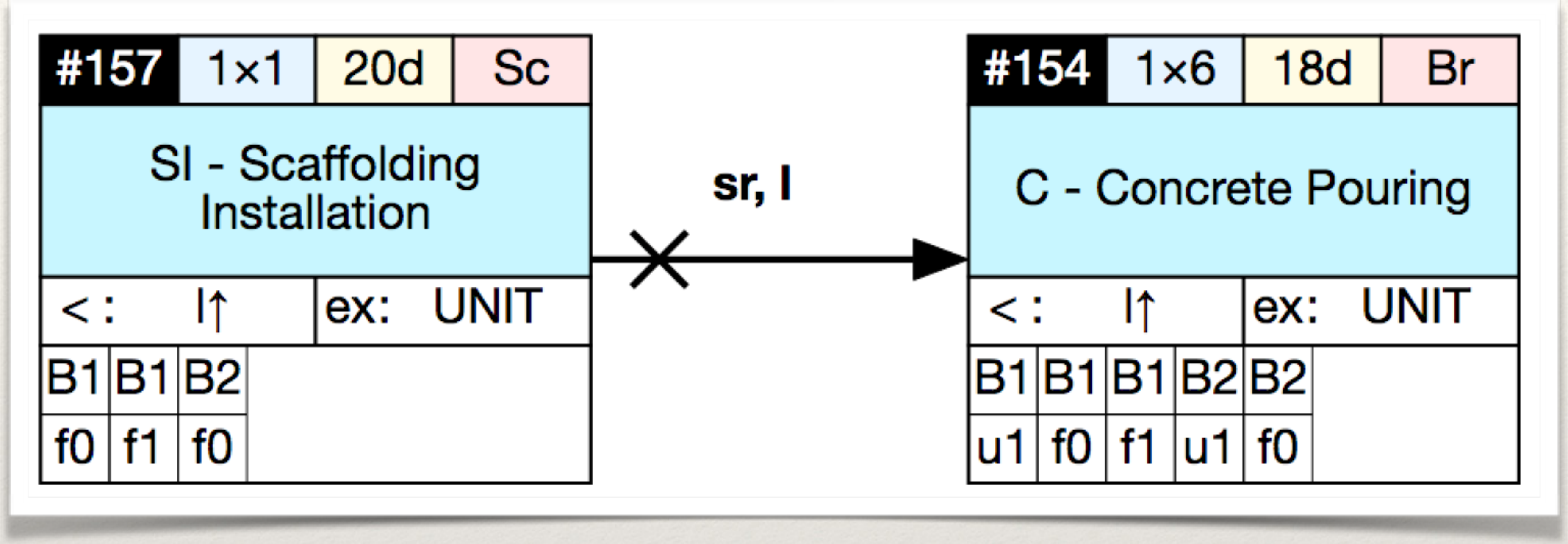
Precedences: Alternate Precedence



#157 | 1×1 | 20d | Sc

SI - Scaffolding Installation

<: l↑ | ex: UNIT

B1	B1	B2
f0	f1	f0

sr, l

#154 | 1×6 | 18d | Br

C - Concrete Pouring

<: l↑ | ex: UNIT

B1	B1	B1	B2	B2
u1	f0	f1	u1	f0

- **Alternation** between antecedent and consequent:
  - antecedent **before** consequent
  - **and** the antecedent has to **wait** for the consequent

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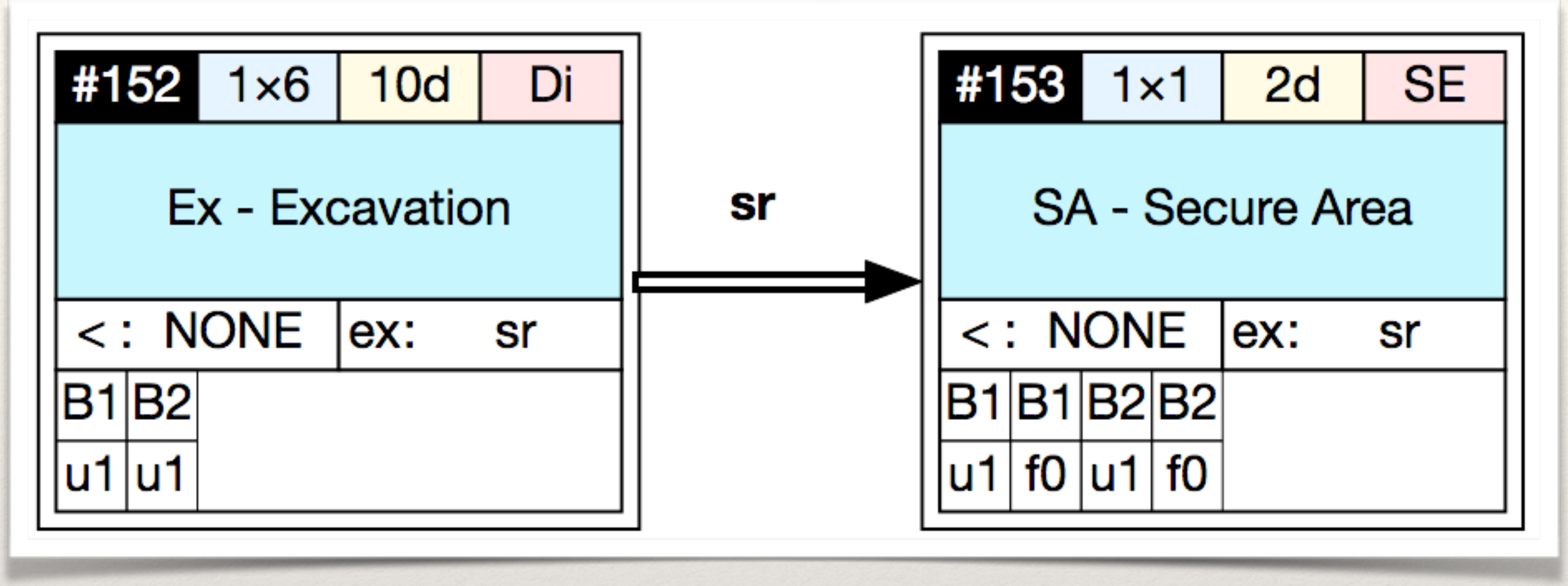
Precedences: Chain Precedence



- **Chain** between two activities:
  - **no** other activities can be performed **in-between**

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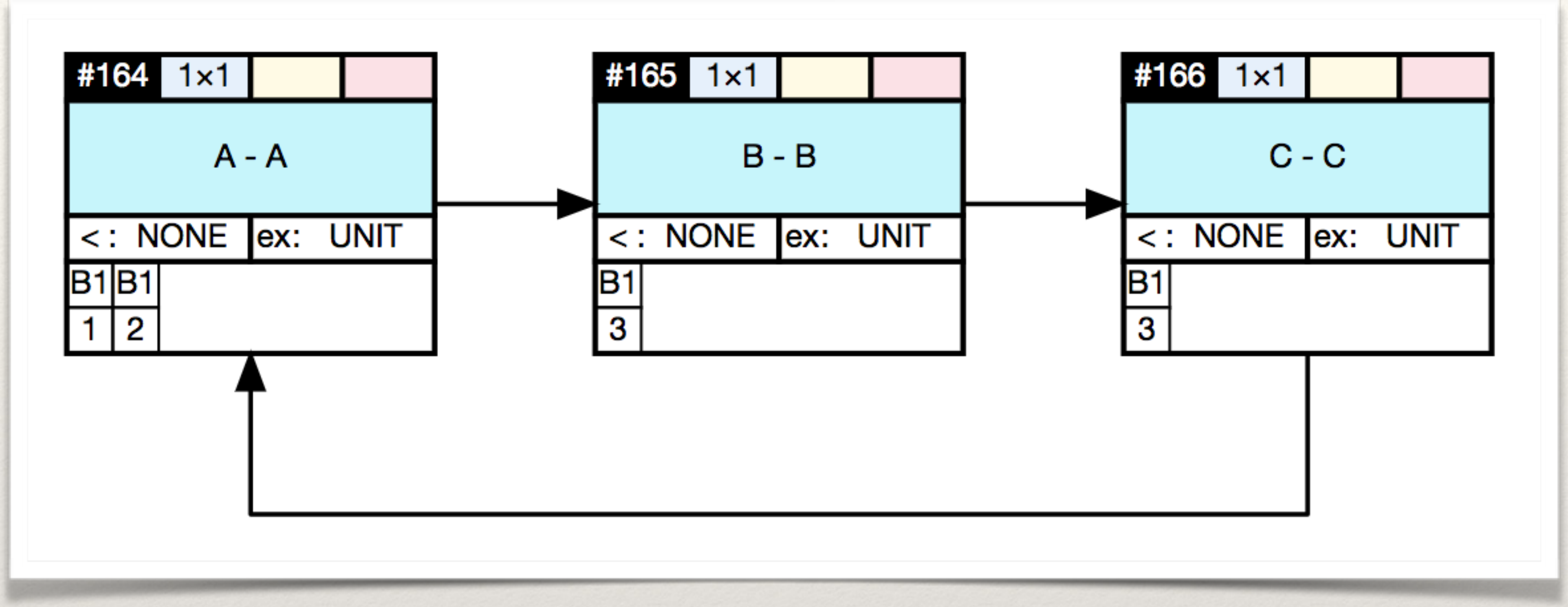
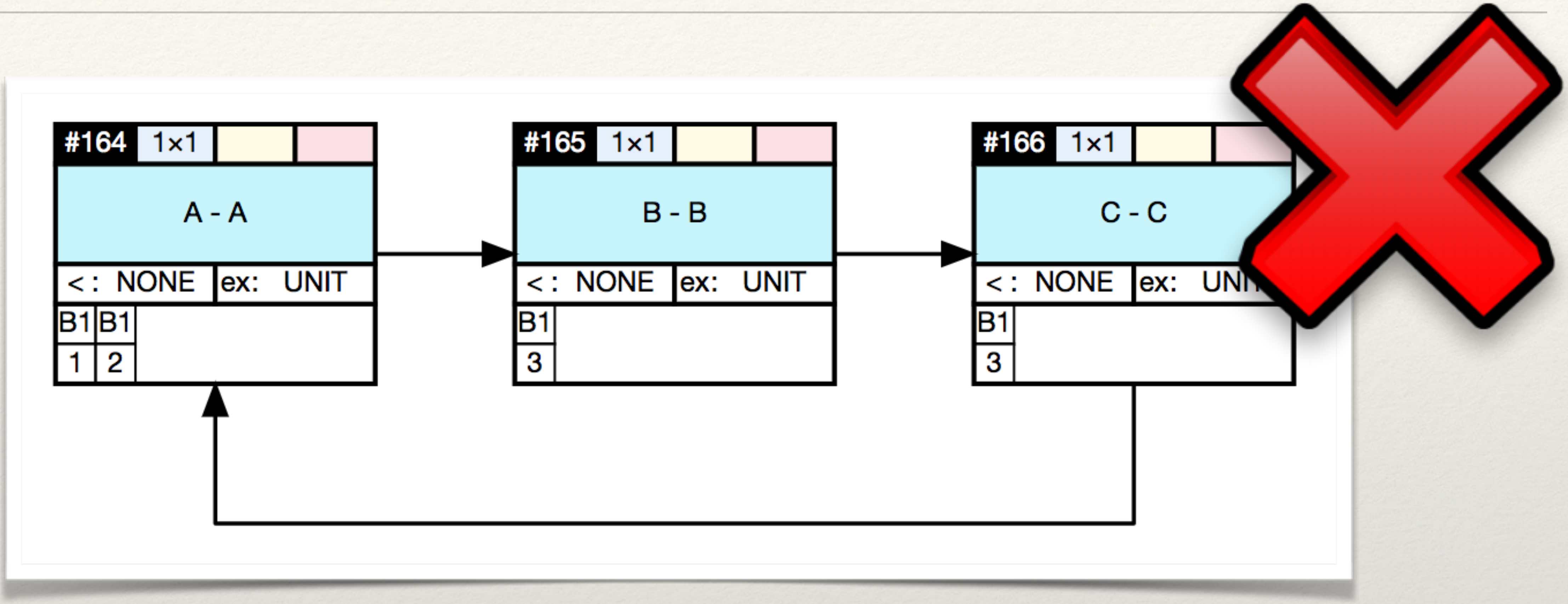
Does my model make sense?



Does my model make sense?



- Is there an execution satisfying all the constraints?
  Satisfiability Check

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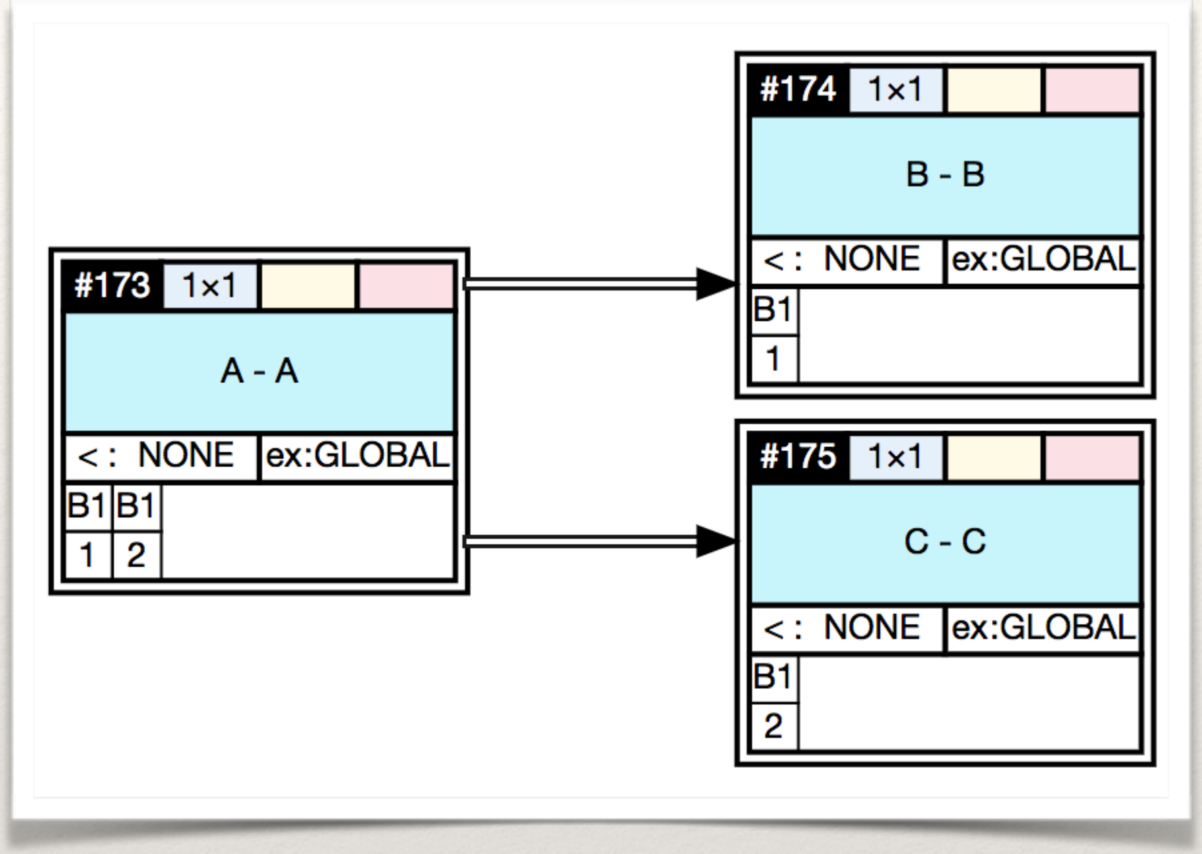
Satisfiability Check



- Is checking for loops enough to determine **Satisfiability**?

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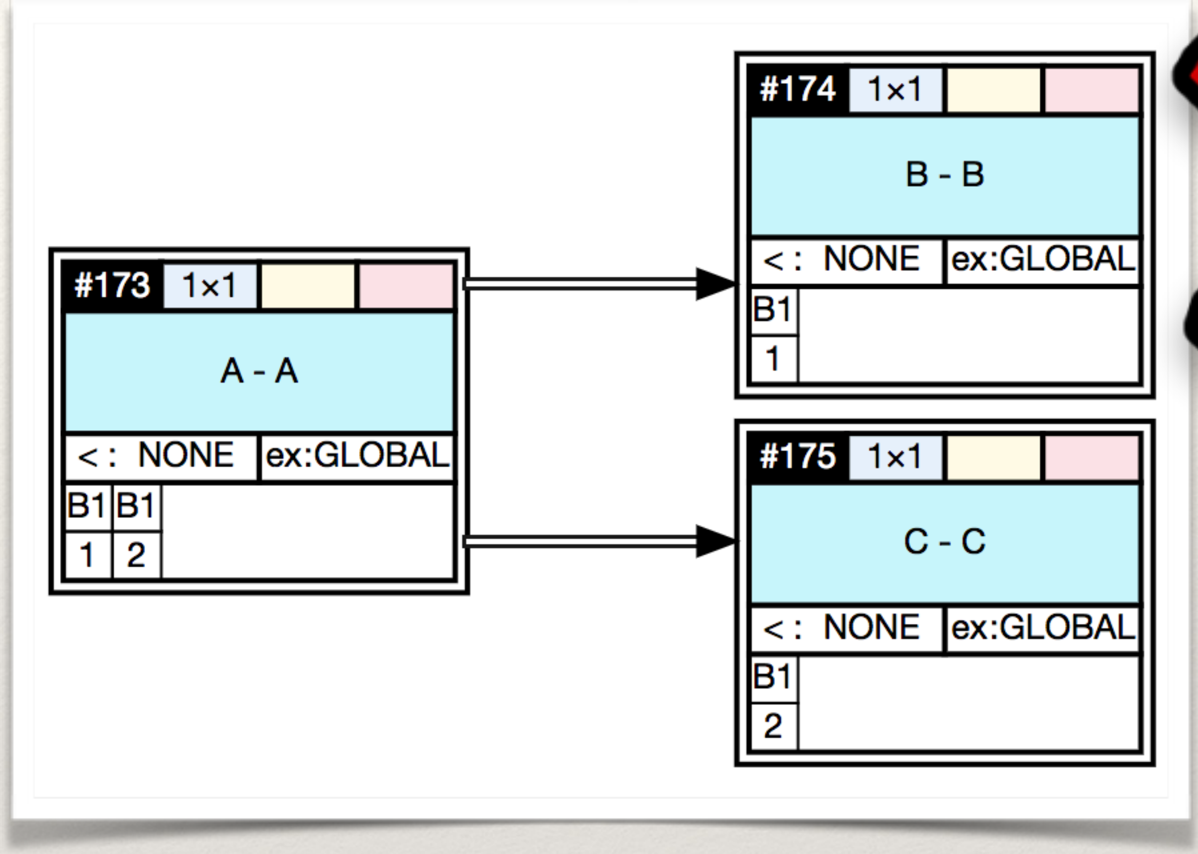
Satisfiability Check



- Is checking for loops enough to determine **Satisfiability**?
    - **No,**
    - Consider also the **dependencies**, **scopes** and **locations**

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How to Check Satisfiability?

- Our model has a logic based semantics (LTLf)
- We can apply model checking techniques
- We performed some experiments using NuSMV

(state-of-the-art model checker)

How to Check Satisfiability?

	Model	Tasks	Dep.	Loc.	NuSMV
✓	Sat.	8	9	312	**2min 35s**
✗	Non-sat.	8	9	312	**>1h**

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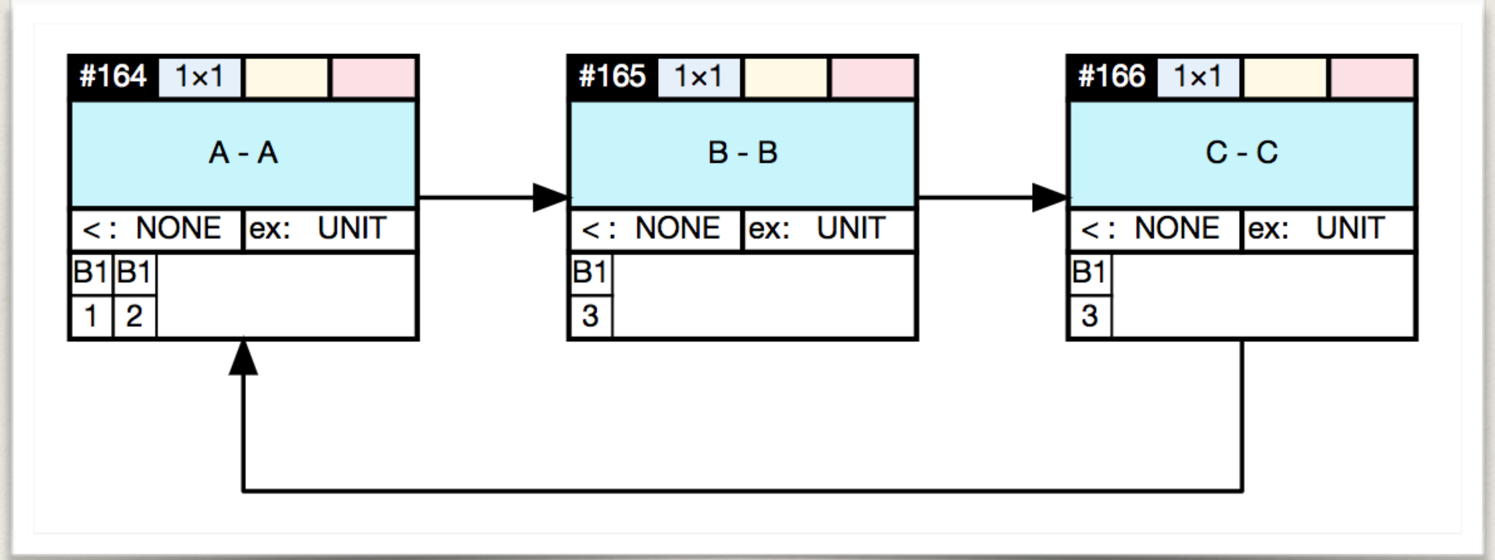
Other Way to Check Satisfiability?

- Translate a Diagram into a Task-Unit (TU) Graph



<A, B1-1>

<A, B1-2>

<B, B1-3>

<C, B1-3>

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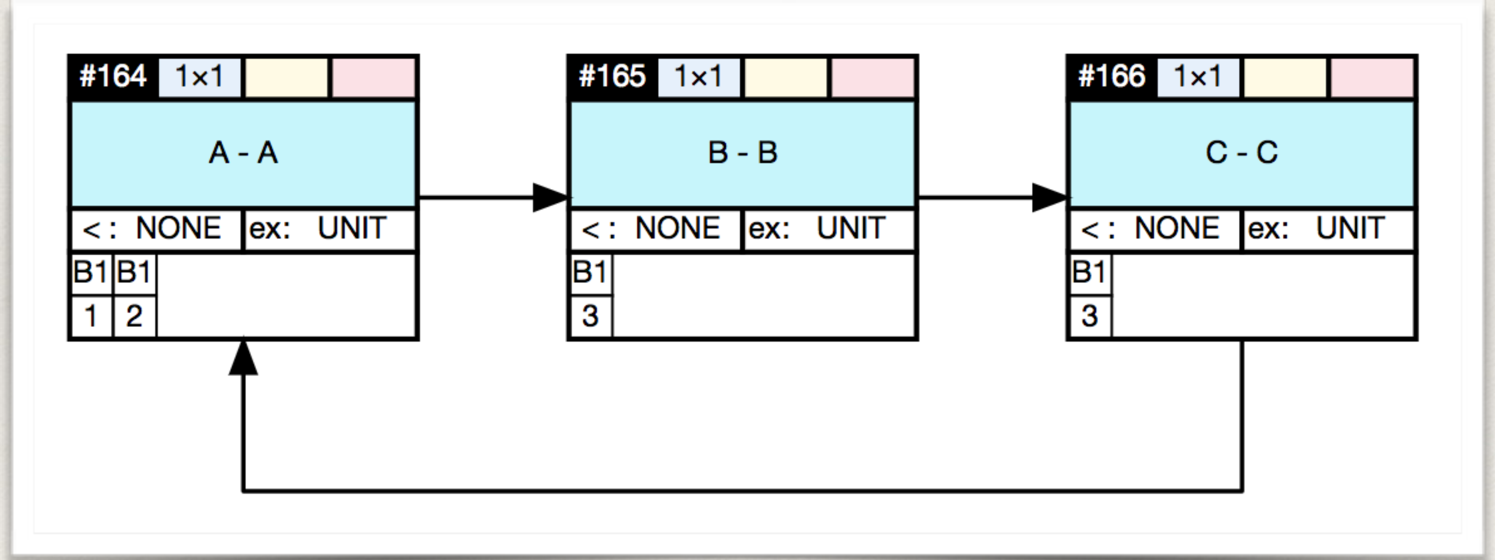
Other Way to Check Satisfiability?

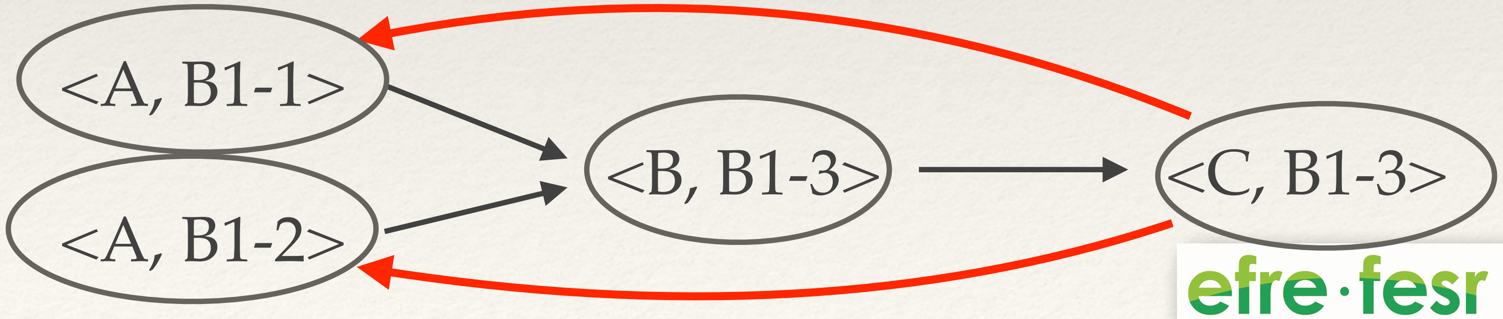
- Translate a Diagram into a Task-Unit (TU) Graph
- Translate the precedences into arrows between TU nodes



#164 1×1
A - A
<: NONE ex: UNIT
B1 B1
1 2

#165 1×1
B - B
<: NONE ex: UNIT
B1
3

#166 1×1
C - C
<: NONE ex: UNIT
B1
3



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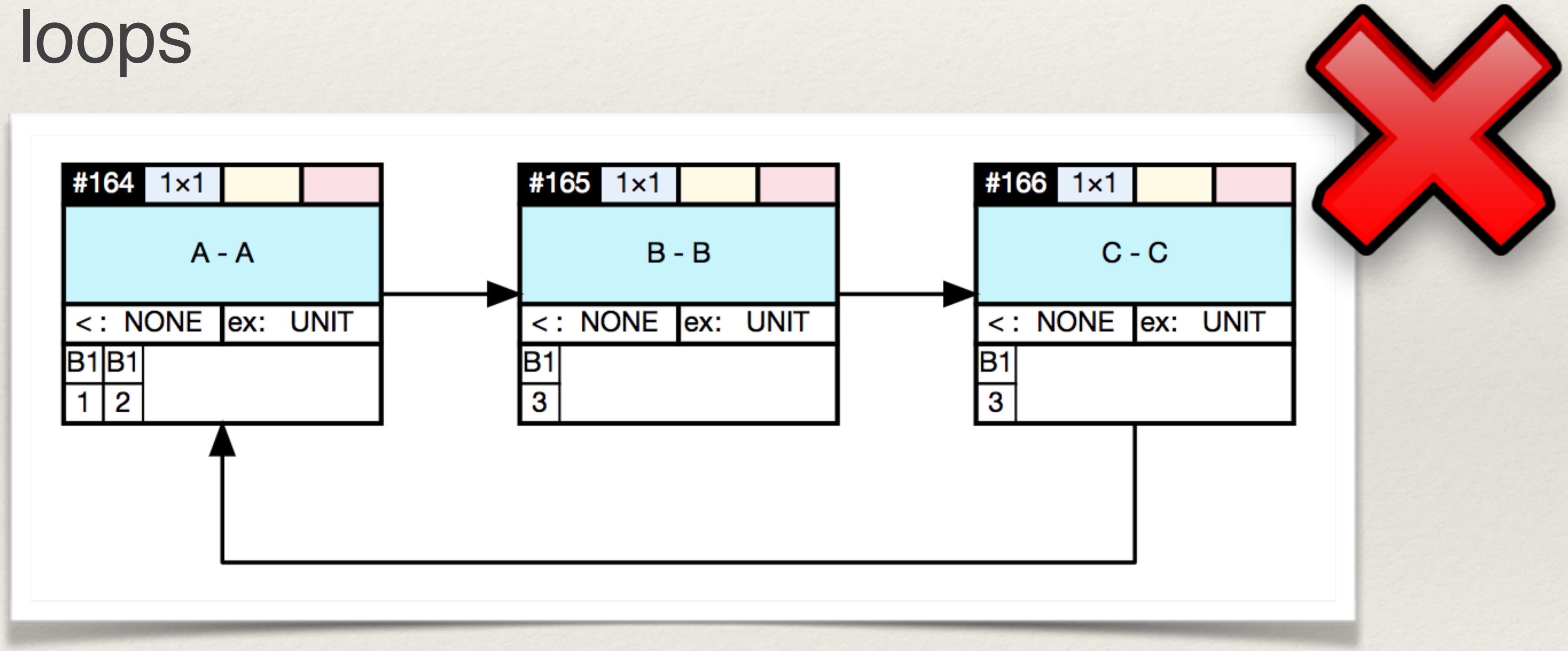
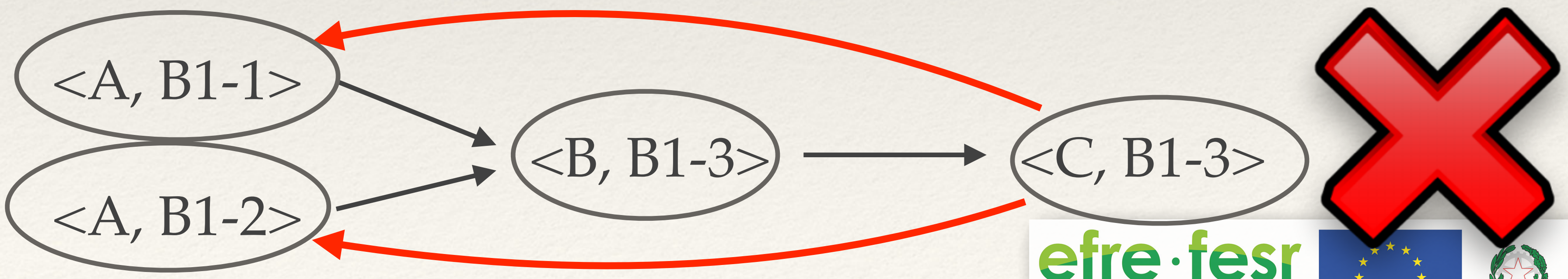
Other Way to Check Satisfiability?

- Translate a Diagram into a Task-Unit (TU) Graph
- Translate the precedences into arrows between TU nodes
- Check for loops





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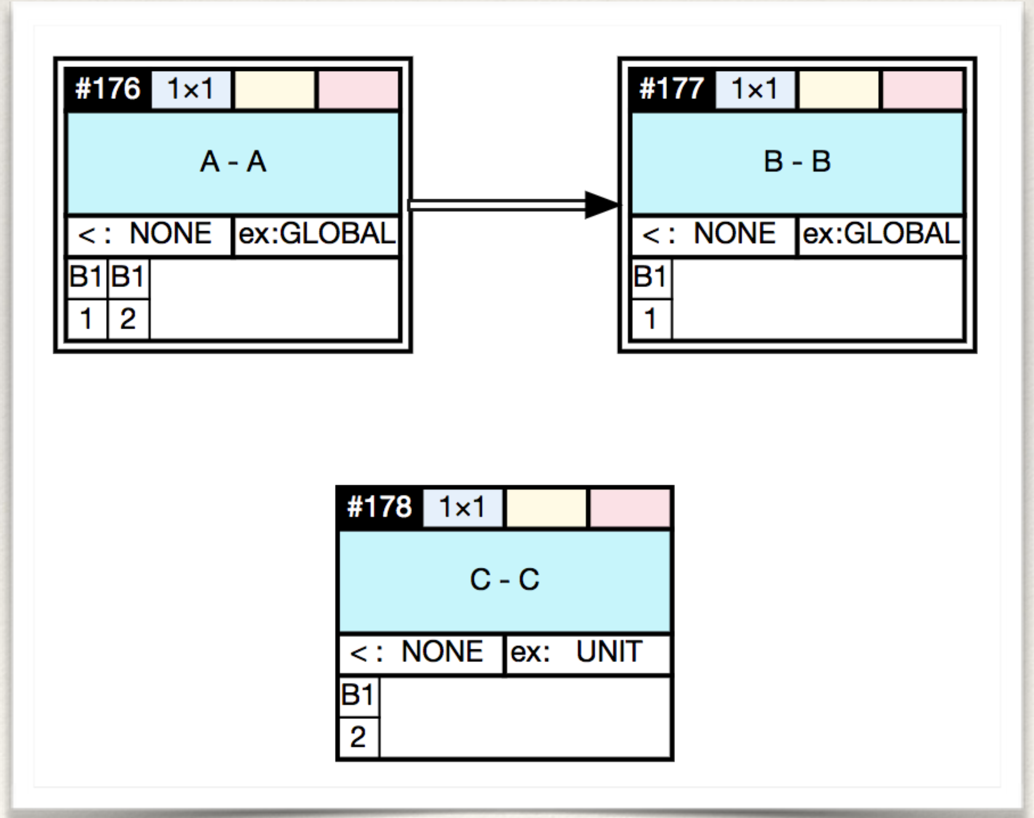
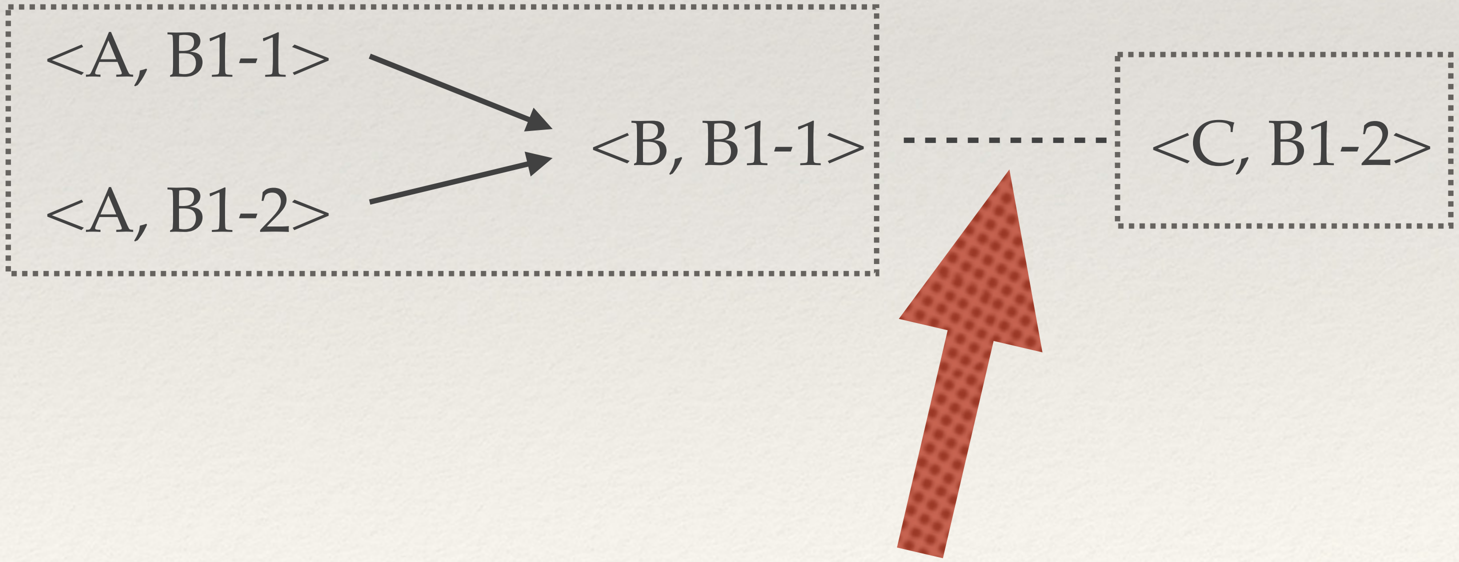
Disjunction in the TU Graph

- Some constraints introduce disjunction
- One has to check possible orientations





<A, B1-1>

<A, B1-2>

<B, B1-1>

<C, B1-2>

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Algorithm at a Glance

- **Check for Cycles**
    - Cycles: If the graph contains a cycle then is not orientable

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Algorithm at a Glance

- **Check for Cycles**
  - Cycles: If the graph contains a cycle then is not orientable
- **Deterministic Orientation**
  - Direct the undirected edges for which only one orientation is possible

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Algorithm at a Glance

- **Check for Cycles**
  - Cycles: If the graph contains a cycle then is not orientable
- **Deterministic Orientation**
  - Direct the undirected edges for which only one orientation is possible
- **Divide&Conquer**
  - Partition the graph so that:
    - orientability can be checked for each subgraph
    - by trying all orientations

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Satisfiability Check

	Model	Tasks	Dep.	Loc.	Nodes	Arcs	Edges	NuSMV	US
✓	Sat.	8	9	312	236	9415	524	2min 35s	**27 ms**
✗	Non-sat.	8	9	312	236	10003	521	>1h	**5 ms**

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✗	Bigger	12	14	312 (2)	244	9435	574	>1h	10 ms
✗	More Edges	12	14	312 (47)	424	15131	1740	>1h	23 ms

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✗	More Edges	12	14	424	15131	1740	23 ms
✗	Bigger	480	1291	16,960	1,436,759	678,680	55,866 ms (~1 min)
✗	Bigger	720	2,526	25,440	3,082,925	1,526,820	379,409 ms (~6.32 min)
✗	Bigger	960	4,187	33,920	5,217,426	2,714,160	OOM

Summary

- CoPMod: Constuction Process Modelling Language
  - Graphical
  - Declarative: captures process requirements (what and not how)
  - Formal
- Effective algorithm to check satisfiability
- proof-of-concept tool @copmod.inf.unibz.it

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Future Work

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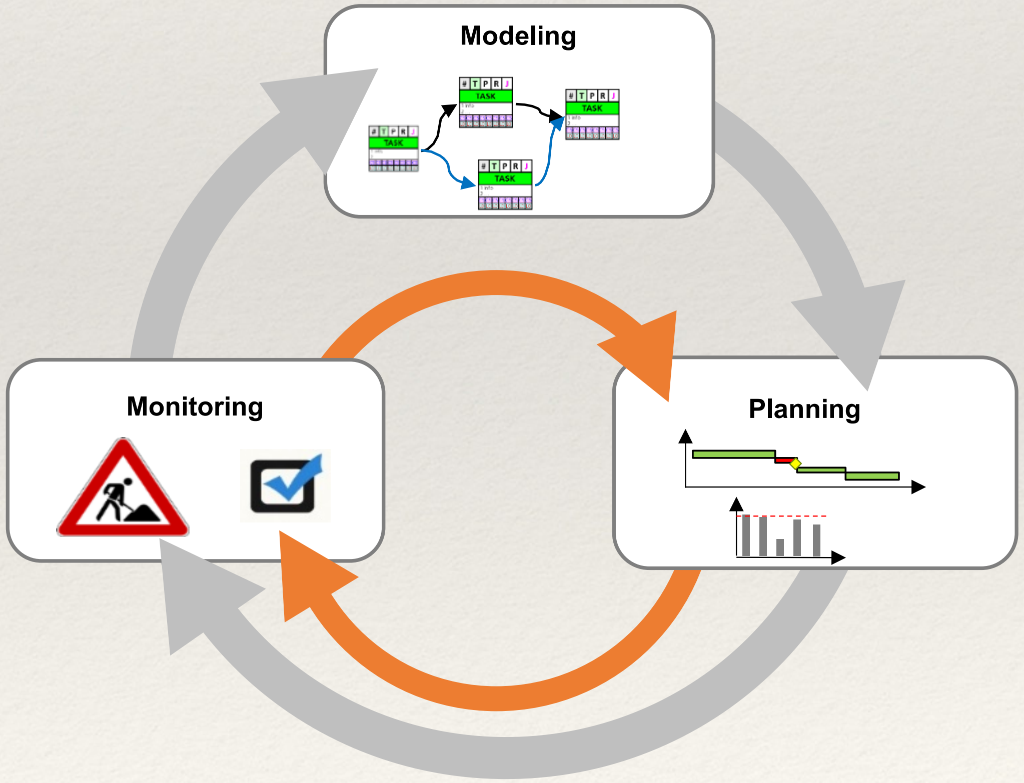
- COCkPiT:
  Collaborative Construction Project managemenT
- Integrate Automatic Schedule:
  - Modeling
  - Automated Scheduling
  - Monitoring/Analysis



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KRDB — Summer Online Seminars

Thank you

Elisa Marengo
Werner Nutt
Matthias Perktold

Free University of Bolzano