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Discrete-Event Modeling and Simulation for Development of Embedded and Real-Time Systems

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Carleton University Centre on Visualization and Simulation

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- **Interdisciplinary research**
  - Systems Engineering
  - Mechanical & Aerospace
  - Cognitive Science
  - Architecture

ARSLab — Advanced Real-Time Simulation Laboratory
SIMULATION EVERYWHERE

- *9 Faculty members (3 Invited Professors)*
- *8 Postdoctoral Fellows*
- *6 Ph.D. and 7 Masters students; 12 UG*

- *8 Postdocs, 18 Ph.D. and 58 Masters Students graduated since 2000*
- *120+ Engineering Capstone Projects since 2000*

MASTERS IN MODELING AND SIMULATION

Research Support

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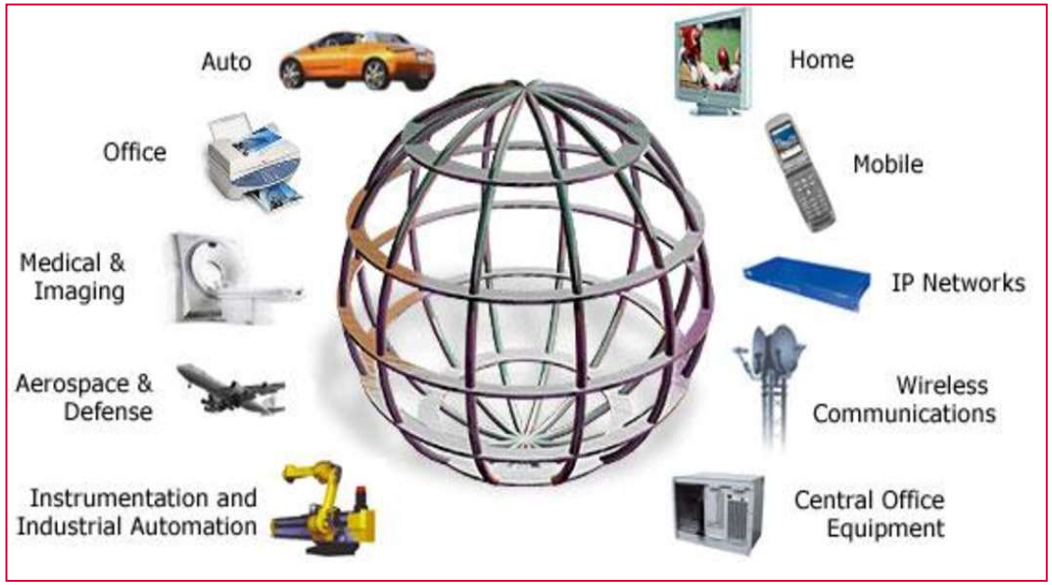
Motivation

- **Cyber-PhysicalSystems (CPS)**



- Growing popularity; increasing heterogeneity and complexity.
- Tightly coupled hardware and software for a dedicated function.
- Logical and functional correctness + Timing correctness.
- critical applications

Solution? Formal Methods

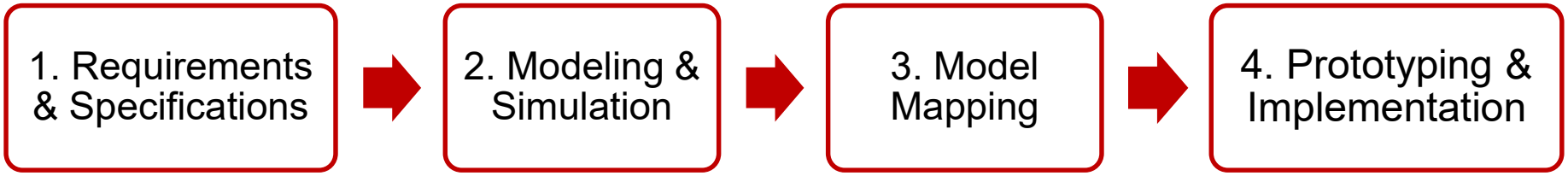
- **Formal Methods**
  - *(+) Mathematical specification and analysis of the designs*
  - *(+) Provable; Reliable*
  - *(-) Too complex*
  - *(-) Hard to prove when the design space scales up*

- **Techniques focus on software only**
  - Models of the controlled **physical environment**?
  - Decision-making, training, validation: no good **visualization** tools

Motivation

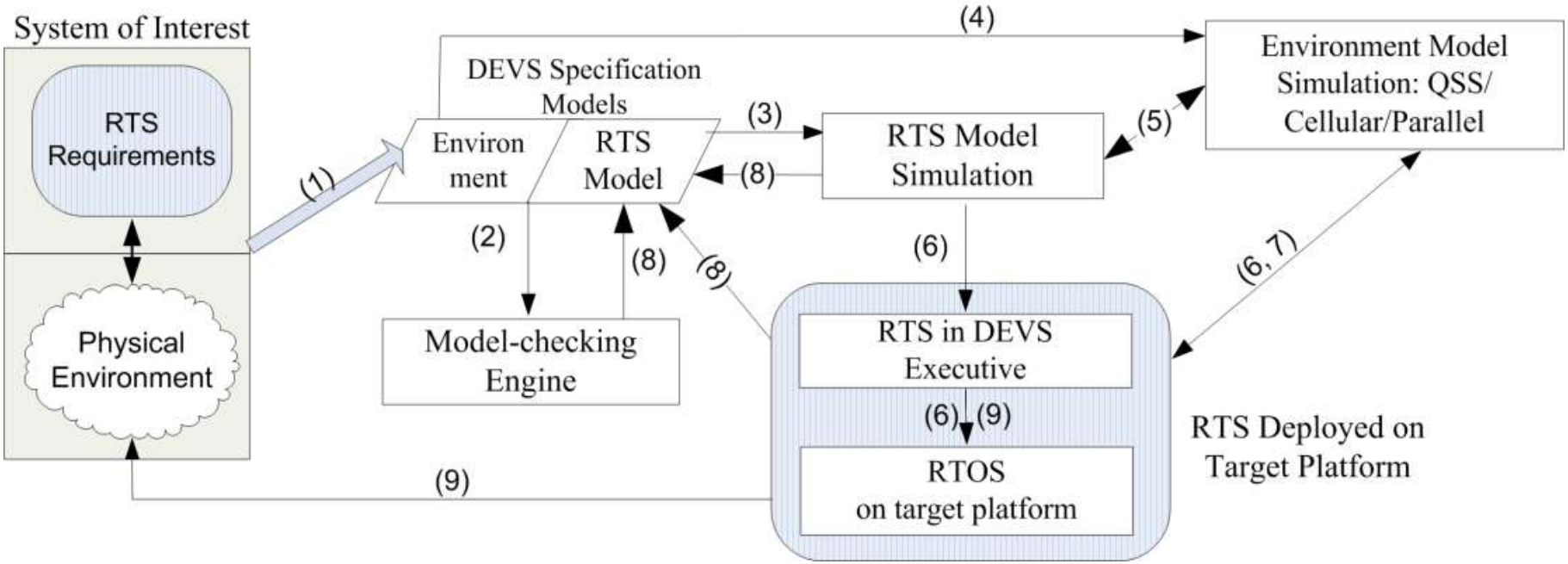
Development Methods

- No adequate and robust framework for design optimal solutions.
- Suggested solutions and shortcomings:
  - *Formal Methods – Hard to scale up*
  - *Modeling and Simulation (M&S) approaches – Not formal*



- Key Issue: Model Continuity
  - *Models thrown away*
  - *Development done from scratch*

DE Modeling of Cyber-Physical Systems Methodology



Model Specification

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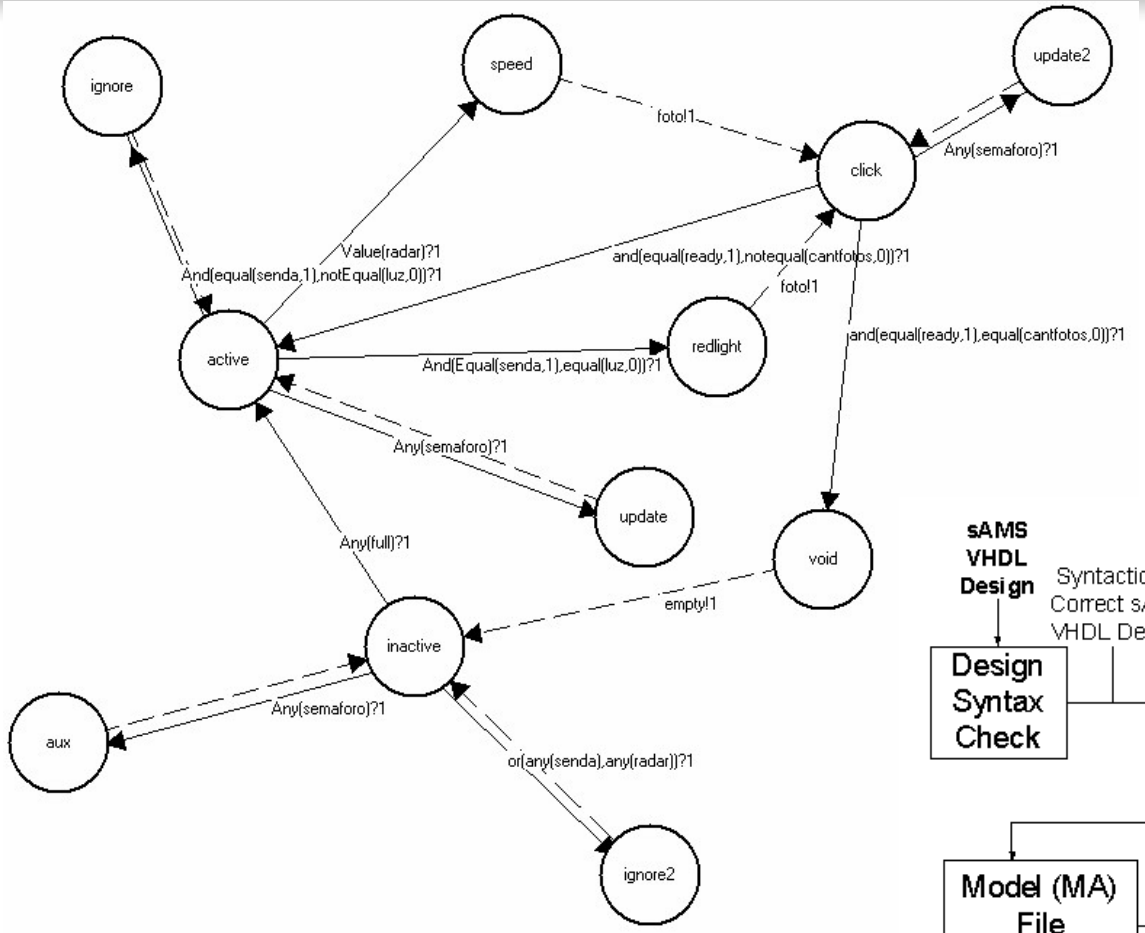
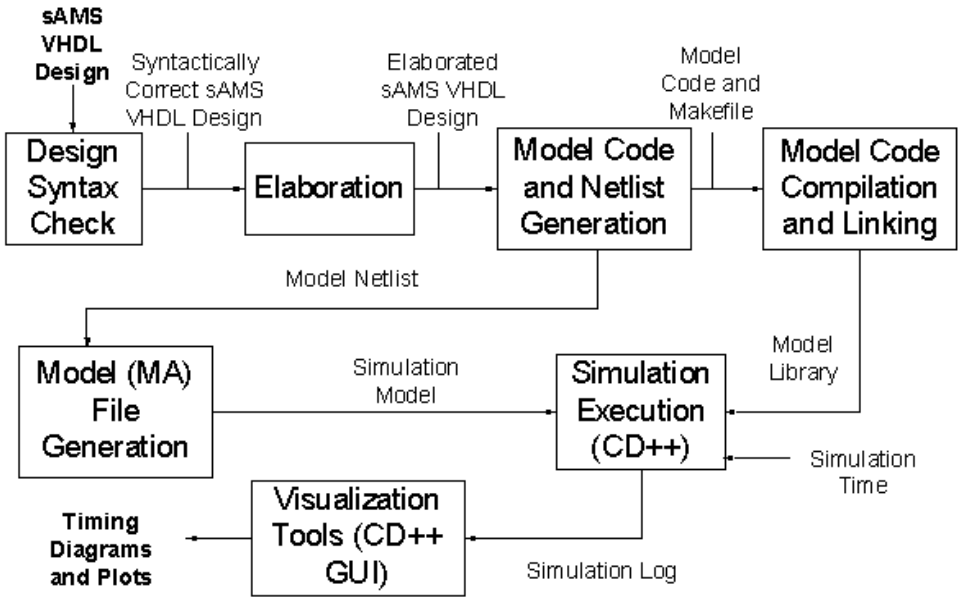
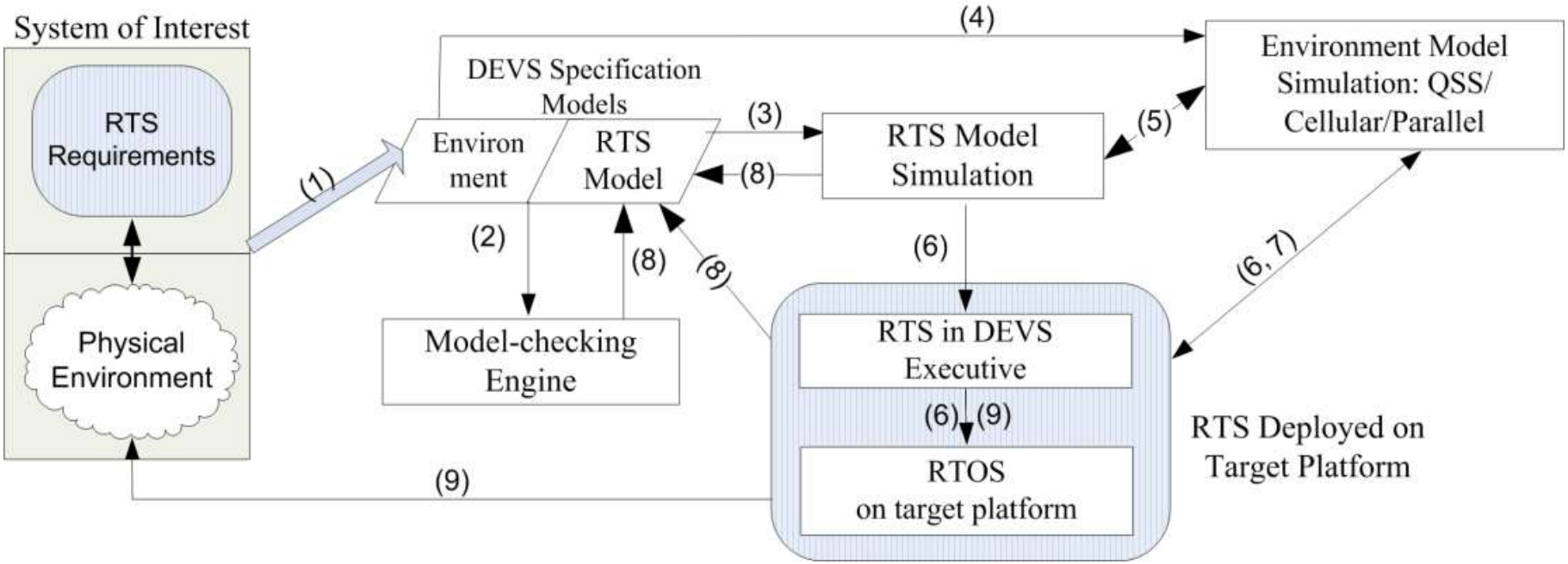




Methodology (2 –Model Checking)



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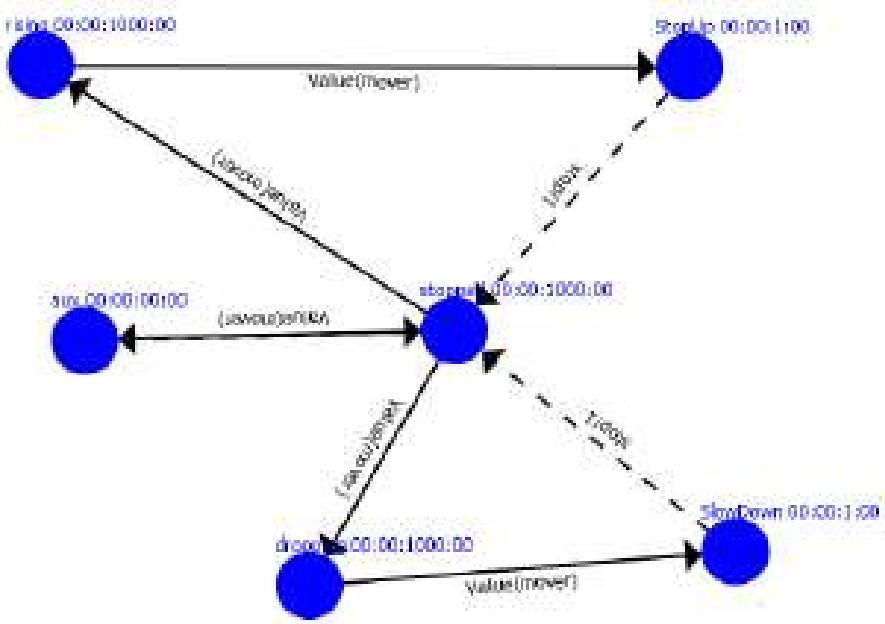
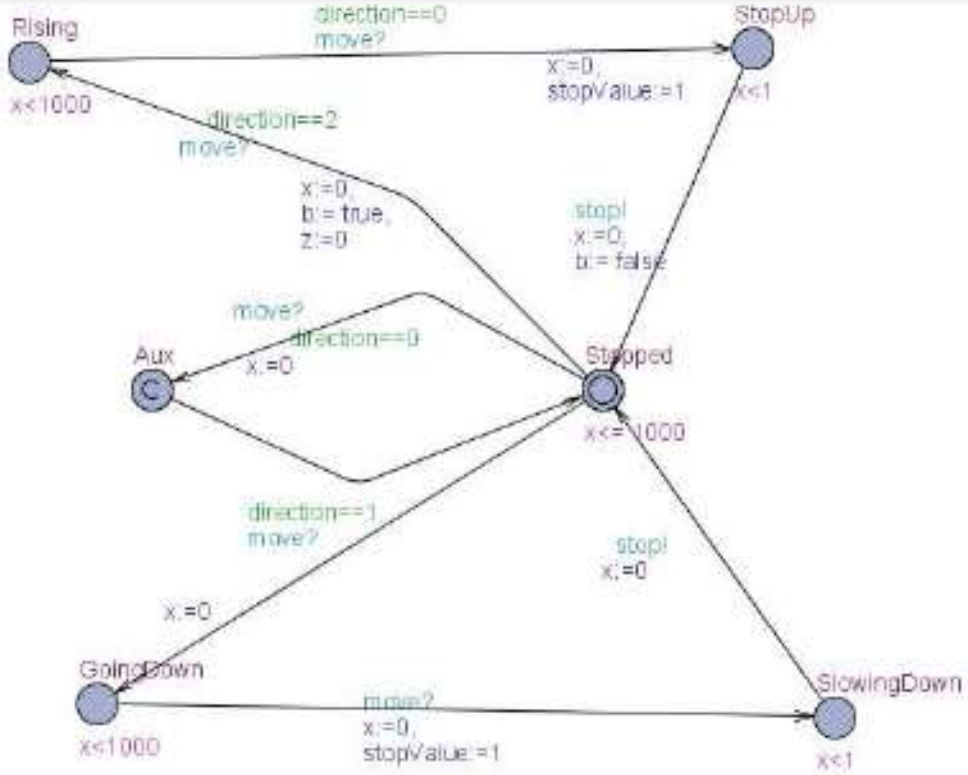
Model Transformation



Elevator Model in DEVS Graph notation.

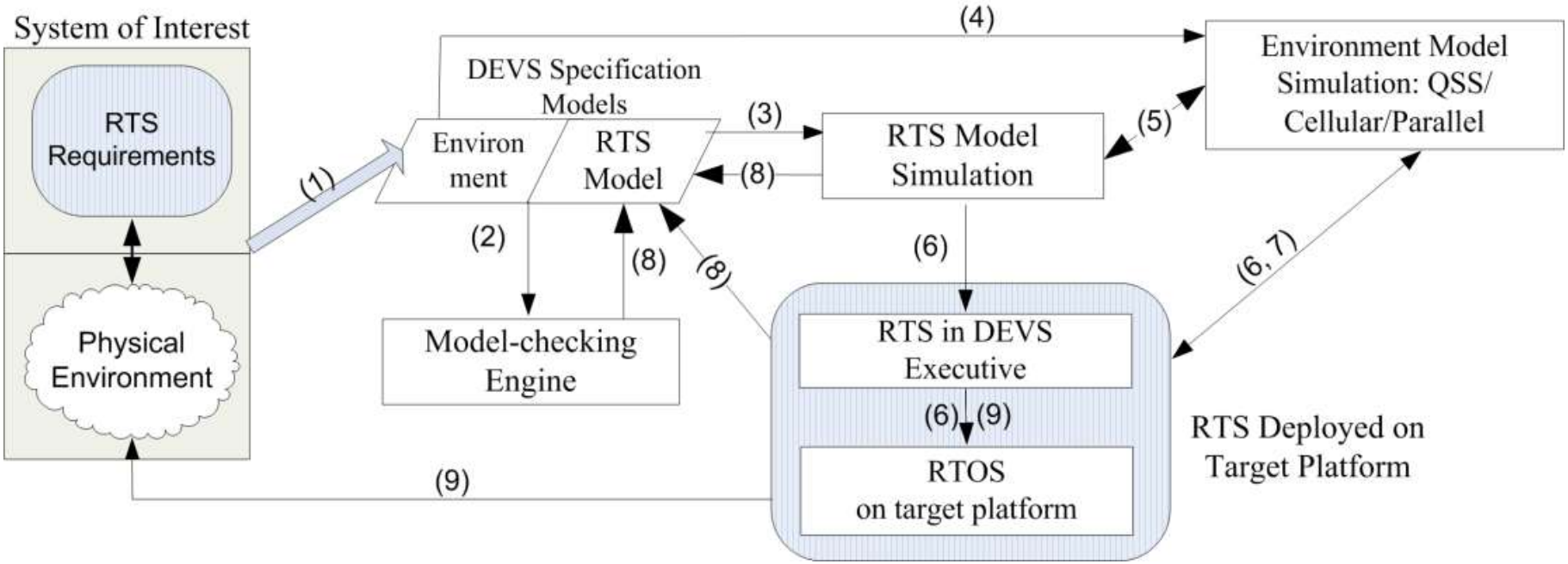


Elevator TA model in UPPAAL.

Preserve behavioural equivalency

- **Bi-simulation Equivalence**

Methodology (3 – Controller simulation)



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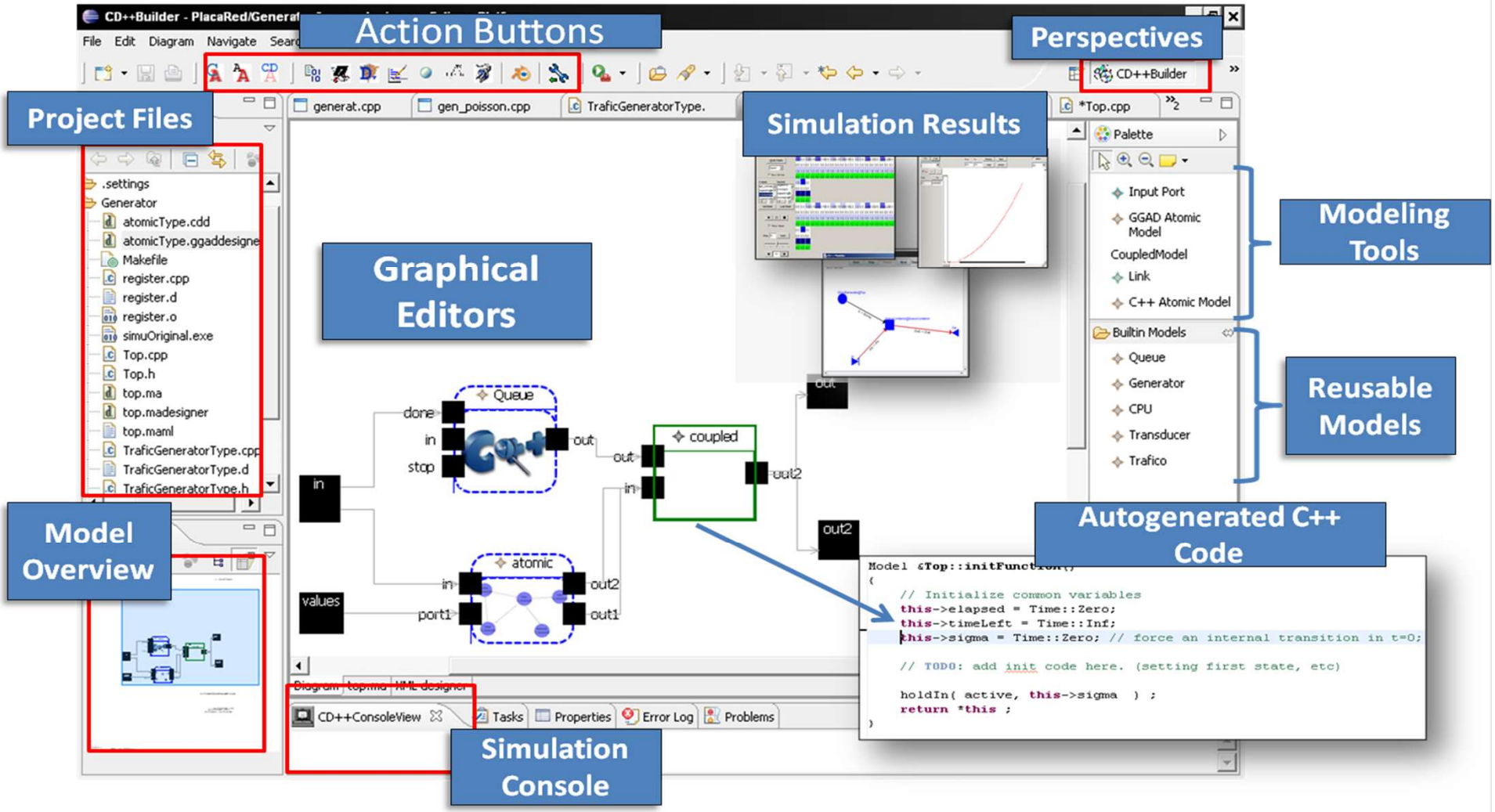
CD++ Builder Environment



Methodology (4/5 – Physical Environment Simulation)

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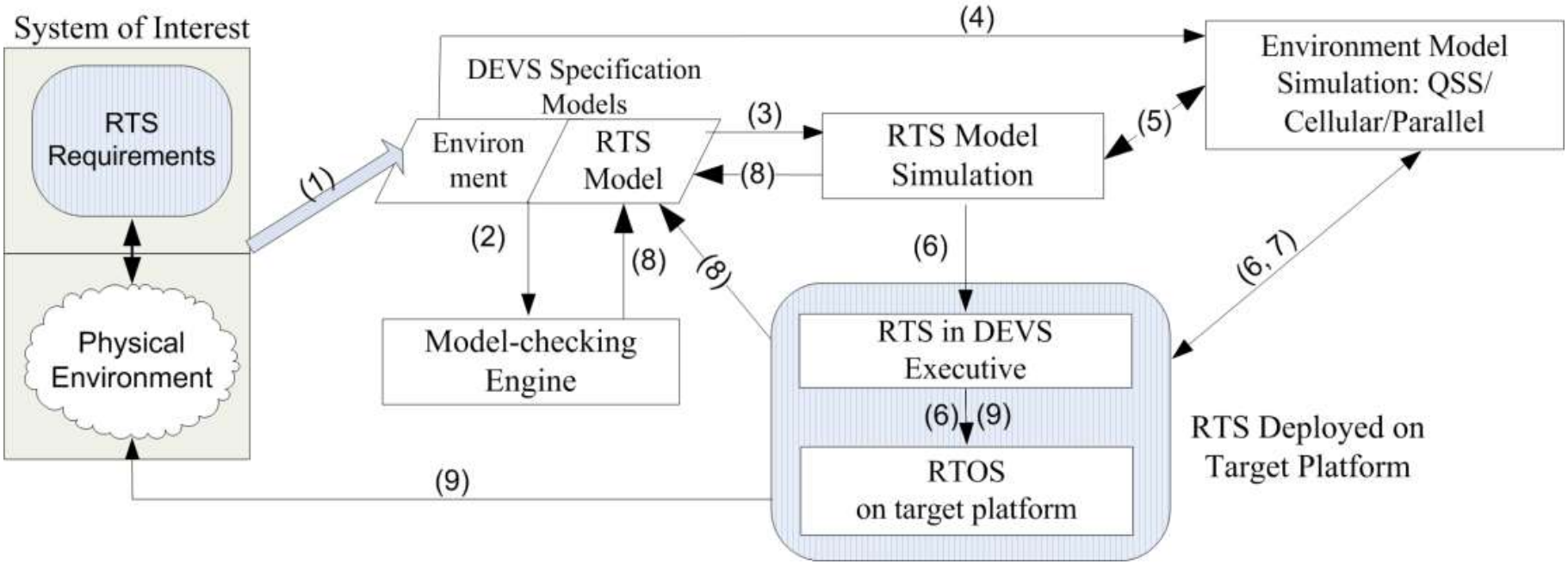

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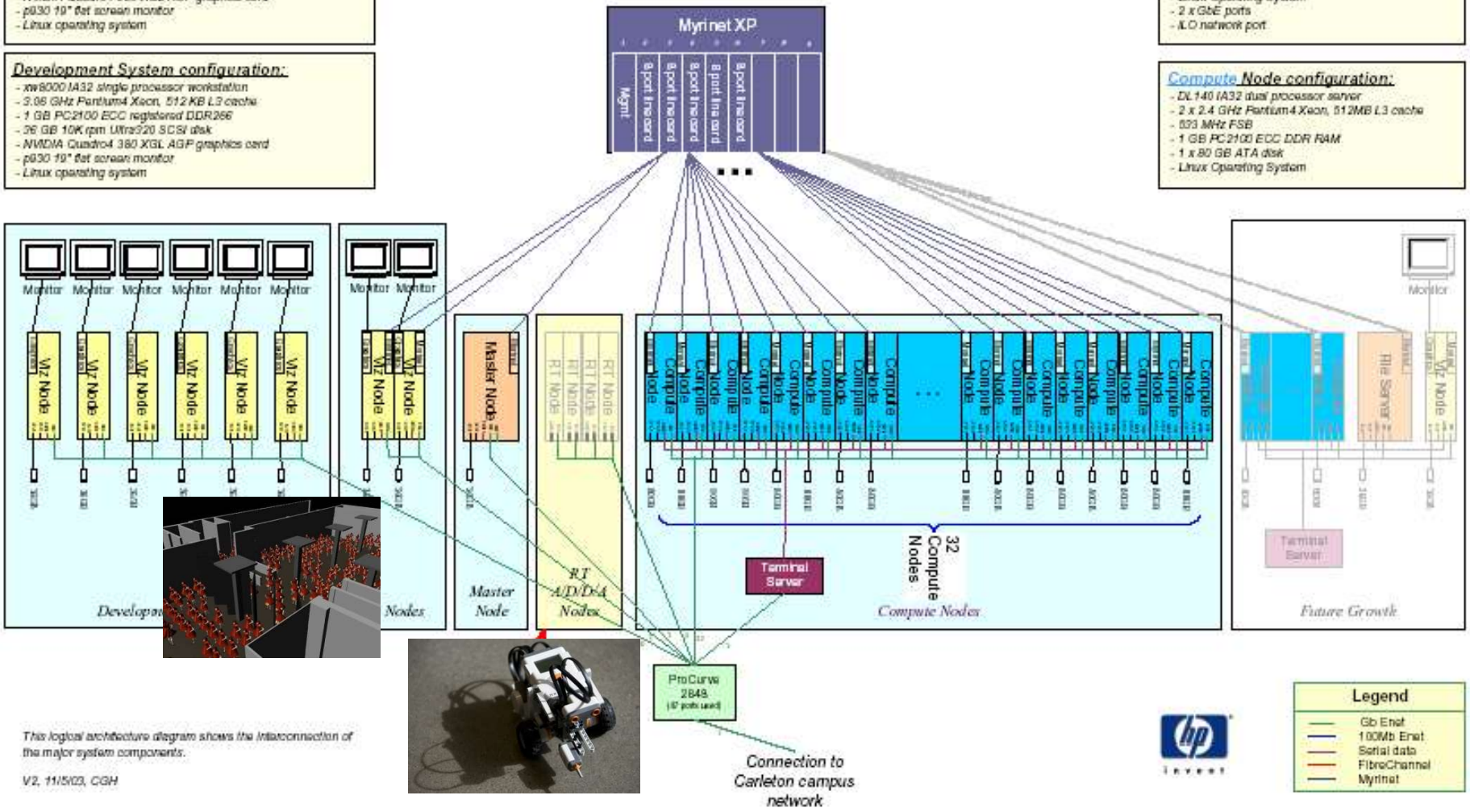
Advanced Laboratory for Real-time Simulation Cluster

Visualization Node configuration:
- xw8000 IA32 dual processor workstation
- 2 x 3.06 GHz Pentium4 Xeon, 512 KB L3 cache
- 1 GB PC2100 ECC registered DDR266
- 36 GB 10K rpm Ultra320 SCSI disk
- Myrinet XP PCI-X card
- NVIDIA Quadro4 980 XGL AGP graphics card
- p930 19" flat screen monitor
- Linux operating system

Development System configuration:
- xw8000 IA32 single processor workstation
- 3.06 GHz Pentium4 Xeon, 512 KB L3 cache
- 1 GB PC2100 ECC registered DDR266
- 36 GB 10K rpm Ultra320 SCSI disk
- NVIDIA Quadro4 380 XGL AGP graphics card
- p930 19" flat screen monitor
- Linux operating system

Master Node configuration:
- DL360-G3 IA32 2P server
- 2 x 3.06GHz Pentium4 Xeon, 512KB L3 cache
- 533 MHz FSB
- 1 GB PC2100 ECC DDR RAM
- 36 GB 10K rpm SCSI disk
- Linux Operating System
- 2 x GbE ports
- iLO network port

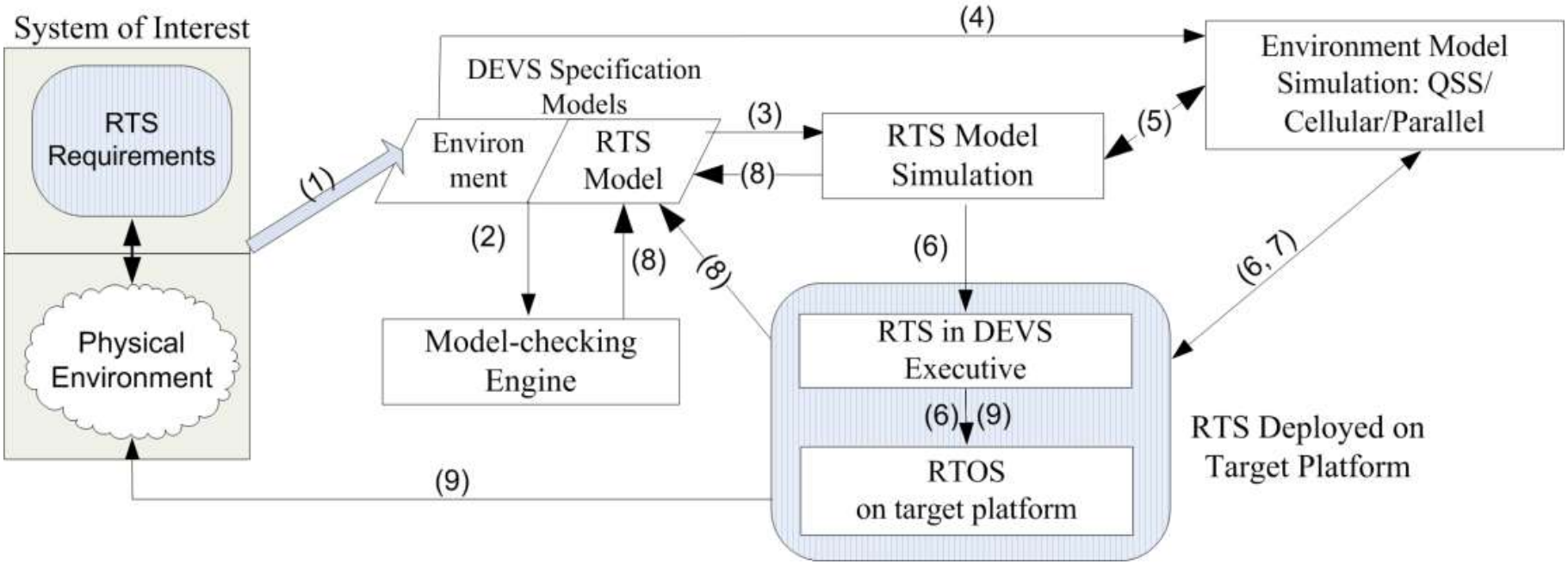
Compute Node configuration:
- DL140 IA32 dual processor server
- 2 x 2.4 GHz Pentium4 Xeon, 512MB L3 cache
- 533 MHz FSB
- 1 GB PC2100 ECC DDR RAM
- 1 x 80 GB ATA disk
- Linux Operating System



This logical architecture diagram shows the interconnection of the major system components.

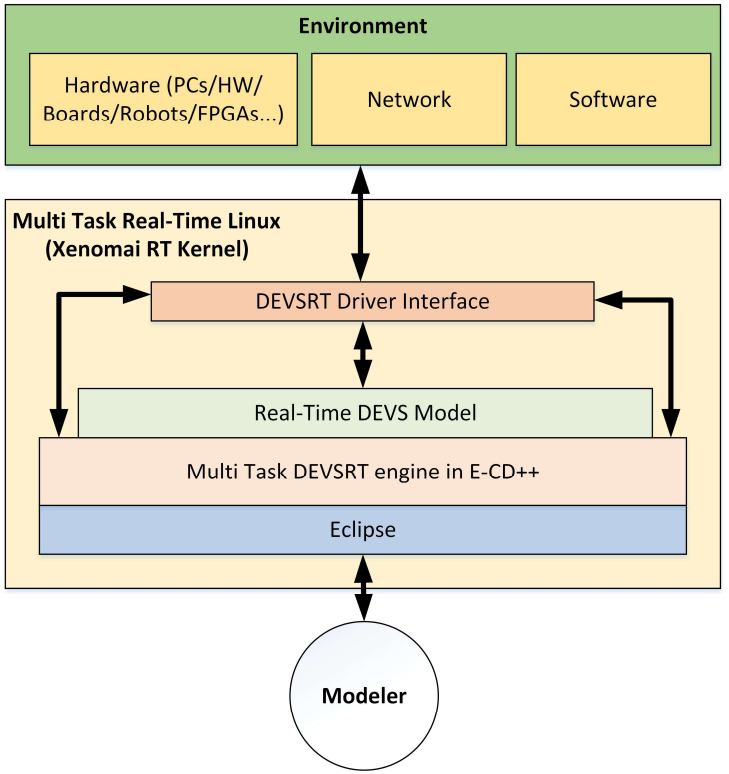
V2, 11/5/03, CGH

Methodology (6 – Deploying in the target platform)



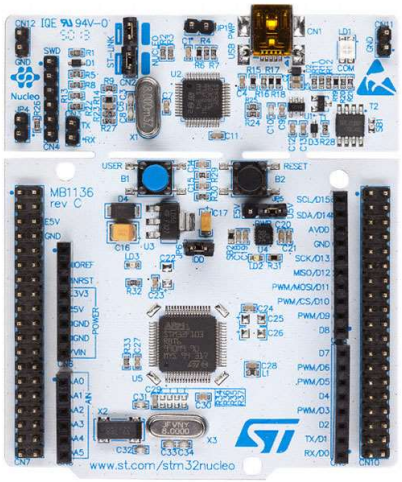
E-CD++

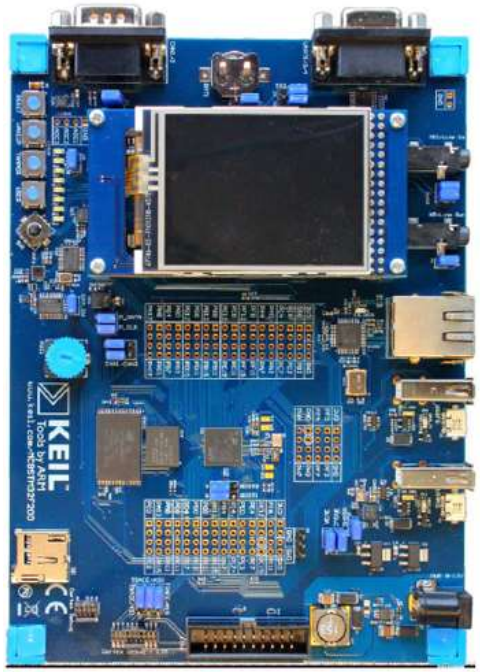
- Cyber-Physical toolkit based on DEVS Real-Time
  - *Use wall-clock time*
  - *Handle inputs from the external environment*
  - *Interact with hardware*
- System design with DEVS:
  - *Behavioral & Structural) models*
  - *Formal timing specification*
- Hardware Interface
  - *Port and Driver concepts*



ARM – based microcontrollers

- Models → Processes
- Simulation: cost reduction for development
- Direct execution on a hardware platform





Complete model specification

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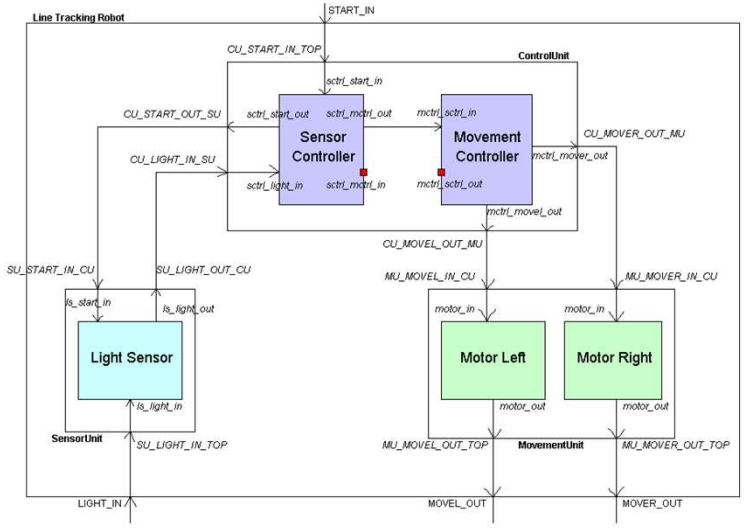
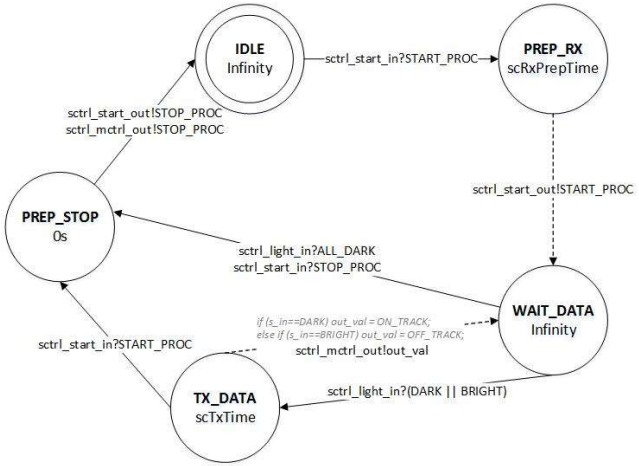
Modeling



Implementation

```
Model &MovementController::externalFunction( const ExternalMessage &msg ){
    if (msg.port() == mctrl_sctrl_in) {
        sctrl_input = static_cast<int>(msg.value());
        if (sctrl_input == STOP_PROC) {
            state = PREP_STOP;
            holdIn( Atomic::active, ZERO_TIME );
        }
        else if (sctrl_input == ON_TRACK) {
            if (state == WAIT_DATA || state == IDLE) {
                state = PREP_MOVE_FWD;
                holdIn( Atomic::active, movePrepTime );
            }
        }
        else if (sctrl_input == OFF_TRACK) {
            if (state == MOVE_FWD) {
                state = MX_STOP;
                holdIn( Atomic::active, ZERO_TIME );
            }
            else if (state == WAIT_DATA || state == IDLE) {
                state = PREP_TURN;
                holdIn( Atomic::active, movePrepTime );
            }
        }
    }
    return *this;
}
```

State transitions



I/O Mapping

Port Name	*Port Value*	*Hardware Command*	*Description*
START_IN	10	START	Manual Start Command
	11	STOP	Manual Stop Command
LIGHT_IN	0	BRIGHT	No line detected
	1	DARK	Line detected
	2	ALL_DARK	Destination Reached
MOVER_OUT/ MOVEL_OUT	0 1 2	STOP FORWARD REVERSE	Stops the motor Spins Clockwise Spins Anticlockwise

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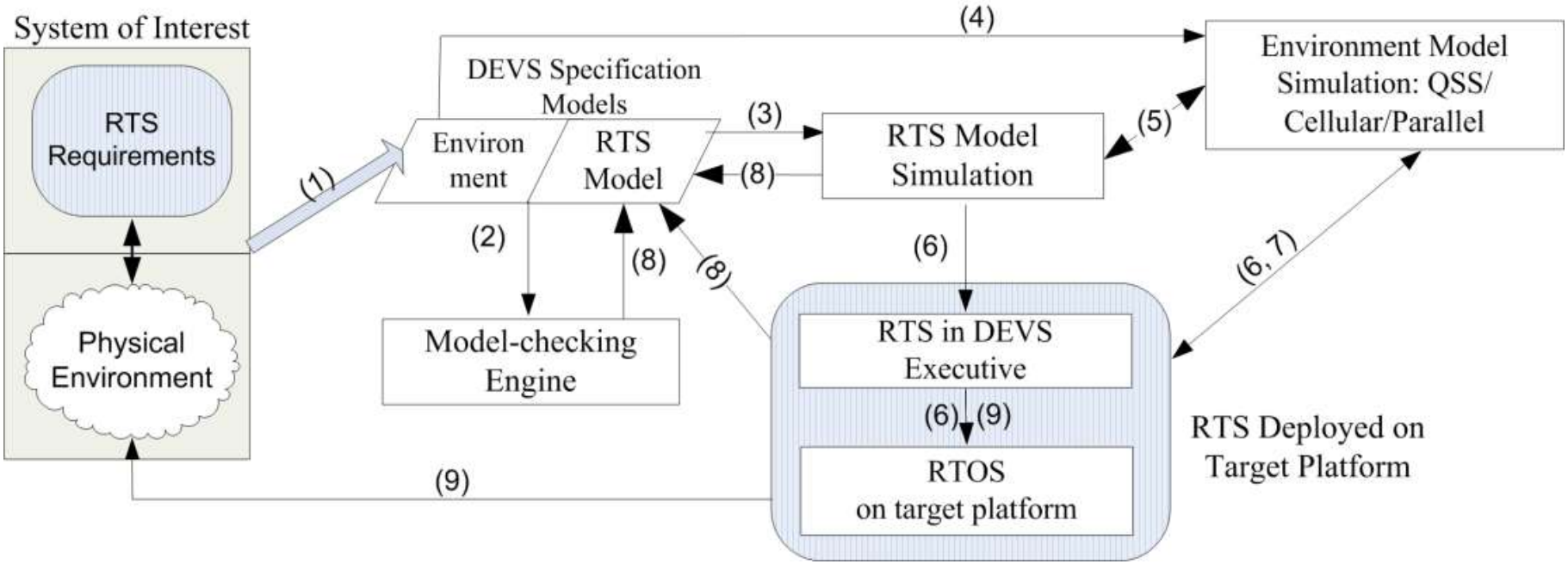
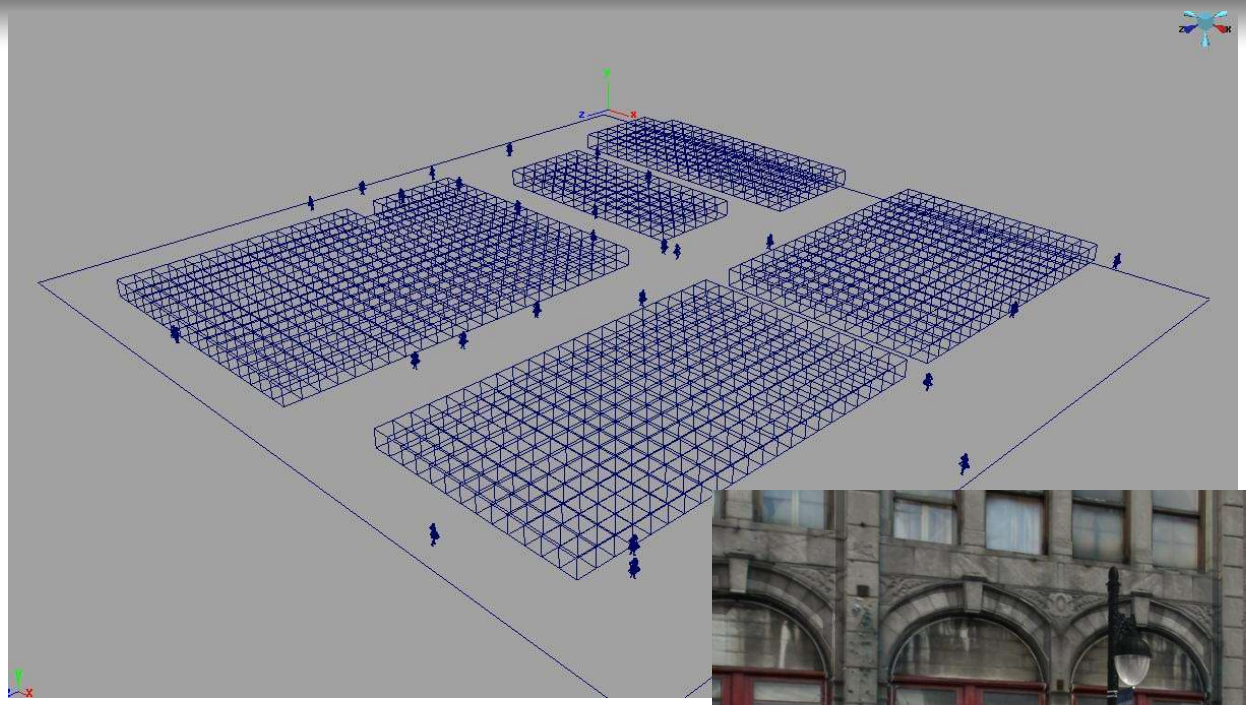
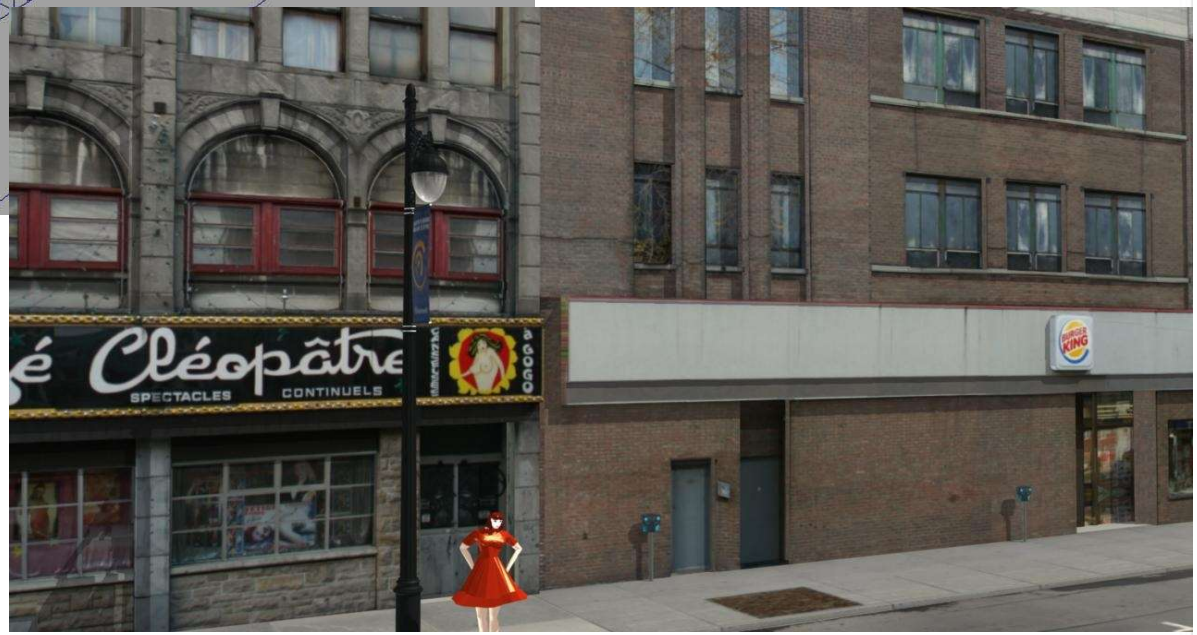
Methodology (7/8/9 – Validation and Training)






Cléopâtre
SPECTACLES
CONTINUELS
BURGER KING

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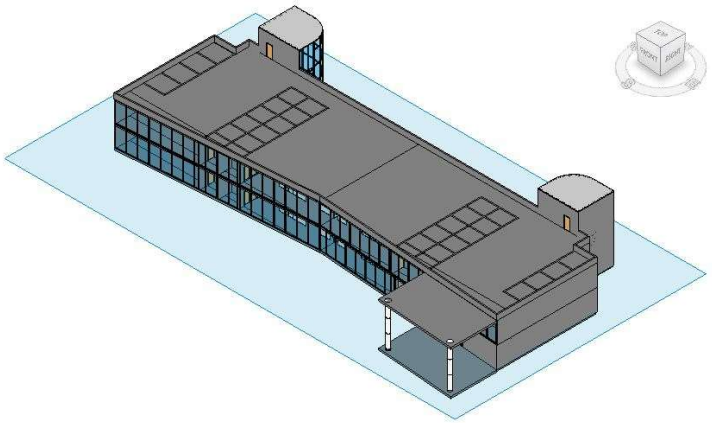
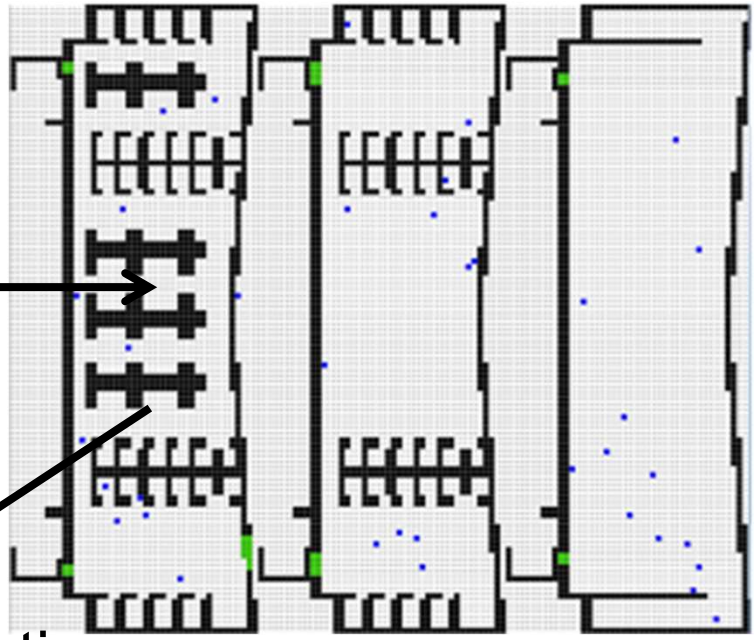
Architecture and Visualization

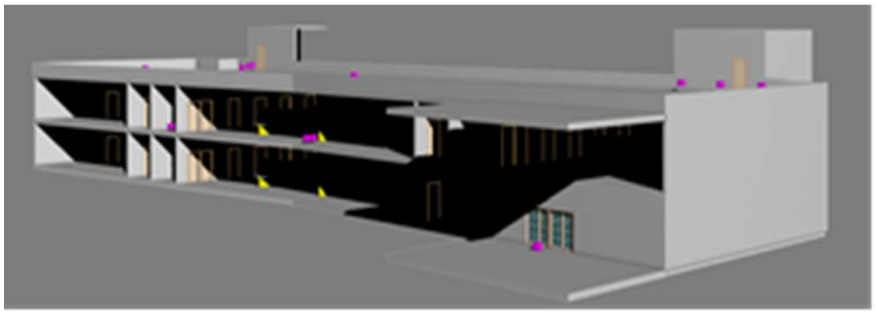
Real Building Floor Plans



Cell-DEVs model



3D Visual Implementation



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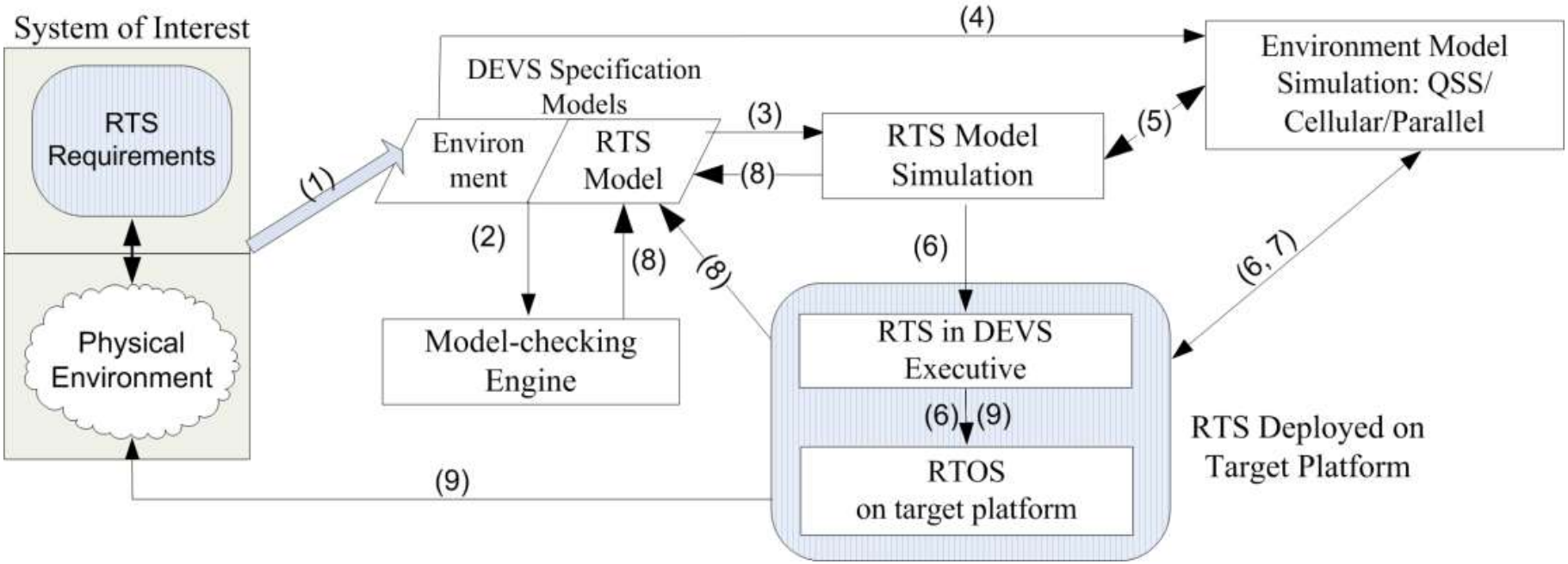
SUSTAIN

Methodology - Review



Summary

- *Model-Based Engineering for software development*
- Varied hardware , software and 3D visualization
- Models reused throughout the process => cost improved
- Collaborative environment
- Advanced visualization facilities (serious games; training)

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Cotutelle

- Bilateral doctoral enrolment/co-enrolment
- Two universities in different countries.
- Dissertation research collaboratively
- A faculty member from each of the universities
- Dissertation examined by a committee from both institutions
- Dual degree/diploma

https://gradstudents.carleton.ca/program-options/cotutelle/

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THANKS!!!!

- **Further information:**

@ARSLab_CU

- **VIDEOS**

http://www.youtube.com/arslab