Distributed experiment for the calculus of optimal values for energy consumption in buildings

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***Abstract*—**In this paper we address the problem of define and execute an environmental model, that describes the behavior of a building from the point of view of sustainability, in a distributed scenario. The inherent complexity of the experiment and the demanding amount of resources needed to perform the calculus, justify the need of distribute the execution of the experiment. This distribution is done through the use of a formal language that not only defines the model behavior, but also the experiment distribution. This methodology can be applied to other modelling environmental problems that usually requires a huge amount of resources to obtain the results, reducing the amount of time needed to perform the Modelling, Implementation, Verification and Experimentation.

***Keywords*—S**DL, building, simulation, optimization, NZEB.

I. Introduction

ENVIRONEMNTAL simulation is a demanding area for several aspects. First because the models depends on several variables and factors, in a number that usually is higher than in other disciplines. Secondly because the teams that are involved in the definition and in the implementation of the models, belongs to several different areas, implying that is needed to stablish a common language to start working. Third because, and due the huge amount of parameters and factors that exist in the models, the experimentation tends to become time and resource consuming.

In this paper we try to address the second and the third problem, presenting a methodology that simplifies the communication between the different actors that are involved in the project and allowing to define a distributed execution scenario of such models. This distributed scenario execution allows to reduce the time needed to obtain the results and possibilities the exploration of more alternatives as we will discuss later.

II. The system

The "Energy Performance of Buildings Directive (EPBD)" approved by the 2010/31 / EU European directive, aims to speed up energy saving policies in the building sector in order to achieve a 20% reduction of energy consumption in the European Union . Among many other measures, the Article 9 of the directive stipulates that from December 31, 2020 the new buildings must be nearly zero in energy consumption, and on December 31, 2018 for occupied buildings and/or public property buildings. In relation to this measure, the board recommends to the Member States establish intermediate objectives in 2015 and gradually adopt the goals until 2020 to ensure the compliance the objectives set.

In relation to the rehabilitation of buildings, where the present study is focused, a series of measures must be taken to ensure that a minimum requirements are compiled when renewing at least 25% of the building or its surroundings. The same policy explains that to adjust and set the minimum requirements for energy efficiency, all methods must be based on a cost benefit analysis, in order to achieve optimal levels of profitability methods.

The MARIE project, that is framed in the Catalan context and led by the Department of Territory and Sustainability of Catalonia, has the overall aim to define a strategy for improving energy rehabilitation of the Mediterranean buildings. In this context, the study aims to provide the necessary management to

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be able to set the minimum criteria for energy rehabilitation, ensuring optimal levels from an energy and economic point of view, and propose solutions adapted to the particular building characteristics of Catalonia (climate and construction).

Thereby, the overall objective of the project is to conduct a technical study in order to find optimal values regarding energy consumption. With the knowledge obtained from the simulations is it possible to propose modifications on the buildings to gradually achieve near-zero energy buildings (NZEB). The optimization criteria on this project follows a multi-objective schema.

The study is focused on 4 representative typologies and 4 climates from Catalonia (see Fig. 1). A dynamic simulation of every building typology was carried out in TRNSYS 17 [1]. One of the main challenging problems of this kind of simulations is the huge amount of factors we must consider. The building models (BIM) includes a detailed characterization of the building, their systems and the behavior of the occupants. The results obtained for each simulation are: (i) energy consumption, (ii) comfort evaluation and (iii) global costs calculation.

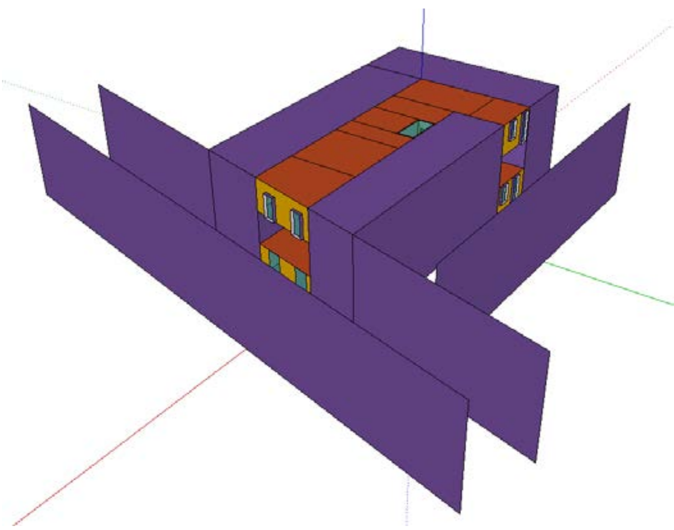

Fig. 1 One of the typologies to be simulated on the MARIE project.

The multicriteria optimization was done with SDLPS (http://sdlps.upc.edu), simulation software infrastructure that makes possible to find optimal values for several model parameters. In the core of the distributed and discrete simulator SDLPS, a model rules the main simulation process in a Co-simulation scenario [2] optimizing the building parameters and their associated impacts; TRNSYS is used as a calculus engine for energy simulation in this Co-simulation scenario.

Around 10,000 simulations been done for each typology and climate, needing about 15 minutes to complete each simulation, making this a demanding simulation scenario.

III. Model formalization

The need to share at least the model structure and behavior in a transdisciplinary environment justify the need to use a formal language to define the model.

In our approach we propose the use of a widely used formal language to represent the models, to structure the co-simulation mechanism, and to define the experimental design to be conducted.

A. *Specification and Description Language*

Several languages exist to formalize a simulation model [3]. In our approach we use Specification and Description Language (SDL) [4], a formal, graphical, unambiguous and complete formalist that is widely used to represent simulation models.

The structure of the language allows to easily obtain the code needed to perform the simulations [5], aspect that simplifies the Verification of the models [6].

The language have a modular structure that simplifies the definition of the different model components.

Specifically, SDL is an object-oriented formal language defined by the International Telecommunications Union–Telecommunications Standardization Sector (ITU–T) (the Comité Consultatif International Telegraphique et Telephonique [CCITT]) on the Z. 100 recommendation [7]. The language was designed for the specification of event-oriented, real-time and interactive complex systems. These systems might involve different concurrent activities that use signals to perform communication. In our cur-rent scope SDL SIGNALS represents the events of the simulation model, hence in the paper SDL SIGNAL or event can be considered equivalent, since the SIGNAL is the representation of the event in the language. SDL is based on the definition of four levels to describe the structure and the behavior of the models: system, blocks, processes and procedures. In SDL BLOCKS and PROCESSES are named AGENTS. The outermost block, the system BLOCK, is an agent itself. Figure 1 shows this hierarchy of levels.

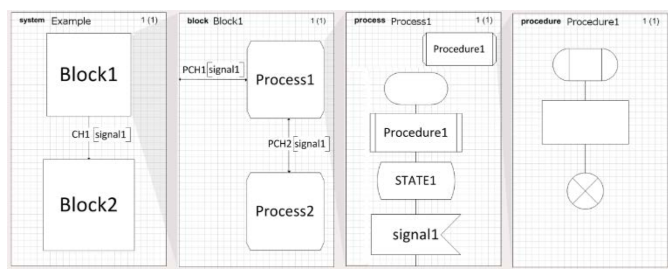

Fig. 2 A structural vision of an SDL model with its 4 main levels.

The different concepts that the SDL language covers are:

1. System structure: from the blocks to the processes and their related hierarchy.
2. Communication: signals, communication paths or channels, parameters that can be carried out by the signals, etc.
3. Behavior: defined by different processes.
4. Data: based in Abstract Data Types (ADT).
5. Inheritance: useful to describe relations between objects and their properties.

Although a textual SDL representation is possible (SDL/PR), this paper uses the graphical representation of the language (named SDL/GR).

Thanks to the use of this approach the schema that depicts a modelling process proposed by Sargent [8] can be simplified at operative level. To understand the areas affected in the modelling process by this approach see Fig. 2 that depicts, in red boxes, the areas affected by this proposed methodology.

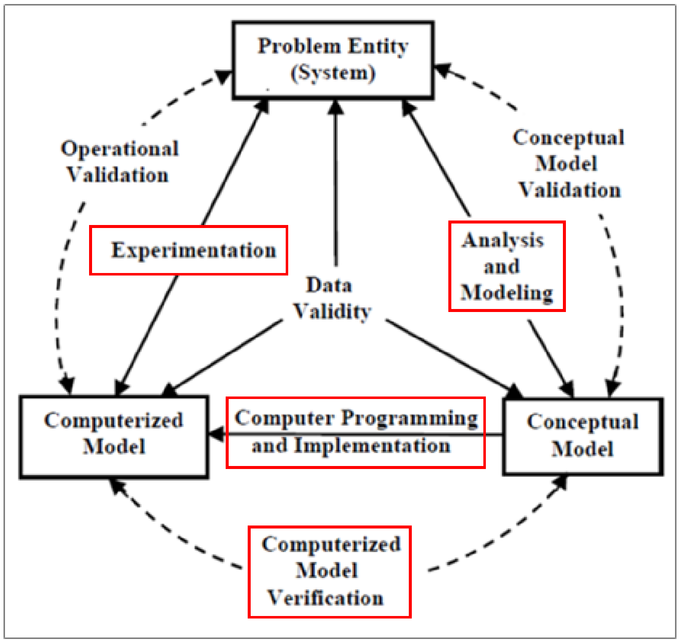

Fig. 3 Areas of the modelling process diagram affected by our proposed methodology. The diagram ins based on [8].

IV. Analysis and Modeling

In this project we follow a transdisciplinary approach, this means that not only we work with personnel with different formation and background, but also we want that the different actors be involved in all the parts of the project. To do this is needed to stablish a common language that allows to stablish this communication. As we said d previously we use SDL. The complete definition of the model is detailed on [2]. Since we need to calculate the energy demand of the buildings we use a Co-simulation approach. This allows to use in the model a widely use and accepted calculus engine like is TRNSYS®.

On Fig. 4 is shown the first level of the building simulation model. Four main blocks exists representing the environment, the building, the compensation and the waste treatments. In this experiment we are mainly focused on building block, since we want to analyze the use of the building and we do not consider other aspects.

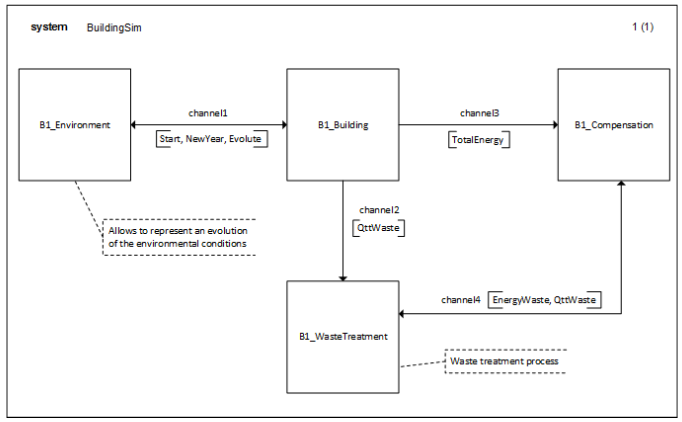

Fig. 4 The first level of the building simulation model.

V. Implementation and Verification

Once the definition of the model is done, through SDL, it is needed to implement it.

In our case we use SDLPS, a software infrastructure that allows the automatic execution of models represented by SDL or DEVS languages. This simplifies the implementation process, since the tool assures that the execution follows the definition of the model proposed on the Conceptual Model. On Fig. 4 is shown SDLPS with the model defined on SDL ready for his execution.

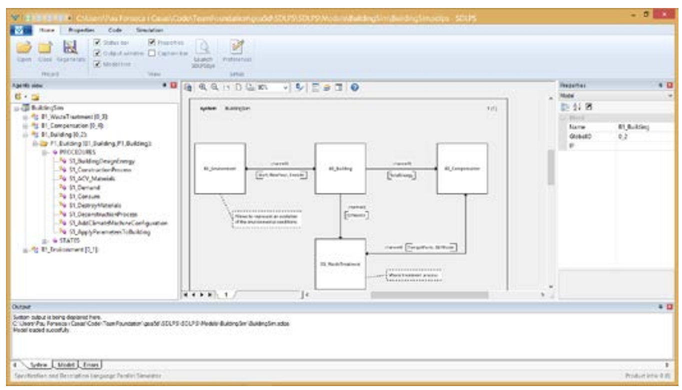

Fig. 5 SDLPS with the model loaded, ready for its execution.

Since SDLS understands the formalized model thought SDL language, the Verification process is assured thanks to the capability of SDLPS to execute correctly the model.

VI. Experimentation

The definition of the experiment was based on the definition of several factors that determines the structure of the buildings we want to model. This structure determines the main typologies for Catalonia residential area. In the Fig. 6 is show a subset of the experiments to be executed to analyze the behavior of the multi-family house constructed previous to 1939.

n	Clima	NVENT	FAC	COB	WIN	TOL
19	E1	YES	10	13	10	10
691	E1	YES	26	13	10	10
187	E1	YES	14	13	10	10
247	E1	YES	15	16	10	10
677	E1	YES	26	10	12	10
47	E1	YES	11	10	12	10
107	E1	YES	12	13	12	10
19	C2	YES	10	13	10	10
691	C2	YES	26	13	10	10
187	C2	YES	14	13	10	10
247	C2	YES	15	16	10	10
677	C2	YES	26	10	12	10
47	C2	YES	11	10	12	10
107	C2	YES	12	13	12	10

Fig. 6 Experiment definition for the multi-familiar houses constructed prior to 1939.

On the overall project it is needed to conduct more than 60.000 simulations, implying moths of calculus using a single computer. The method used to conduct the simulations is described on [9]. The first time that we confront a simulation model where the required a time to perform the calculations was too large with respect to the time we had to be able to offer the answer to the client, was in the project of the Barcelona Airport [10]. In this project we use a set of machines to run different replications of the same model with the aim of reduce the time needed to obtain the answers.

In this case, the problem is not the number of replications of model that are needed to be performed, but the large number of different scenarios that we want to evaluate. This is due to the huge amount of variables that we can consider in a building. Specifically, in a first approach for one of the typologies we wanted to evaluate, the time was about 20 days. This time was excessive due to the temporal constrains of the project.

In order to accelerate this process we define a method to automatically generate the different experiments to be executed as we discuss in the next section.

A. *Distributing the experimentation*

In order to solve the problem, we divide the experimental design in independent pieces that may run on different machines, and then we join again all the answers on a single computer following a server farm approach.

We use one of the teaching rooms, installing on each computer the simulation systems that we must use, SDLPS, with the model of energy efficiency for buildings, which acts as a co-manager simulation yelling at other simulation systems, TRNSYS ®, as a calculus engine and, finally, it was necessary to install a manager to stablish a synchronization between all the computers. We chose BitTorrentSync®, a peer-to-peer synchronization system that would allow us to centralize the results and the definition of the scenarios on a single central server. It takes more time to prepare the experiments that run the 6000 different simulations. Given that in the classroom had 25 computers, in this particular scenario we are presenting here, each one of these computers would run 240 simulations. The time it took each PC to complete their task was less than 8 hours, but to prepare the configurations of each PC and install the programs we take more than 10 hours.

In Fig. 4 you can see the computer room with the PC's configured and with the results obtained in the screens.

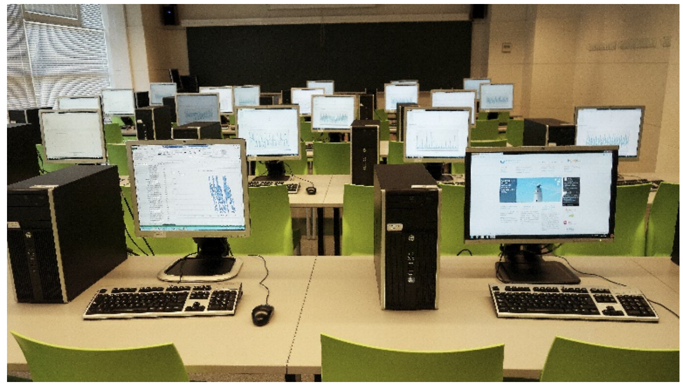

Fig. 7 Computer lab used to execute the simulations. Note that all the computers compose a farm that shares the model and executes a part of the experiment, uploading the results to a central server.

To prepare the distribution of the experimentation along all the computers, we implement a feature on SDLSP to detect the IP's of the local network and automatically assign an IP to each one of the parts in which we divide the complete experiment. We can also select IP's over Internet. In the Fig. 8 is shown the assignation of the IP's (intranet) for the 25 computers we have in the room to be used for the experimentation.

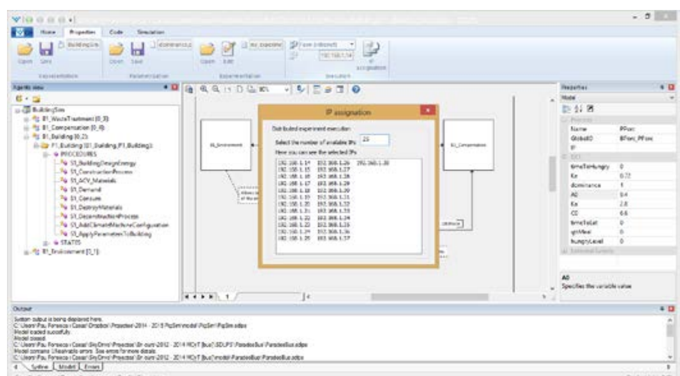

Fig. 8 Assigning the IP's of the local network to distribute the experimentation over the farm.

Once we detect the computers are going to be involved in the farm execution the parametrization file that describes what is going to be executed in each computer is prepared. Each computer (through SDLPS) detects his own IP and, according to that executes the part of the job that has assigned. SDLPS assures that the distributed experimental definition, following a factorial design is correctly divided, and that the results can be obtained again correctly.

VII. Concluding Remarks

When we talk about distribute simulation the first approach that we think is to try to segment the simulation model in several pieces that can share information is an optimistic or in a

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conservative approach [11], [12]. However a simple approach exist; the distribution of the experimentation through several computers allows to dramatically reduce the time needed to perform the simulation. In order to do so it is needed to assure that each one of the experiments are independent, and to stablish a method to simplify the results recollection.

The proposed methodology reduces the time needed to perform the verification of the model and the Analysis and Modelling. This give more time to our team to complete the experimentation, allowing to execute the overall scenarios in some cases without the need to use any optimization algorithm, using just force brute. This was very convenient for us, since we can use the complete dataset obtained to conduct a further research.

The proposed methodology works well in a transdisciplinary scenario, allowing to accelerate the process to understand the different details of the model definition, the implementation and the model execution by all the team members.

Regarding the specific results of the project, the information obtained was very useful to define the priority actions and the most effective solutions for the energy renovation of existing buildings, guaranteeing comfortable conditions for the users and energy and economic savings

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