



**HAL**  
open science

## System control of situations perceived by their simplicity: case-study and open-issues

Frédérique Mayer, Jean-Marc Dupont, David Gouyon, Eric Levrat,  
Jean-Pierre Hennebicq, Gérard Morel

► **To cite this version:**

Frédérique Mayer, Jean-Marc Dupont, David Gouyon, Eric Levrat, Jean-Pierre Hennebicq, et al..  
System control of situations perceived by their simplicity: case-study and open-issues. 2020. hal-  
02487442

**HAL Id: hal-02487442**

**<https://hal.science/hal-02487442v1>**

Preprint submitted on 21 Feb 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# WHITE PAPER:

## System control of situations perceived by their simplicity: case-study and open-issues

F. Mayer, ERPI EA 3767, Université de Lorraine, Nancy, France (Corresponding author)

J.M. Dupont, CRAN UMR 7039, Université de Lorraine, Nancy, France

D. Gouyon, CRAN UMR 7039, Université de Lorraine, Nancy, France

E. Levrat, CRAN UMR 7039, Université de Lorraine, Nancy, France

J.P. Hennebicq, R&D retired engineer, France

G. Morel., CRAN UMR 7039, Université de Lorraine, Nancy, France

**Abstract:** Control is the key-element of respondent large-scale systems to situations perceived as complex to satisfy the multiple operational conditions of use by any individual. Another perspective of this situation-system paradigm is derived in order to be applied to situations which may be perceived by their simplicity, meaning a portion of reality human-readable by detour. The indoor-air quality-control situation contains thus such phenomenological evidence of which its related framing by detour as a simplex-wholeness reveals the tangible togetherness on which all the contingent situations must be architecting as a system. We base the main modelling key-artefacts of this revisited situation-system paradigm from a body of knowledge in Systems Science, Systems Dynamics, Systems Engineering and Integrative Physiology. The coupling of the specification process with this affording reality brings out an interdisciplinary-wholeness resulting of the model-based orchestration of all the relevant encoding and decoding multidisciplinary knowledge. An early orchestration time points out the right oxygen molar fraction of indoor-air flowing in order to maintain a right hybrid-homeostasis for the occupant. The transition of the resulting mathematical model into a stock-flow diagram specifies then the balancing and reinforcement loops that a respondent-homeostat should satisfy to control the physico-physiological dynamics of this core situation-system from which a broader system may be defined. The increasing maturity of ambient technologies as well as modelling and simulation technologies make us intent for this type of application the perspective of coupling the in-situ source of the phenomena with an online or remote in-silico platform to better personalize indoor-air quality-control systems.

**Keywords:** Situation-System, Simplicity, Systems Dynamics, Systems Engineering, Integrative Physiology, Interdisciplinary Orchestration, Indoor-air Quality-Control. Learning Situation.

## 1. Introduction and Context

Individual control of indoor-air right-quality is the challenge of personalized indoor-environment systems (Li et al., 2017) shared between a general area where indoor-air quality-control standards are applied and areas surrounding each occupant. Issue then arises is how these two controls should be specified to take into account the influences of individual occupant behavior on indoor-air quality and vice versa. The measure of many factors must be usually compliant with different indoor-environment standards defined from problem-situations of occupant discomfort and ill-being in order to warrant a "service level agreement" contractualizing the customer-supplier relationship. But as pointed out by (Olesen, 2012), it is necessary to specify certain "standardized" models of occupant behavior in order to consider what is required for well-being and comfort with regards to related indoor-air physical phenomena. A system-control paradigm change is required, in our opinion, to transcend expertise in multidisciplinary systems engineering as well as in information and control technologies to integrative physiology and system thinking, perhaps not sufficiently taken into account.

*In that direction, the situation-system paradigm that we revisit as "system modelling of situations perceived by their simplicity" focuses on the framing of what is vital rather than merely problematic for the occupant in his or her natural field of activity ( $\setminus N$ ). The specification in the related formal domain ( $\setminus F$ ) of a ( $\setminus \text{system}$ |wholeness) in alignment to this essential ( $\setminus \text{simplex}$ |wholeness) requires by congruence an orchestration process of an ( $\setminus \text{interdisciplinary}$ |wholeness). The co-optation of multidisciplinary knowledge in the course of a project system leads to the specification of a core control of the dynamics of the ( $\setminus \text{situation}$ |system) around which the contingent situations must be architecting to preserve this tangible togetherness (figure 1).*

The situation-problem we deal with as archetypical case-study reveals the phenomenological evidence that breathing must be first considered for control issues in order to put occupants in the right physiological situation (Ahtisham & Jacoline, 2015) for teaching and learning right (OFSP, 2019). Return of experiments in section 2 from multidisciplinary works (Rondeau et al., 2015) point out to us that the specification of an indoor-air quality monitoring-system is oriented either towards a technical solution or towards an extended representation of the situation-problem, without sufficient coupling between both in congruence with the reality even though directly sensitive in-situ. According to (Berthoz, 2009), this phenomenological evidence is characterized by its simplicity, because although it is perceived as complex, it can be designated by "detour", i.e. in a non-linear way, by simple rules. That led us to explore the essential artefacts of a scientific corpus in systems science, system thinking and systems dynamics to define this simplex-wholeness as a portion-of-interest of the reality of an indoor-environment to be encoded and decoded (Rosen, 1985) as a situation-system in an interdisciplinary manner by relying on relevant multidisciplinary knowledge to look outwards.

We therefore consider that the human organization of the project-system must be aligned with this simplex-wholeness in order to orchestrate an interdisciplinary-wholeness at certain key-times of the "problem-solution" dilemma (Millot et al., 2011) characterizing the non-linear system-architecting rationale (Krob, 2014). We first reassess in section 3 some best practices rather dedicated to large-scale systems engineering to orchestrate by detour, to at our scale factor, the multidisciplinary knowledge to frame a system of situations. We present then an adjustment to our case-study of previous work (Dupont et al., 2019) enhancing our interdisciplinary specification heuristic process enabled by a collaborative in-silico platform. The knowledge boundary, illustrated by a multi-colored dotted curved line (red for physics, green for physiology, blue for control as respective engineering's, purple for situation-system framing, grey for system architecting), embodies the interdisciplinary and multidisciplinary alignment of the project-assets on the simplex-wholeness under system framing and specification.

At a certain time of this orchestration process, an inferential entailment in section 4 makes of the oxygen molar fraction contained in flowing indoor-air the tangible element of togetherness of the breathing simplex-wholeness. So framed by integrative physiology, the breathing physiological phenomena is a prerequisite to ensure the right homeostasis of the occupant whatever the others air-components such as carbon-dioxide (INRS, 2012)(RAE, 2014). Thus, a right physical ventilation of the indoor-environment is the enabler in return to close the balancing loop of a hybrid homeostasis, i.e. physiologico-physical, that must be dynamically maintained whatever others indoor-criteria, such as well-being or other forms of comfort<sup>1</sup>. We therefore argue that this hybrid homeostasis embodies the togetherness of the simplex-wholeness in real (in the sense of togetherness, chapter 5 in (Boardman & Sauser, 2008)) which becomes de facto constitutive (in the sense of whole and part (Koestler, 1978)) of the reflected situation-system wholeness in formal.

---

<sup>1</sup> "Well, oxygen's even more important", Dr. House's quote

At another time in this orchestration process, the transitioning in section 5 of the mathematical model of this hybrid homeostasis to systems dynamics aims to explore broader causal entailments of the physico-physiological situation-system. The result is the highlighting of both balancing loops preserving the tangible togetherness of the simplex-wholeness and reinforcement loops counteracting the former ones. Our situation-system control strategy is then to make of the oxygen molar fraction a measurement requirement of an air-flowing homeostat-like specification which can be refined for wider surroundings indoor-wholeness issues, dealing not only with air quality but also with person needs and activities. Model-checking with regards to systems-dynamics rules-correctness and model-checking with regards to hybrid-homeostasis requirements-consistency aims to ensure the satisfaction (Fanmuy et al., 2012) of a holistic response to a system of indoor-situations (Nazaroff, 2013) under architecting specification refinement .

Although the interdisciplinary architecting of situation-system control alternatives is a relevant concluding result of these works, we point out in section 6 our intent to better dynamically reflect in-situ simplex-wholeness by coupling both ambient-technology and in-silico platform for situation-system collaborative-engineering. We aim thus to open model-based multidisciplinary systems engineering to the particular case a certain simplex-wholeness can be contained to control a system of situations, such as for efficient indoor-personalization issues.

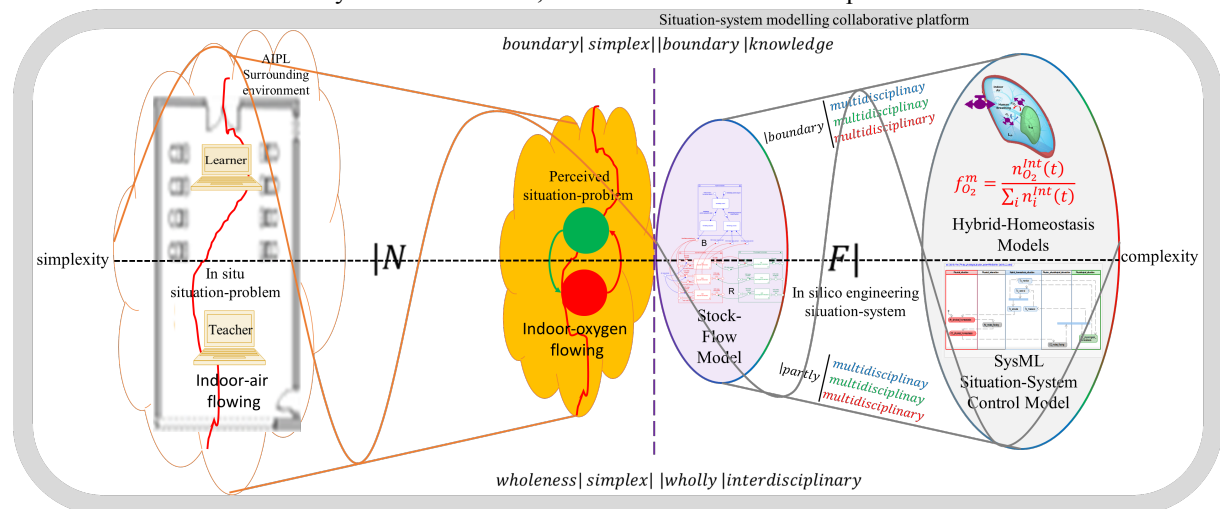


Figure 1: Situation-system paradigm framework

## 2. Situation-system framing perspective

### 2.1. Introduction

We first report our collaborative experiments on a situation-problem easy-to-share to become aware of air-quality monitoring concerns in a bounded indoor-environment, in that case the learning-by-doing situation to system thinking for multidisciplinary systems engineering. We propose then the key-artefacts of a situation-system paradigm (Edson, 2008)(Lawson, 2015) revisited in feedback of these in-situ intuitive practices in order to perceive more from the role of air-flowing to close the framing loop of the simplex-wholeness binding into togetherness indoor-situations in congruence to reality.

### 2.2. Situation-problem case-study

The experiences presented below are based on the integrative precept of the same shared situation-problem in order learners and teachers feel together the impact of indoor-air quality on their own activities. The indoor-environment place (room 108, orange cloud, and figure 2) is located inside the AIPL<sup>2</sup> training center (red cloud, figure 2) which goal is provide a realistic area for learner relating to the integration of advanced manufacturing technologies and their related multidisciplinary technical environments. The central hall aims to reflect a manufacturing plant while the surroundings training rooms aim to reflect a center of systems engineering available to architect a targeted manufacturing system. A technical staff reflecting a system-operation centered-engineering (IOcE) has over time taken charge of technological developments towards Industry 4.0, so that the pedagogical engineering team (TcE) can focus more on each learning-by-doing situation-problem (Morel et al., 2014).

<sup>2</sup> Systems.Manufacturing.Academics.Resources.Technologies; <https://s-mart.fr/>

A first experience has dealing with model-based systems engineering applied to the situation-problem in the context of a training course dedicated to *Pervasive Computing and Communications for Sustainable Development* of an Erasmus Mundus joint master degree with the *Complex Systems Engineering* master<sup>3</sup>. More precisely, courses on systems fundamentals and systems engineering principles aims to specify a green ICT system-architecture to monitor a humidex-like index of indoor-air quality in room 108 (see stakeholders' requirements, figure 2) from a direct sensing of some properties (temperature, humidity) characterizing the indoor environment formed by the training room. However, we noted the difficulty in sharing the situation-problem due essentially to the subjectivity of the notion of comfort leading to as many contextualization's of the felt situation as there are stakeholders, i.e. each team of learners, as well as the tutoring teacher, perhaps even (|TcE) and (|OcE). This difficulty led de facto to subordinate the situation-problem to the architectural principles and practices of the ordered (known) domains (Kurtz & Snowden, 2003) of multidisciplinary engineering ((|F++), figure 2) to specify the solution-oriented technological system of response (Gouyon et al., 2014). It must be noted that this practice to look inwards leaves out by some extent the essence in reality of what makes the physiological comfort of humans in a physical indoor-place, although the requirements come from reality (Jackson, 1995) because they relate to phenomena that should be satisfied by the respondent system.

A second experience (Mayer in (Morel et al., 2015)) has dealing with the application of the precepts and techniques of system thinking (Ponto & Linder, 2011)(Allegrò-Daniel & Smith, 2017) to look outwards the architecting of a system structure breakdown of the situation-problem by (|F++). The main goal is to make learners aware of the heuristic coupling (Figure 3.1 in (Lawson, 2015)) of (|F++ with the unordered (unknown) domain (|N, Figure 2) of a real situation. This awareness relies on, among other artefacts, the acquisition by learners of higher abstraction architectural patterns such as the "conceptagon" (Boardman et al., 2009) to guide them in their specification process to check the (|whole|part) completeness of a system holarchy when applying the holistic paradigm (Koestler, 1978) to see (|H) outwards (|h). This "what-if" inquiry aims to reassess possibly "hidden" but essential phenomenological influences of interactions between objects of interest that may be sources or sinks of reinforcement loops beyond the visible balancing loops. Problem-oriented capture of the dynamics of a portion of this felt reality (figure 1 in (Kuras, 2006) can be framed in (|F+) using systemigrams (Chapter 3 in (Boardman & Sauser, 2013)) and then architected using causal loop diagrams as well as stock-flow diagrams for formal checking purposes. The main challenge remains, however, to frame the expansion towards the "big picture" by guiding rules (Cabrera & Cabrera, 2015) in order to make visible the coupling by (|F+) of certain phenomenological evidences (chapter 1 in (Berthoz & Petit, 2006)) of (|N) to be taken into account for the modelling in (|F++) of a situation-system of interest beyond the users' needs.

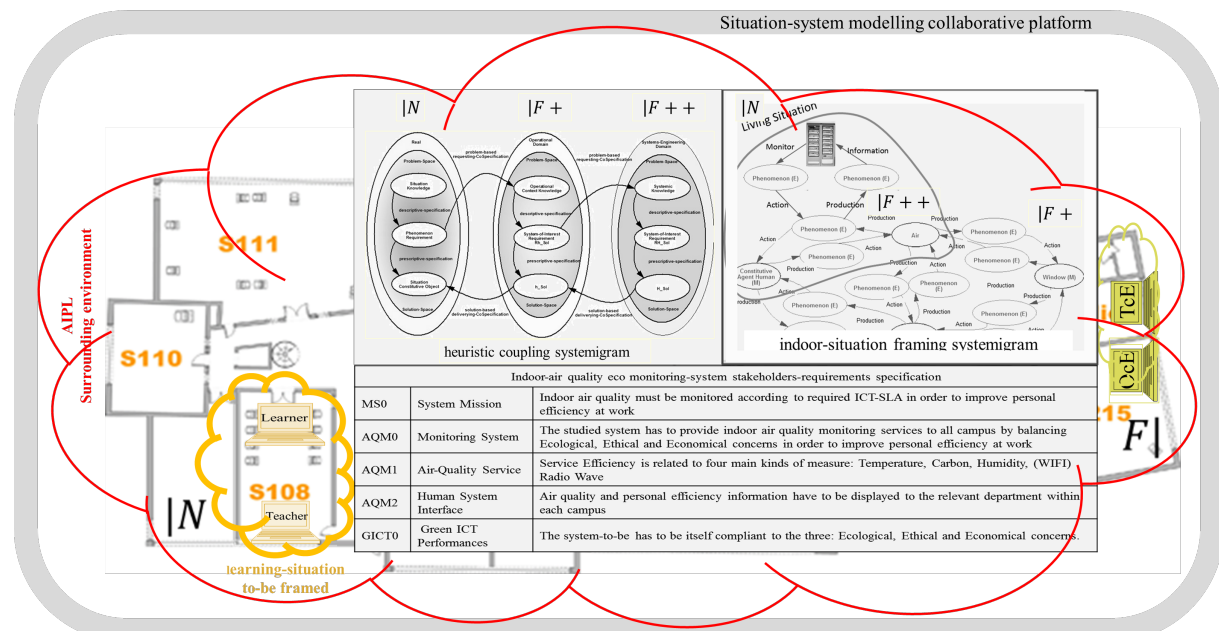


Figure 2: Systems thinking and engineering applied to the situation-problem

<sup>3</sup> EMJMD Pervasive Computing and Communications for Sustainable Development, <http://fst.univ-lorraine.fr/formations/master-ingenierie-des-systemes-complexes>

A complementary experience has resulting from the opportunity of a new 5-year research-driven university program<sup>4</sup> of a multidisciplinary engineering cursus based on active pedagogy by project-based training. Our collaboration with practitioners of system thinking and systems engineering, both in industry and education, justified to place trainees and trainers in a real shareable situation in order to acquire and apply the domain best practices. A key point has been to raise awareness of program managers on the limits of project linear management practices, even with technology-enhanced learning (Dillenbourg, 2011), to address the non-linear orchestration of multidisciplinary knowledge inherent to the system paradigm. Thus, one of the main results has been to show the interest of moving from an additive approach of multidisciplinary learning driven by open situations-problem to an integrative approach to interdisciplinary learning driven by a framed reality that can be shared because perceptible. This broader scope, strengthening our situation-problem as case-study among others possible options, revealed a system-of-systems (SoS) architecting of the multidisciplinary courses as a whole sharing the common mission of “well-being at work in the training room”. Executable formal scenarios<sup>5</sup> enabled to check the behavioural wholeness of the resulting SoS-architecture prototyping of the learning-program. The main challenge faced by these practitioners for a "Fab Lab" practice in an academic setting has lying in the co-optation of the relevant expertise as the project evolved, at the right time to perceive right the situation-problem in a real context, breaking so the usual contextualization imagined from (|F++) (Allegro-Daniel et al., 2016).

Although previous experiences show the interest of a common focus on a shared situation-problem to orchestrate multidisciplinary knowledge in a project-system, the fact remains nevertheless a system modelling rationale subordinating the "natural domain" (|N) by the attracting "formal domain" (|F). That raises the question of what is missing to control more by seeing more (McFarlane, 2003), on a certain analogy with the paradigmatic leap enhanced by auto-id technology to make of a flowing-object the controller of the contingent manufacturing and logistic situations (figure 5 in (Morel et al., 2019)).

### 2.3. Situation-system paradigm key-artefacts

We address in section 3 the remaining challenge within the domain of multidisciplinary systems engineering to check formal congruence from (|F) with a portion of reality (|N) of a situation-problem, both with a priori language-based unifying techniques as well as with a posteriori model-based reducing one. Thus, we propose a paradigm-change in case a system-relationship (Mayer, 1995) carries within it the essence of a certain simplex-wholeness in (|N) inferring a related interdisciplinary-wholeness in (|F). This is why we revisit (figure 3) first the modelling relationship of (Rosen, 1985) as a knowledge-block "to right perceive" the causalities giving "life" to (|N), embodying de facto a simplex-wholeness discernible in-situ by simple rules (Berthoz, 2009). Then, we address the orchestration process by detour of an interdisciplinary-wholeness in (|F) to specify the most possible congruent system-control in the form of a situation-system to right acting in (|N).

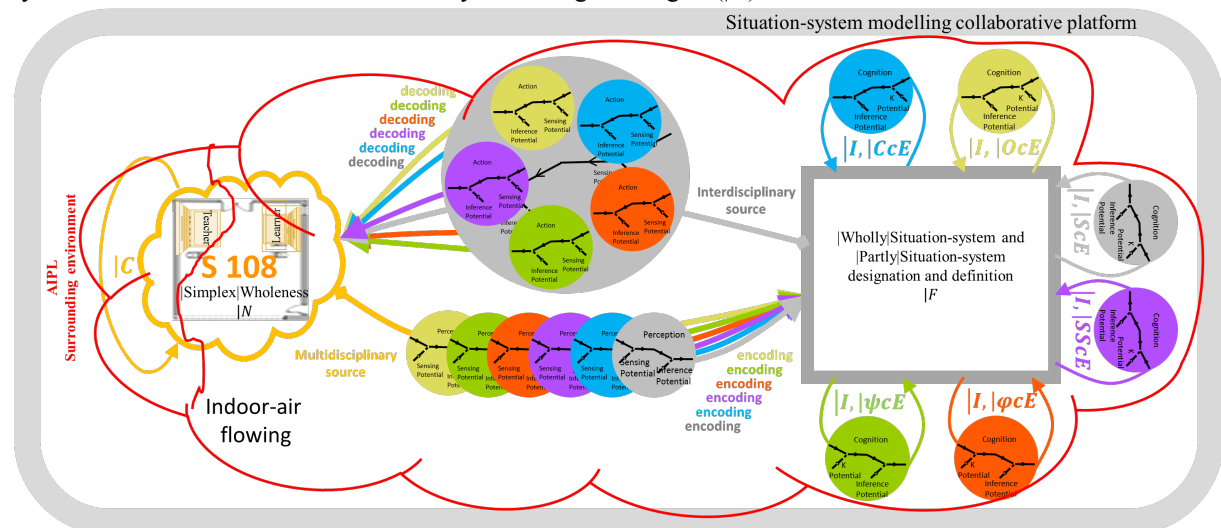


Figure 3: Situation-system framing interdisciplinary orchestration

<sup>4</sup> CMI and figure network, <http://figure-network.org/>

<sup>5</sup> Extended Functional Flow Block Diagram (Aizier et al., 2012)

### 2.3.1. Situation-system modelling relationship

The scientific corpus we have explored first relies on the modeling relationship, so termed by Robert Rosen in his works on relational biology for systems science. The aim was to answer the question of what are the essential characteristics of ( $\mathbb{N}$ ) that would make us perceive it as a portion-of-interest of the reality, i.e. in our case-study in relation to what is vital for the well-being of the occupant within an indoor environment. By admitting a form of closure that makes ( $\mathbb{N}$ ) autonomous in a relational sense (Louie, 2011), Robert Rosen's answer to this question is the causal entailments ( $\mathbb{C}$ ) embodying the notion of causality because related to the characteristics of existence of ( $\mathbb{N}$ ). Thus, the modelling relationship gives major consideration to the structure of the causal entailments of ( $\mathbb{N}$ ) as source and sink of designation in a formal form in ( $\mathbb{F}$ ), resulting from the concretization of inferential entailments ( $\mathbb{I}$ ) and modelling practices by multidisciplinary knowledge. The correspondence between ( $\mathbb{N}$ ) and ( $\mathbb{F}$ ) relies on an encoding-decoding relationship based on concepts of category theory aimed at formally ensuring the congruence of the inferential structure of ( $\mathbb{F}$ ) with that of ( $\mathbb{N}$ ) (Rosen, 1991). Recently, (Louie, 2009) has formally completed the modeling relationship by providing a set of mathematical proofs of this congruence.

We argued in (Mayer, 2018)(Dupont et al., 2019) that causalities refer to the notion of phenomena for the reason they exert tangible influences from which grows up the connectivity between elements of ( $\mathbb{N}$ ), as addressed by (Sauser et al., 2010) in their search of the system DNA. Phenomena involve purpose or, alternatively, a goal (Nadin, 2012) focusing mainly on dynamics in system control theory (Fusaoka et al., 1983), giving meaning to situations as any time when influences between elements form a connectivity for relevant reciprocal actions (revisited from (Zask, 2008)). It should be noted that the notion of measurability, underlying that of phenomena, is a bridge to that of requirement. Certain situations are vital for human because they commit vital physiological phenomena such as the occupant's breathing, embodying physiological causalities. Others commit physical phenomena, embodying physical causalities, required for the proper functioning of the former. As demonstrated in the theory of systems dynamics (Forrester, 1968), the dynamics of these phenomena is revealed by balancing and reinforcement causal loops. There are thus opposite phenomena whose influences result in balancing loops, leading to connectivity stability. And there are phenomena that must be controlled or at least contained, according to the "problem frame" approach (Figure 6 in (Brier et al., 2004)), by other balancing loops because they counteract this stability by reinforcing unrequired influences leading to a break of one or more situations.

And, to a certain extent with (Ducrocq, 1960)(Gell-Mann, 1995), our belief is that an essential phenomenon, for example the flowing indoor-air, by its capability to "glue" the elements of vital and physical situations for the occupant is at the root of the balancing loop embodying indoor well-being to be preserved to ensure in-fine a right activity and living situation. From our exploration of the perception/action theory of (Berthoz & Petit, 2006), we postulate that the phenomenological evidence of physico-physiological situations is made perceptible<sup>6</sup> from the revealed simplicity of the essential phenomenon and that their connectivity forming the causal structure of ( $\mathbb{N}$ ) is constitutive of the simplex-wholeness.

Thus, the designation distinguishes this phenomenological evidence in ( $\mathbb{N}$ ), leading through a first encoding/decoding loop from the "informal" simplex-wholeness (Jin, 2006) to a more formal situation-system definition in ( $\mathbb{F}$ ). The designation thus reflects what is concurrently decided to be true from the fuzzy perceptions of natural phenomena in ( $\mathbb{N}$ ). Its definition requires an interdisciplinary orchestration process of multidisciplinary knowledge reflecting the diversified nature of ( $\mathbb{N}$ ). This designation is itself a prerequisite for the specification of the basic control of the situation-system that we apply in section 5 to our case-study.

We therefore argue that an essential phenomenon is at the root of the initial causal entailment to be perceived when going through the system-modelling relation  $|\mathbb{N} \sqsubset |\mathbb{F}$ , even if some "detours" may be necessary to require relevant multidisciplinary reassessing inferences when some phenomena cannot be directly perceived.

### 2.3.2. Situation-system modelling process

We postulate that the framing of a system-wholeness embodying a targeted situation-system in ( $\mathbb{F}$ ) congruent with the simplex-wholeness of ( $\mathbb{N}$ ) is the refinement guideline (conical spiral in figure 1) for the orchestration of the interdisciplinary-wholeness formed by the multidisciplinary engineering actors of a project-system ( $\mathbb{F}$ ), themselves individually sensitive to percepts of ( $\mathbb{N}$ ) (as "sentient-being", Wilber in Chapter 1 of (Mella, 2009)). However, we distinguish from  $\mathbb{N}$  only what we are in physico-physiologico-cognitive ability to perceive (Werber, 2000). We explain in (Dupont et al., 2019) the physico-physiological capacity to "right perceiving to right acting

---

<sup>6</sup> Semiosis is, according to Peirce, an action, or influence, which is, or involves, an operation of three subjects, such as a sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into an action between pairs (<https://en.wikiquote.org/wiki/Semiotics>).

" (Berthoz, 2012) by a functional analogy with a thyristor pattern highlighting a non-linear behavior of perception-action. A first "gate" as physical sensory prerequisite then triggers a second "gate" making available a certain source-sink propagation of potential inferential entailments related to cognition and action throughout physiological mechanisms (Chauvet, 1993b). This physico-physiological sensing prerequisite to bind into tangible togetherness a situation-system is applied in section 4 to frame the essential simplex-wholeness in ( $\mathbb{N}$ ) on our case study.

It should be noted that this analogy also reflects the human property, termed simplicity, of making the most likely decision by cobbling "by detour" alternative solutions to complex problems in a given situation (Berthoz, 2014). Thus, we revisit Rosen's modelling relationship by introducing the multidisciplinary perceptions of ( $\mathbb{C}$ ) in ( $\mathbb{N}$ ) as necessary conditions to encode them to ( $\mathbb{F}$ ) (illustrated by colored circles at the bottom in Figure 3). And we make ( $\mathbb{F}$ ) the result of specification inferences concretization through multidisciplinary knowledge (on the right in Figure 3) to be orchestrated in an interdisciplinary manner by the system-architect (illustrated by a grey circle on the right in Figure 3). The respondent-system becomes an interdisciplinary source (illustrated by a grey circle at the top in Figure 3) of multidisciplinary-sinks of respondent-parts (illustrated by colored circles in the grey circle at the top in Figure 3) to be decoded in ( $\mathbb{N}$ ).

Looking at the system-modelling process depicted in Figure 3, the phenomena of interest to be detected in a multidisciplinary manner come from multiple interacting objects of interest whose single source in ( $\mathbb{N}$ ) binds them into togetherness. That directs the framing interdisciplinary process to preserve a certain system-wholeness, within the AIPL indoor-environment in our case-study. Applying the acquired inference rule stating that certain exterior-interior object-flows (red line, figure 3, right) give "life" to the simplex-wholeness, those are the air-occupant mutual influences that designate the breathing phenomenon as candidate to form the essential situation-system, the tangible togetherness of which results of their matter-energy "gluing". Thus, a specialist co-optation is required to identify and then to define the physico-physiological essence of this detected phenomenon. Section 4 deals with this air-occupant simplex-wholeness to be preserved as hybrid homeostasis from which the related respondent situation-system is specified in section 5.

Looking now at the unique interdisciplinary source of multidisciplinary inferences raises the question of the simplex trajectories that cognitive objects must follow to form ( $\mathbb{F}$ ). We argue that the inferential entailments structure of ( $\mathbb{F}$ ), i.e. the project-system structure<sup>7</sup>, must be congruent as much as possible to the simplex causal entailments structure of ( $\mathbb{N}$ ). That gives tangibility to the orchestration metaphor to embody as soon as possible what makes the interdisciplinary-wholeness for framing a situation-system from the designation of a related simplex-wholeness by a collaborative approach by detour. This perspective aims to complement the traditional orchestration that highlights the "system partition" writing all along the multidisciplinary engineering process by mainly inwards to inquire, analyze and synthesize an appropriate solution. Even if a system-architect may be aware as orchestrator of some modelling-simulation techniques as well as systemic fundamentals, both these works and ours show the role of enabling experts, e.g. a multi-model simulation architect or a situation-system one.

Thus, both sections 4 and 5 are articulated according to the situation-system interdisciplinary-orchestration process which specifying nature is presented in section 3 from relevant works of the problem-frame approach pointing out the phenomenological nature of the requirements specification content (figure 1 in (Gunter et al., 2000)).

#### 2.4. Synthesis

Our interest though in situ experiments has been to highlight how situation-system elements can result from the multidisciplinary perception of the connectivity of relevant elements manifesting together a wholeness-behavior in a real world-of-interest. We argue that a form of stability of this reality can be designated from the dynamics of an essential balancing loop between a requesting part and at least one other responding part, such as the occupant to/from the flowing air. This inference results from the coupling of a detected wholeness in "real" by an interdisciplinary knowledge orchestration in "formal", the system-centered process of which is discussed in section 3. First by reassessing how the current body of knowledge in system-architecting may fit with this conceptual framework. Second, by presenting in sections 4 and 5 the heuristic orchestrating process for architecting our studied situation-system.

---

<sup>7</sup> Authors are respective specialists in situation-system framing, integrative physiology, control engineering, systems-engineering, physics and system-architecting



### 3. Situation-system model-based orchestration

#### 3.1. Introduction

The previous section aligns to some extent the interdisciplinary-wholeness orchestration process in (|F) with the simplex-wholeness in (|N) to frame a situation-wholeness which system-architecture must be formally specified for solution-oriented purposes. We first review the means of the engineering system to transcend traditional silos of knowledge to multidisciplinary orchestrate the specification of large-scale systems in real-world situations that are perceived as complex (Penalva, 1997) or simply complicated due to the increasing integration of easy-to-use technologies. From the synthesis of some system modeling key-artifacts, we then present our interdisciplinary orchestration environment in (|F) aiming to enable the specification by detour of a system-situation whose connectivity makes tangible a certain phenomenological-wholeness to be preserved between interacting natural, human and artefactual parts in (|N), for instance breathing at our scale factor.

#### 3.2. Multidisciplinary orchestration

Man-engineered systems result from a multidisciplinary process intending to attribute emergent properties, behaviors and purposes by binding specialized parts into a required-wholeness. The collaborative effort is rather aligned of the feasibility of the technical purpose to manage the constitutive complexity resulting from four types of emergence related to what is required, tolerated or unlikely and what may occur during testing or even in operation (Bombed, 2014). Human factors address in a complementary manner what can be automated or not, or both (Figure 5, chapter 10, (Millot et al., 2011)) in relation to simplicity capability enabling human to be aware of the "unexpected" in an operating situation and thus to make resilient a designed robust system. The guide to the body of knowledge in technology-centered systems-engineering regularly releases certain generic principles of a systemic approach (part 2, foundations of systems engineering, in (BKCASE Editorial Board, 2019)) to apply standardized engineering processes in a recursive, iterative and concurrent manner, scheduled by project management templates. The model-based systems engineering approach aims to contrast with the traditional document-centric approach by replacing the project basic artefact of "process" by that of "model", however without clearly addressing the homomorphic correspondence with a reality (Figure 3.1, (Le Moigne, 1990)). The top-down and bottom-up perspectives that orchestrate the modelling approach focus mainly on the solution-space exploration in such a way to satisfy the operational users' needs of a required system, prior to detailed architecting design of its components and their assembly. The ontological symbiosis of Human centered design (Boy & Narkevicius, 2014) evolving to Human system integration (Boy, 2019) with technical-centered systems engineering raises the question of how to make interoperating these knowledge corpus as a system of systems which hybrid nature is cognitive, technical, physical, and more. That requests the combination of several disciplines within a federating body of knowledge or, pending a certain practical maturity, a multidisciplinary orchestration that remains difficult to satisfy. The cognitive work of an orchestrator can be facilitated by the de facto standardized system modeling language<sup>8</sup> or by domain-oriented languages<sup>9</sup>. Formal languages and techniques are efficient for model-checking issues in a unified domain, namely that of discrete process (Zaytoon & Riera, 2017), but are less suitable to orchestrate multidisciplinary knowledge. For instance, unifying B machines in (figure 4, in (Pétin et al., 2006)) are only a limited transition of the required multi-expertise in physics, hardware-software instrumentation and human-in-the-loop control as further addressed in (Dupont et al., 2019). Digital technology is making possible to improve this orchestration through the use of integrative platforms<sup>10</sup> that provide a standardized continuum of information, documents and models exchanges towards enabling synchronous execution of multiple models built asynchronously in their own environments in order to reflect a system-wholeness (Bouffaron, 2016). Notwithstanding the use of an innovative computing-orchestrator to automate application engineering tasks, it is the simplicity capability of a human-orchestrator we argue suitable at the level of a situation-system abstraction. One has only to look at the recurrent inquiry on 'what is a system' to be true since the early times of Systemics (von Bertalanffy, 1968) (Pouvreau, 2014) and its relationship to cybernetics (Wiener, 1948)(Forrester, 1968) up to (Sillitto et al., 2017).

Thus, we focus our working scenario on the connectivity orchestration between the cognitive attitudes "to detect influences" and "to mark the exterior-interior boundary", among others system-thinking artefacts according to the mind map of (Figure 2, (Allegro-Daniel & Smith, 2017)). It should be noted that the resulting partition of this boundary key-artefact is very dependent on the stakeholder's requirements specification embodied by the concept of operations (CONOPS) in large-scale systems projects and by the actors' driven SysML use-cases diagram in ICT-based systems projects. In order to deal with what this binary "interior-exterior" logic can hide to specify the reality of a situation-system, we interpret (Figure 1) as (|N |B |W |F) the quaternary logic of (chapter 4, (Giré,

<sup>8</sup> SYStem Modelling Language, [www.omg.org](http://www.omg.org)

<sup>9</sup> <https://www.modelica.org/>; Standardlibrary; Physiolibary; Functional Mock-up Interface

<sup>10</sup> 3D experience platform, <https://www.3ds.com/about-3ds/3dexperience-platform/>

1988)) according to which the concepts of boundary, interior and exterior must be linked to a referential-wholeness. It is important to note that the dynamics of the multidisciplinary knowledge orchestration then impacts the construction of this referential-wholeness as long as the interdisciplinary-wholeness does not sufficiently reflect the simplex-wholeness to ground a solution design. We have also adapted the coupling diagram of (Figure 3.1, (Lawson, 2015)) which considers "control" as a key-artefact to direct the orchestration of a respondent-system to a system of situations by going beyond the intuitive basis to formulate our situation-system paradigm. Finally, we translated the twin-peaks refinement process  $|problem \xrightarrow{\quad} solution|$  de (Hall et al., 2002) into a four-time heuristic orchestration for each level in order to ensure scenario-based model-checking of each multidisciplinary outcome as well as that of the related interdisciplinary outcome.

### 3.3. Interdisciplinary orchestration

Let us consider, for explanation only, one scenario among others coupling in-situ an indoor environment, in this case room 108 within the AIPL outdoor environment, with an in-silico collaborative platform surrounding this situation-system in order to enable the interdisciplinary orchestration of multidisciplinary knowledge, requirements and models. Note that the system-assets constitutive of this studied situation-system are the means of the AIPL but also the learners, teachers and engineers depending on their changing role. At different times of training sessions, ill-being problems have been reported to  $|TcE$  (Teaching centred Engineering) and  $|OcE$  (Operational centred Engineering) staffs. As certified ISO 9001 public institution,  $(|OcE)$  became aware of a risky situation by first investigating legal guidelines and standards of well-being at work in order to detect certain causes of problems, justifying a further decision-making with  $(|TcE)$  to launch a case study project about the indoor-environment constitutive of  $(|N)$ . Taking benefit of previous experiences as well as the opportunity to bring together scientific actors, the management of the system-project was under the expertise of a system-architect  $(|ScE)$  aware of certain systemic characteristics of this type of situation-problem, forming at this time the system of interest  $(|SoI)$ . The first requirements specifications through the project-repository with a co-opted physiologist  $|ΨcE$  led  $(|ScE)$  to extend the exterior boundary of  $(|SoI)$  by co-opting a situation-system expert  $(|SScE)$ . The expected result is a specification of a situation-situation of interest  $(|SSoI)$  that better reflects what  $(|SoI)$  will have to control to satisfy the occupant's priority breathing need.

The Venn diagram in Figure 4 describes what is shareable or specific to a knowledge domain at a certain refinement level in  $(|F)$ , keeping in mind that the phenomenological evidence is the simplex-orchestrator in  $(|N)$  driving to some extent another human simplex-orchestrator in  $(|F)$ . We synthesize below four times detailed in sections 4 and 5 of the non-linear process of interdisciplinary orchestration of the originating situation-system specification between  $|SScE$  and  $|ϕΨcE$ , acting himself as architect of the requested multidisciplinary physico-physiological domain:

- *Specification|descriptive|requesting|problem* ;  $(K|F), (R|N) \rightarrow (K|F)$

A knowledge  $(K|F)$  of the sink-domain  $(|ϕΨcE)$  is requested in an understandable form by a knowledge  $(K|F)$  of the source-domain  $(|SScE)$  to encode from the simplex-wholeness  $(|N)$  more than the causalities decoded by the preliminary specification situation-problem  $(|R)$ .

- *Specification|formal|checking|solution* ;  $(I|F), (C|N) \vdash (M|F)$

The required knowledge  $(|ϕΨcE)$  performs inferences  $(I|F)$  to make visible the indicative causalities  $(C|N)$  more or less hidden in  $(R|N)$ . The  $ϕΨ$ -wholeness correctness in  $(|F)$  of the resulting formal model  $(M|F)$  is checking according to the domain best practices (job-right in (Fanmuy et al., 2012)).

- *Specification|prescriptive|responding|solution* ;  $(K|F) \leftarrow (M|F), (K|F)$

An understandable form of  $(M|F)$  is prescribed by  $(K|F)$  in the form of test-cases scenario-results requirements to enable  $(K|F)$  to check the correctness of its transitioned  $(M|F)$ .

- *Specification|contractual|checking|solution*  $(I|F), \{(M|F), (M|F)\} \vDash (R|N)$

The requesting knowledge  $|SScE$  performs inferences  $(I|F)$  to check the consistency of the commitment of the two models  $\{(M|F), (M|F)\}$  in the simplex-wholeness  $(|N)$  inherent to the optative requirement  $(R|N)$ , with some indicative causalities added in  $(M|F)$  (right-job in (Fanmuy et al., 2012)).

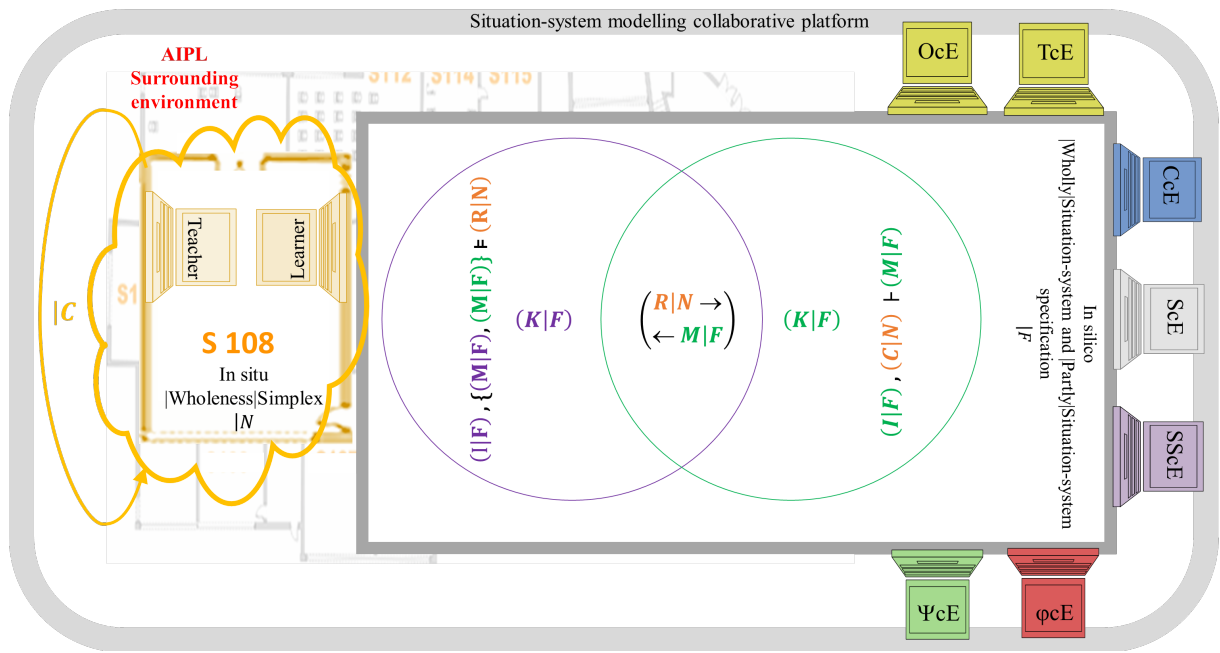


Figure 4: Level of refinement in four times of the interdisciplinary orchestration process between |SScE and |φΨcE of the essential situation-system specification

The result is a model-based specification as (|SSoI) wholeness on which (|ScE) will refer to lead the specification of a system- architecture towards (|SoI) design. As powerful result in § 2.3.2 to distinguish Knowledge from Inference this heuristic highlights the benefit to be gained from a certain harmony<sup>11</sup>, which technology can enhance, within a team of the potential of any inference that responds to the perceived knowledge that required it. Looking back our collaborative experiments, the team orchestrator capability is first to maintain the interdisciplinary encoding-decoding in a centripetal synchronous manner, i.e. scheduled, on the reality of the targeted situation-system. But the orchestrating art is also to enable multidisciplinary strengthening in a centrifugal asynchronous manner, i.e. at their own time, between involved actors. That all the more so these experts may be multidisciplinary domain-architect recursively orchestrating specialized knowledge and skills they require with always their look on the reality under framing, at least at the early situation-system specification.

### 3.4. Synthesis

This knowledge orchestration trajectory, successively source and sink of inferences, is put into the perspective of the *Integrative Physiology* framework in section 6. The model-based specification collaborative-environment we present aims to enabling the scientific interest to early frame a situation-system from a certain interdisciplinary phenomenological evidence of a reality.

The related cognitive orchestration may take benefit of some systemic key-artefacts coming both from the technology-centered and human-centered communities involved in large-scale projects and programs. Nevertheless, we point out another benefit to take from the containment of our indoor-situation case-study by preserving some simplex-wholeness binding into togetherness both the reality and the multidisciplinary knowledge domains. A result could be to postpone the exterior boundary framing of a respondent system to a system of multi-domain situations all along a refinement process before decision-making for definition and design architecting, as addressed throughout sections 4, 5 and 6.

## 4. Hybrid-homeostasis model-based specification

### 4.1. Introduction

An early refinement level in the interdisciplinary orchestration process according to  $(K|F), (R|N) \rightarrow (K|F)$  led (|SScE) to interoperate with (|ψcE) to perform  $(|I |ψcE)$  in (|F) (Figure 5) in order to designate first what is required as vital for indoor-occupant. This decision-making in the project-system is based on (|ψcE) perceived knowledge in integrative physiology whose mathematical and simulation basis make it possible to define then, according to  $(I|F), (C|N) \vdash (M|F)$ , a formal response based on a model of the occupant breathing phenomena as core source

<sup>11</sup> [\[1\]](http://www-03.ibm.com/software/products/en/conn) Togetherness enabling means; <http://www-03.ibm.com/software/products/en/conn>

of evidence of the simplex-wholeness in  $(|N)$ . The correctness of the resulting hybrid-homeostasis model  $(M|F)$  is checked in §4.3 in the form of scenario-based test-cases, the results of whose enabling in return to check its consistency transition by  $(|SScE)$  in §5.2. Cognitive exchanges are performed in understandable forms through the specification repository according to  $(K|F) \leftarrow (M|F), (K|F)$ .

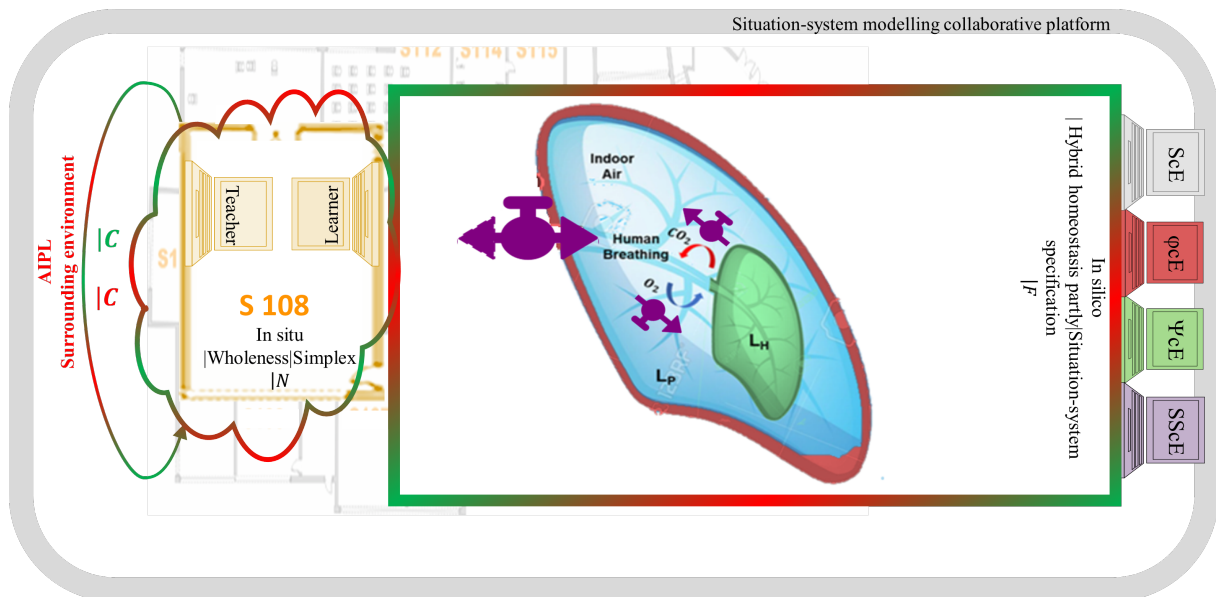


Figure 5: Understandable breathing co-specification

#### 4.2. Breathing phenomena modelling key-artefacts

The interest of the mathematical theory of integrative physiology (MTIP) relies with the possibility of quantifying certain physiological conditions and proprieties based on physics, some of which may become requirements prescribed by a physiologist-asset coopted in a system-project. Effectively, for (p. 11 and 15, (Chauvet, 2005)), even if “biology is not reduced to physics [...] [however] the living thing is surrounded by the physical universe that it comes from; it is subject to laws that it has had to use to its advantage. It is very difficult under these conditions to believe in a biological universe without unity that emerges from a physical universe of which the harmony of laws leads to research into the famous unitary theory”. In addition, for him, the organism, i.e. all the physiological processes that take place between the various biological structures, is a continuous and finite hierarchical system of structures as well as a combination of functional interactions between these structures. This mathematical theory of integrative physiology is built with the triplet  $\{source|functional\_interaction|sink\}$  (Chauvet, 1993b, 1993c, 1993d) and mathematically described by a field equation to follow the propagation of the functional interaction according to specific space and time scales (Chauvet, 1993a). And it is postulated that all physiological mechanisms are a set of elementary processes consisting to a source in functional interaction with a sink and along the different discontinuities of structure or/and nature between these sources and sinks.

This brief scope of MTIP fit right to deepen the air-occupant mutual influences designating the breathing phenomenon as candidate to make the tangible togetherness of the essential situation-system. The functional interaction has several specific properties giving meaning to air-flowing required by occupant oxygenation:

- $\{non-symmetry\}$ : the functional interaction acts from a structural unit “source” towards a structural unit “sink”; it represents a unidirectional action; thus, at a same level of organization and in the same time, the signal will not retroact from the sink to the source; for example, a certain quantity of oxygen ( $O_2$ ) is coming from (inhalation) outside (source) towards the human lungs (sink) and only later is coming out (exhalation) them with less oxygen.
- $\{event\ causality\}$ : the cause-effect relationship is due to the existence of an event; a breathing muscular movement triggers inhalation or exhalation of oxygen carried by air and this flowing object can be regarded as a breathing event from outside to inside of the occupant or inversely; since this event existed as a cause in a previous instant ( $t$ ) the effect is going to exist at an instant ( $t'$ ).
- $\{non-instantaneity\}$ : the speed of transport of an elementary function is finite; according the pulmonary rate, the speed of oxygen carried by air is around several meters per second.
- $\{non-locality\}$ : an elementary function acts remotely and creates couplings between structures that are far apart; the exchanged product is transported from one place to another non-neighboring one by

propagating across structural discontinuities; for human breathing, the mouth and nose can be regarded as a transition between both human outside and inside for the flowing oxygen carried by air.

With this in mind, a functional interaction expresses a mechanism of passing a product (here oxygen carried by the indoor-air) between at least two structural units, for example between the indoor-place (as a physical space) and a human being or between pulmonary alveoli and blood capillaries for the same product (oxygen) but to lower levels and different finalities. This passing mechanism depends both on time and space (figure 6, top).

Thus, the MTIP can be used as a guide to qualitatively follow, and in a first step before any mathematical calculation, the possible trajectories/paths of the functional interaction(s), once this one has been identified through a physical quantity that supports it (matter/physical dimension of the interaction). As the trajectories/paths obey together to the laws of conservation of matter and energy, they can be used to find them. Concerning the human breathing, as mentioned in (Chauvet, 1999), ( $|O_2$ ) under a molar form (physical/chemical quantity) can represent the first functional interaction and two main pathways can be identified depending on whether oxygen is exhaled (exogenous phenomenon - exhalation) or fixed in the blood after passing through the walls of the pulmonary alveoli to reach capillaries (endogenous phenomenon – pulmonary gas-exchange) as shown in (figure 6, bottom). And into the pulmonary alveoli, ( $|O_2$ ) is still supported/carried by the air (in gaseous form) as a molecular component. Only the first trajectory will be studied but whatever the chosen path, the first elementary mechanism, that's to say inhalation of oxygen by air breathing from outside to inside the human body, justifies stereotyping the first requirement as physical-physiological.

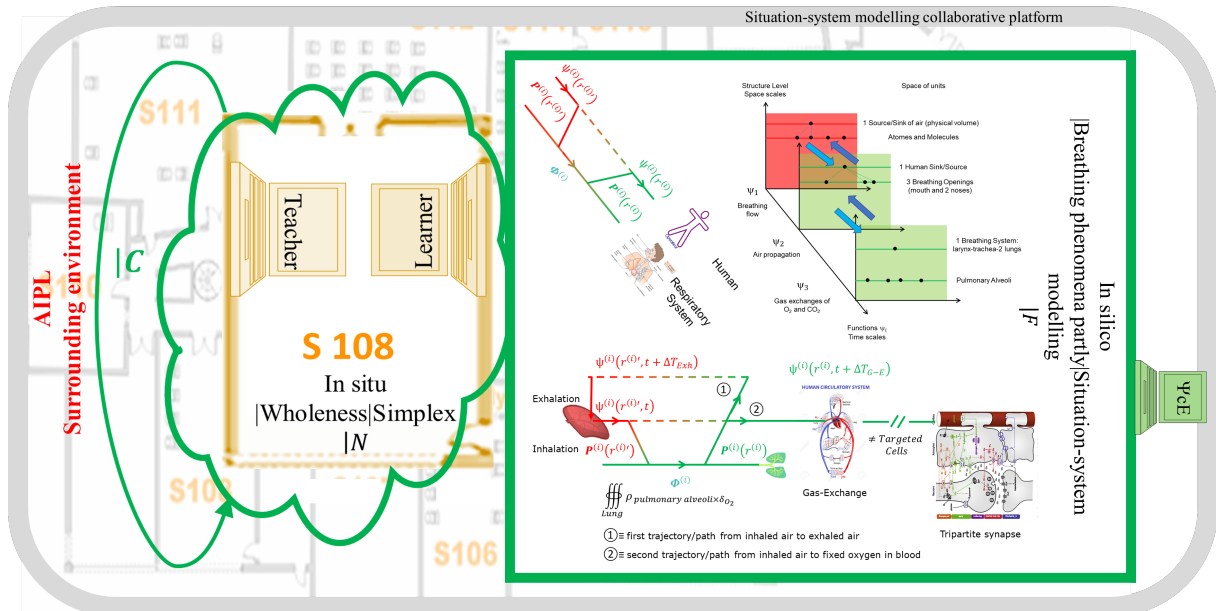


Figure 6: Breathing phenomena preliminary and alternative inferences

#### 4.3. Breathing phenomena formal modelling

As in adults, the normal respiratory rate at rest is around of 12–18 breaths per minute and the oxygen is at least estimated on several hours (temporal learning unity), the physiological mechanism of human breathing can be regarded as a unique human lung (with a breathing rate proportional to the number of human beings in the indoor-place). And in a bio-inspired transposition, ( $\psi$ CE) can prescribe Human breathing from a global Human Lung (LH) in a physical lung-like (LP) contained indoor-space as shown in figure 5 for understandable specification exchanges purposes. To estimate the dynamics of molar oxygen concentration, we use a balance equation for ( $|O_2$ ) from (Herman, 2016). On average, each human being typically breathes  $\sim 6L/$  of min air, which is the ventilation or inhalation rate ( $d_{Breathing}^{Air}$ ). And 5% of inhaled oxygen is consumed, 4 % of carbon dioxide and about 0.5 kg water vapor/day are produced and carried in the exhaled air, Nitrogen is constant. As we suppose the physical space of the indoor-place is contained, the modification of the quantity of ( $|O_2$ ) comes only from the human breathing in terms of consumption:

$$n_{O_2}^{Int}(t) = \frac{n_{O_2}^{Int}(t=0)}{\left(1 + nbH \times \left(\frac{5}{100}\right) \times \left(\frac{d_{Breathing}^{Air}(t)}{V_{Int}}\right) \times t\right)}$$

With  $V_{Int}$  and  $nbH$ , respectively the physical volume of the indoor-place and the number of human occupants.

To evaluate the quantity  $n_{O_2}^{Int}(t = 0)$ , we can use the ideal gas law:  $PV = nRT$  where P, V and T are, respectively, the pressure, volume and absolute temperature in the indoor-place before the incoming of human occupants; n is the number of total moles (indoor-air); and R is the universal constant of the ideal gases (8,314 J/(K.mol)). Note that this law exemplifies a simple rule for framing a simplex-wholeness in an indoor-environment as suggested by (Nazaroff, 2013). The oxygen molar fraction noted  $f_{O_2}^m$  is written:

$$f_{O_2}^m(t) = \frac{n_{O_2}^{Int}(t)}{\sum_i n_i(t)}$$

As a first reasonable approximation, the main components of air are nitrogen ( $|N_2$ ), oxygen ( $|O_2$ ), carbon dioxide ( $|CO_2$ ) and water vapors ( $|H_2O$ ), the last two one mainly coming from the product of the human breathing in the indoor-place. And in the same way, the dynamics of the molar concentration of carbon dioxide and water vapors can be evaluated with a matter balance equation (production of carbon dioxide and water vapors):

$$\begin{aligned} n_{CO_2}(t) &= n_{CO_2}(t = 0) + nb_H \times \tau_{CO_2}^{HB} \times t && \text{With respectively } \tau_{CO_2}^{HB} \text{ and } \tau_{H_2O}^{HB} \text{ the rate of carbon} \\ n_{H_2O}(t) &= n_{H_2O}(t = 0) + nb_H \times \tau_{H_2O}^{HB} \times t && \text{dioxide and water vapors.} \end{aligned}$$

Each field of knowledge such as Physics or Physiology is based, among other, on principles, and some trajectories given by MTIP may cross these fields, thus giving the possibility to extend certain principles to other fields (artificial/technical principles versus natural principles) or even better to hybridize them (hybrid principles such as stereotyped physico-physiological). In Physiology, one of the most important core concepts or principles is homeostasis (Michael et al., 2017). Based on the observations of various physiologists such as Claude Bernard with his “milieu intérieur” or Charles Richet and his quotation – “In a sense it [the living being] is stable because it is modifiable”. Charles Cannon wrote in 1929 (Cannon, 1929): “The coordinated physiological reactions which maintain most of the steady states in the body are so complex, and are so peculiar to the living organism, that it is suggested that these states be specifically designated by the homeostasis.”. Such a principle can be used in a solution-oriented (physical or/and physico-physiological) approach in order to find later technical solutions (organic allocation). Thus, starting from the “source” state, the indoor-place becomes a “sink” of exhaled air by the human occupants and considering a possible partial or even total containment of this indoor-place, the molecular composition of the indoor-air will change. So, we introduce a kind of hybrid homeostasis with the molar fraction of oxygen as the quantity that must be (or maintained) stable around [19% - 21%] and its mathematical formulation makes it possible to identify the elements that vary and are therefore candidate to be controlled as shown in the figure 7.

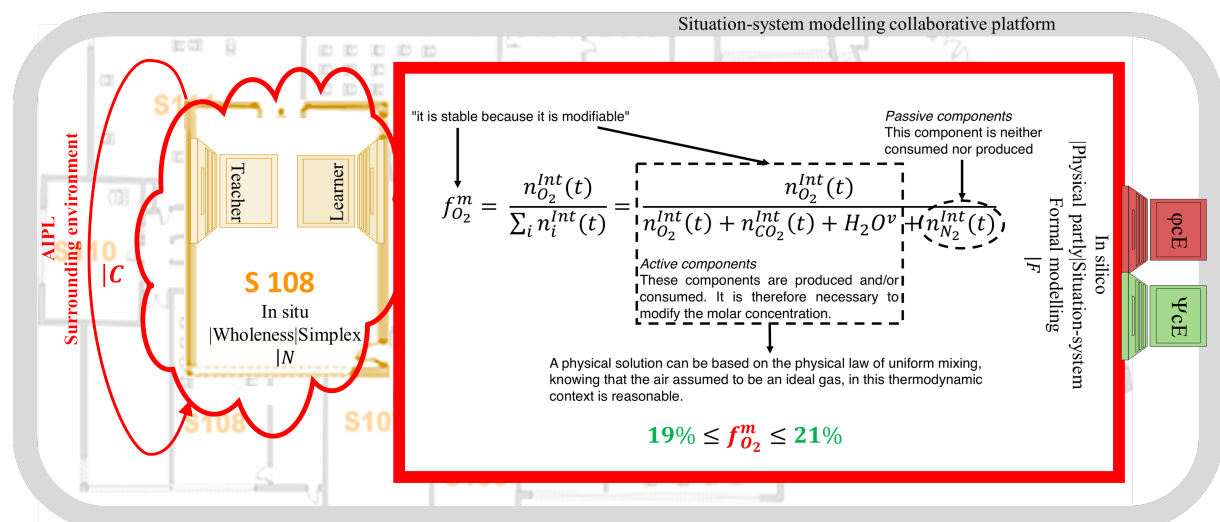


Figure 7: Hybrid-homeostasis mathematical model

This molar fraction can be considered as a kind of invariant according to a general principle introduced into the theoretical framework of MTIP, called P.A.A.S. for Principle of Self-associative Stabilization (Chauvet, 2006) and can be stated as follows: “For any triplet ( $s\psi S$ ), denoted as  $s \xrightarrow{\psi} S$ , where  $s$  is the system-source,  $S$  the system-sink, and  $\psi$  the functional interaction, the area of stability of the system  $s \xrightarrow{\psi} S$  is larger than the areas of stability of  $s$  and  $S$  considered separately.” And for our application, we can identify ( $s$ ) as the “source” outdoor

environment (supposed to contain "good" air), ( $I\psi$ ) is still oxygen ( $I\mathcal{O}_2$ ) as the functional interaction carried by air from outdoor to indoor and finally ( $I\mathcal{S}$ ) as a hybrid (socio-technical) "well" system-sink with the physical place and the human group constitutive together of the indoor-environment for 'doing right' things. The range of stability is the window [19% - 21%] for the indoor molar fraction of oxygen. And carbon dioxide and water vapors must be considered as a kind of "biological" waste. Thus, the PAAS could be posed as "*a principle of construction and organization of a biological system*", extended to a hybrid system, it could be used to identify additional technical and/or biological elements (source) likely to ensure a better stabilization of the identified and therefore targeted invariant.

#### 4.4. Breathing phenomena model-checking specification

A following orchestration specification time in return of ( $I\mathcal{S}ScE$ ) request relies with a model-checking process to transitioning the hybrid-homeostasis mathematical model to model-based systems-dynamics. The resulting transitioned mathematical modelling diagrammed in Matlab®Simulink® (Figure 8) enables to reduce semantics loss by ( $I\varphi\psi cE$ ) having acted as physico-physiologist orchestrator while facilitating openness to multiphysics system-control and to MBSE co-specification in large.

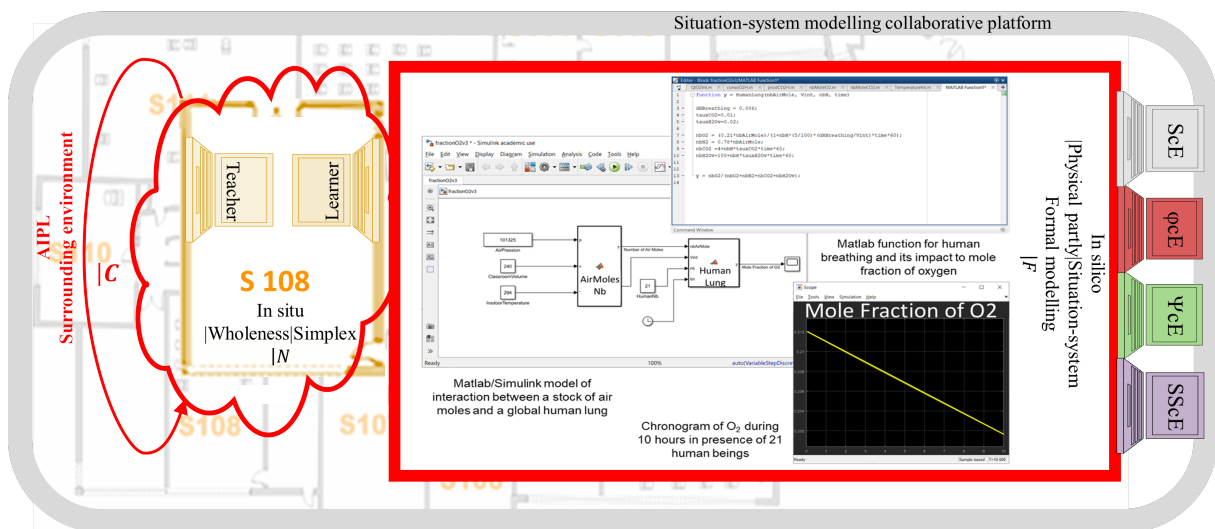


Figure 8: Transitioned Hybrid-homeostasis mathematical model to systems-dynamics and control

The correctness-checking of the resulting transitioned mathematical model with that of (Figure 7) is performed with scenario-based test-cases which results are depicted in the form of chronograms of ( $I\mathcal{O}_2$ ), ( $I\mathcal{CO}_2$ ), ( $I\mathcal{H}_2\mathcal{O}$ ) and of the resulting molar fraction of oxygen (Figure 9). For the mathematical simulations, we instantiated some parameters previously used to build the different balance equations with the physical properties of (room 108). The pression of the air is equal to 101305 Pascals, the initial indoor temperature is equal to 21° Celsius (about 294 kelvins), the volume of the room is equal to about 240 m<sup>3</sup> and the group of human occupants consists of one teacher and 20 students. Thus, the evolution of the different molar quantities of air can be evaluated over time and over two time slots, in the morning (8:00-12:00 AM) and afternoon (2:00-6:00 PM), in order to obtain the molar fraction of oxygen in the indoor-room from the evaluation of the quantity of oxygen, carbon dioxide and water vapours.

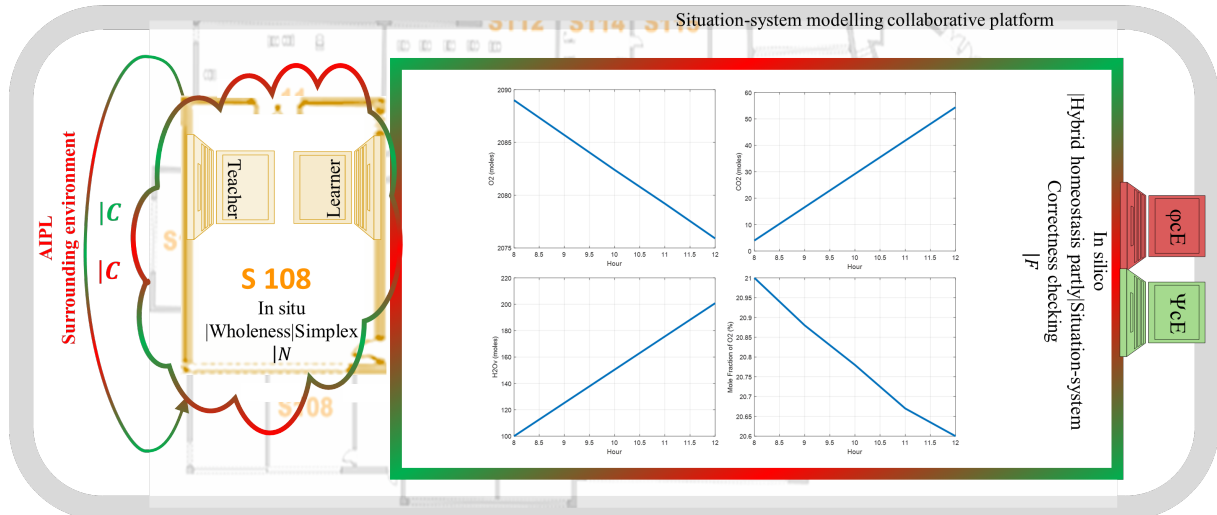


Figure 9: Correctness-checking of the transitioned hybrid-homeostasis mathematical model

At a later co-specification time, the consistency-checking of the transitioned hybrid-homeostasis in systems-dynamics by (SScE) in section 5 is performed from the results of four scenario-based test-cases by ( $\varphi\psi cE$ ) which chronograms are depicted in (Figure 10). This prescriptive specification relates with human breathing-wholeness as core situation-system in the contained space of room 108. We also assume that between learning periods, the air in the classroom can be totally, partially or not renewed. And we introduced a simple rate of air renewing, called  $\tau_{Air}^r$  with the following values: 0%, 30%, 50% and 100% for no renewal, renewal to around one-third party, half and total, respectively. We thus obtain a different temporary evolution according to the scenarios from the results of which we can conclude that the less air in indoor-room is renewed during the learning periods, the more the molar fraction of oxygen decreases. It should be noted that |TcE can be requested to make personalized pedagogical improvements.

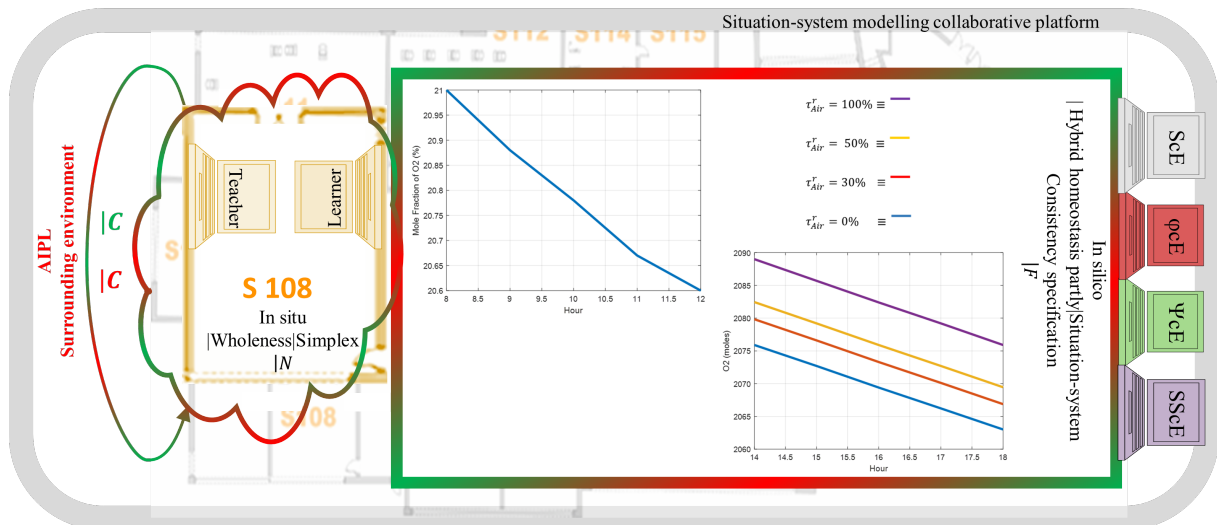


Figure 10: Consistency-checking of the transitioned core situation-system model

#### 4.5. Synthesis

The mathematical grounding in (|F) by ( $\varphi\psi cE$ ) of the breathing phenomenon as simplex-wholeness from (|N) previously framed by (SScE) as core situation-system relates not only to the evolution of the quantity of oxygen in the indoor-room, but mainly its molar fraction which depends on the composition of the indoor-air flowing in the same contained space. In a first (more qualitative) step, we used MTIP as a tool to define and then explore the relevant trajectories of the functional interactions implicit to the situation-system paradigm. And in second step (more quantitative), we directly build a simple mathematical model which inference relies (qualitatively) on the field equation of the MTIP illustrating the physico-physiological modelling framework of such situation-system. It should be noted that this preliminary mathematical modelling for co-understanding purposes, can be deepen within MTIP to explore source-sink density of connectivity according to a spatial distribution for another human need (nutrition) if required, depending however a large amount of data relating to human anatomy, physiology and



biochemistry which are not currently all available. On an interdisciplinary orchestration side, this mathematical simplicity quality enables a representation by detour of the essential simplex-wholeness.

By revisiting physiological homeostasis, we have introduced a kind of hybrid state between the physical indoor-room (artificial entity) and the group of human occupants (biological entity) with the molar fraction of oxygen posed as invariant to be stabilized between 19% and 21%. We have also revisited the P.A.A.S. by qualifying it as augmented in order to identify some additional functional interactions that are likely to maintain at best this molar fraction in a system-control goal. It should be noted that by starting from a physiological point of view with human breathing, we finally manipulate entities and concepts from physics such as the law of ideal gases. And finally, we paid attention of robust model-checking of the transitioning of the resulting hybrid-homeostasis model to MBSE co-specification purposes, first to become the core situation-system reference model for (SScE) in section 5 and then to perspectives in section 6.

## 5. Breathing situation-system model-based specification

### 5.1. Introduction

A later refinement level in the interdisciplinary orchestration process led (SScE) to interoperate with ( $\varphi\Psi cE$ ) and (CcE) to perform systems-dynamics inferences (IISScE) in (F) (Figure 5) in order to specify the control of the core breathing situation-system. This decision-making in the project-system is based on certain system-thinking acquired knowledge by (ScE) leading to reassess the dynamics of the intended core situation-system, both from balancing and reinforcement loops. The hybrid-homeostasis model is first transitioning to system-dynamics according to  $(I|F), (M|F) \vdash (M|F)$ . Another inference according to  $(I|F), (R|N) \vdash (M|F)$  refines then the resulting transitioned model, augmented by this systems-dynamics perspective, in order to commit the core situation-system into simplex-wholeness in (N) by checking the preservation of the essential hybrid-homeostasis. This recursive process ends to transitioning to SysML an understandable model of the control of the core situation system according to:  $(I|F), (M|F) \vdash (M|F)$ .

### 5.2. Hybrid-homeostasis transitioning to systems-dynamics

By having shared a preliminary requirements specification of the simplex-wholeness with the physiologist ( $\Psi cE$ ), (SScE) can now transitioning in (F) the corresponding system-wholeness making hybrid-homeostasis the architectural model of an essential situation-system to preserve indoor-occupant from surrounding indoor-environment.

The prescription of the occupant vital homeostasis framed by ( $\varphi\Psi cE$ ) contains an implicit designation of the causal implications (C) of (N) that (SScE) explicits in a first time in the form of a causal loop model diagrammed by the means of a shareable mental tool<sup>12</sup> enabling "system thinking" in (F) with few modelling rules (I). The resulting understandable map (Figure 11, top) points outs the oxygen molar fraction ( $f_{O_2}^m$ ) as basic modelling-artefact of the essential balancing loop (B) of a preliminary construct to system-dynamics compliance. It should be noted that this recursive transitioning process adds a counteracting reinforcement construct (R) to take into account internal as well external phenomena which can degrade the physiological situation vital to occupant. This augmented model aims to better check the simplex-wholeness to be framed from the dynamics of the influences exerted by the phenomenon of indoor-air flowing as source and sink of the hybrid-homeostasis balancing loop (B) in (N) to maintain when influences exerted by certain others physical phenomena are source of reinforcement loops (R).

In order to check this framing-consistency with ( $\varphi\Psi cE$ ) beyond informal exchanges, we applied translation rules from the theory of systems dynamics to perform architectural inferences (I) to formally model the essential breathing system-situation in the form of a stock-flow model (Figure 11, bottom) diagrammed by the means of the Stella Architect tool<sup>13</sup>, a system thinking modelling and simulation technology. Thus, stocks (illustrated by rectangles) and flows (illustrated by pipes and directional valves) model occupant homeostasis as a stock of physiological phenomenon (in green) and the indoor homeostasis-like as a stock of physical phenomenon (in red). The variation of the value of the "air renewal rate" converter (illustrated by a circle) from 0% to 100% enables to modulate the phenomenon of indoor-air flowing. This simulated propagation of the influences of this phenomenon as "glue" of the connectivity of the essential situation-system thus formed is represented by red arrows (of physical nature) and green arrows (of physiological nature) representing the gaseous exchanges through the breathing hybrid-homeostasis. The essential balancing loop is made visible by the "O2 molar fraction" converter whose variation outside the range required by ( $\varphi\Psi cE$ ) indicates a lack of O2 and an increase in CO2 and water vapors, as source of a reinforcement loop leading to the rupture of the vital physiological situation of an indoor occupant.

---

<sup>12</sup> <https://ncase.me/loopy/>

<sup>13</sup> <https://www.iseesystems.com/>

This essential situation-system specification points out the importance of the quality of the dynamics of the essential phenomenon of indoor-air flowing to maintain the range of ( $f_{O_2}^m$ ) between 19%-21% to ensure the right hybrid-homeostasis as essential to perform right any activity.

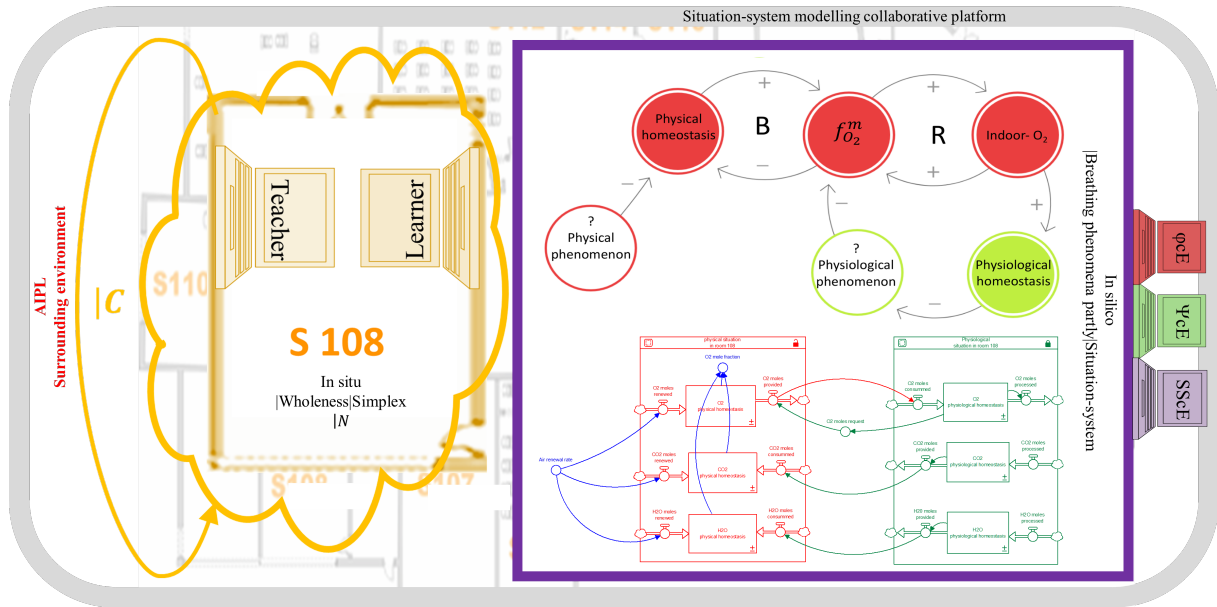


Figure 11: Breathing hybrid-homeostasis transitioned to systems-dynamics

Data chart in (Figure 12, top) displays the results of four simulations performed first by ((SScE) in ((F) for correctness-checking of the formal transition of the hybrid-homeostasis model by satisfying test-cases (Figure 10) prescribed by (( $\varphi\Psi cE$ )). The simulations run in discrete time by varying the rate of indoor-air renewal to highlight the balancing loop as well as the reinforcement loop leading satisfying right breathing or not. The consistency checking in return by (( $\varphi\Psi cE$ )) enables to satisfy that our augmented essential situation-system model preserves the role of air exchange rate connectivity and oxygen molar fraction between the occupant physiological homeostasis and the related physical homeostasis-like.

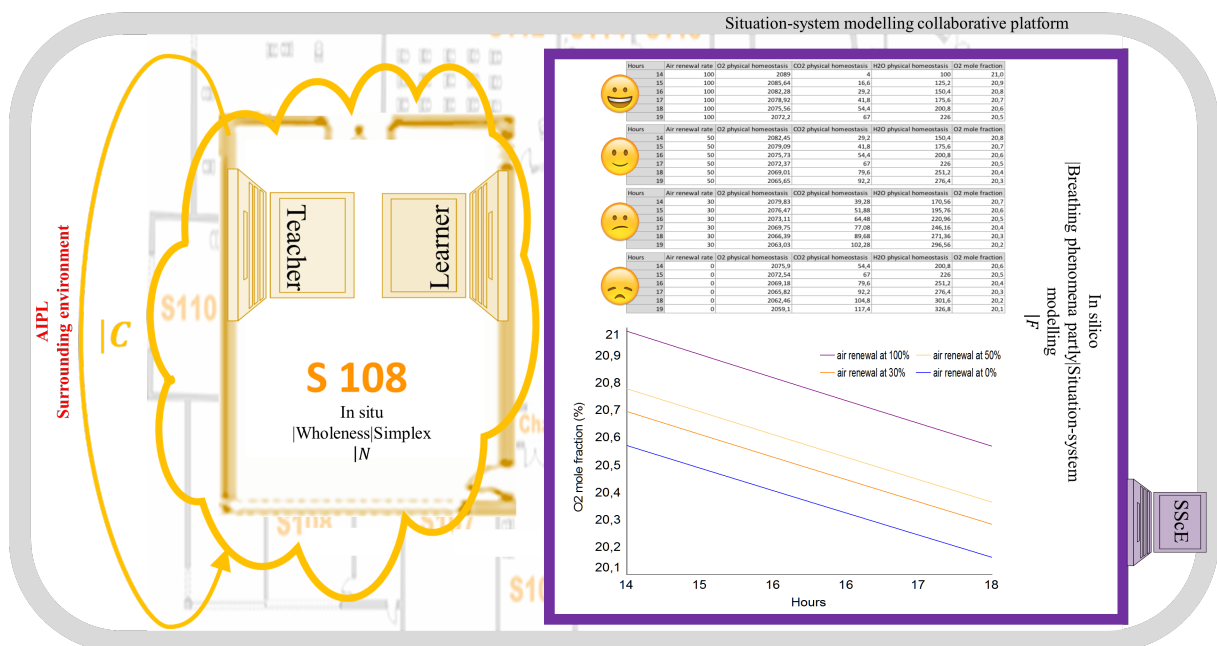


Figure 12: Breathing transitioned core situation-system model-checking

### 5.3. Core situation-system control refinement

Reflecting a certain hybrid-homeostasis process to be controlled, the previous flow and stock model then infers a homeostat-like to actuate indoor-air flowing from oxygen molar fraction measurement, so that to preserve the balancing loop between “*le milieu intérieur et le milieu extérieur*”. Previous chronograms (Figure 12, bottom) showing the variation in air composition enable us to define the set point of this oxygen-flowing driven homeostatic- control of indoor-air ventilating from the range of oxygen molar fraction to be monitored. The refined stock-flow model depicted in (figure 13, left)) the three basic blocs, i.e. physiological homeostasis (in green), physical homeostasis (in red) and logical homeostat (in blue), of the core situation-system thus formed.

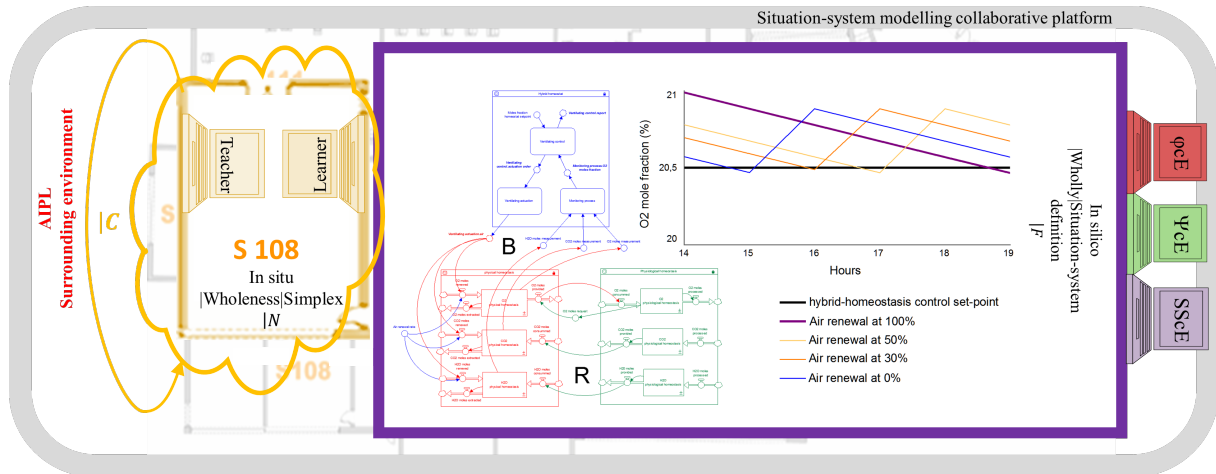


Figure 13: Breathing refined situation-system control model-checking

For model-checking purposes, we define both a limit value (20.5) for the molar fraction of oxygen not to be exceeded as well as scenarios of total, partial or zero air renewal just before the start of a learning situation as prescribed in (Figure 10). The simulation results (Figure 13, right) of the stock and flow diagram are intended to check the correctness of the control architecture model of the refined core situation-system, even its consistency by feedback exchanges with ( $\varphi\psi cE$ ).

### 5.4. Refined situation-system control transitioning to SysML

Sharing this model-based situation-system control specification within the project-system repository remains challenging the congruent knowledge and model transferring between the systems-thinking and dynamics domain and practical MBSE and control engineering domains. The challenge to face is that addressed by (Cloutier et al., 2014) to transitioning problem-capturing systemigrams to SysML as the de-facto solution-architecting “system language”. Use-case diagrams, Internal block Diagrams and Activity Diagrams enables a certain transitioning of respectively a requirement, structural and behavioral specification as depicted in figure 14 between ( $SScE$ ), ( $ScE$ ) and ( $CcE$ ).

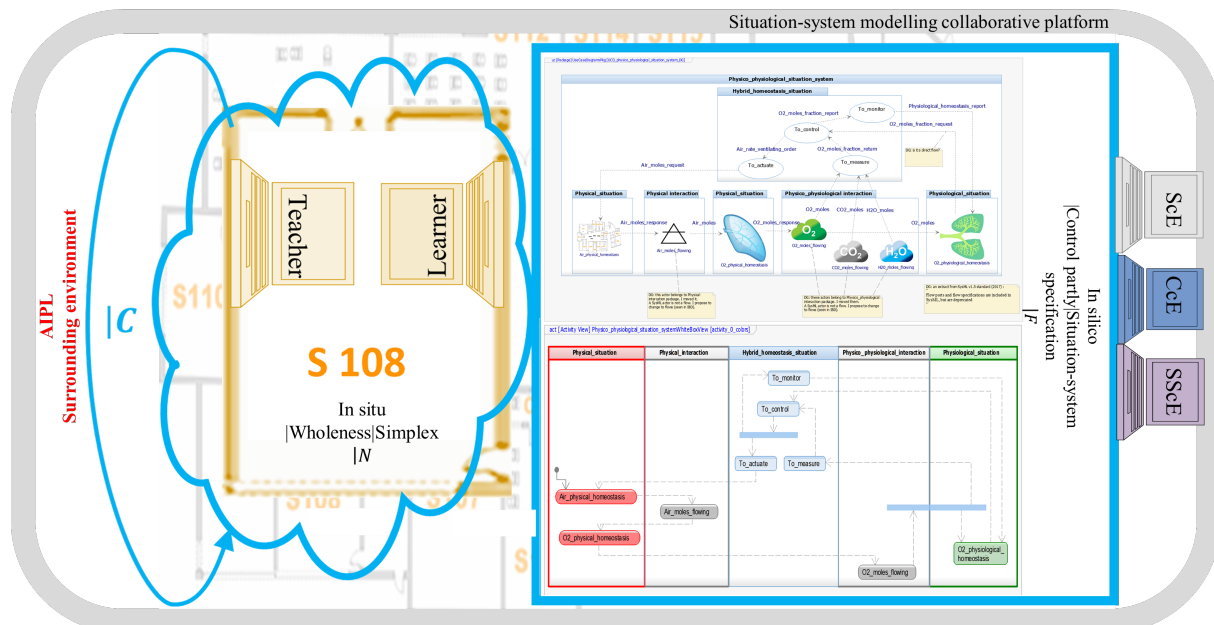


Figure 14: Breathing refined situation-system control transitioned to SysML

Because of direct translation not yet available in multidisciplinary systems engineering, our model-checking recursive process can improve this transitioning process for simulation issues, e.g. based on sequence and state chart diagrams with the used IBM® Rational® Rhapsody®, by the means of data chart import/export facilities. Even if complementary techniques enable some co-simulation, e.g.; with Matlab®Simulink® blocs such as the hybrid-homeostasis ones (figure 8), the related discretization fashion only enables to roughly translate the dynamics of a source stock-flow diagram (Figure 13) reflecting the non-linear framing of a situation-system control perceived from an affording simplex-wholeness. So, based on previous prototyping experiment which drastically breaks with what remains in-silo approach, we addressed in section 6 another perspective.

### 5.5. Synthesis

From its checking-understanding by the physiologist expert ( $(\varphi\Psi cE)$ ), of the vital hybrid-homeostasis to the occupant in an activity indoor-situation, the situation-system expert (SScE) applied system-dynamics inferences rules to specify an homeostat-like to control the right oxygen molar fraction flowing in order to right modulate indoor-air flowing. The related overall recursive transitioning orchestration process by (ScE) from/to ( $(\varphi\Psi cE)$ ), (SScE) and (CcE) is based on robust scenario-based test-cases results in order to ensure both model-based correctness and consistency checking. The main result is a core situation-system model augmented by the control of reinforcement loops which can counteract the balancing loops to be preserved as vital. This transitioning process around this core situation-system reference architecture can be recursively applied to refine a respondent-system architecture to situation problems as well as to engineering solutions. To meet the situation-system paradigm we propose, we put into perspective in section 6 an interdisciplinary orchestration paradigm change enabling to better to right transitioning the multidisciplinary knowledge inferred from the phenomenological wholly or partly framing of a simplex-wholeness committed from reality.

## 6. Situation-system specification open issues

Our research and teaching environment at AIPL gives us the opportunity to combine advanced technologies and knowledge to deepen our situation-system paradigm. Our scientific purpose is to open the multi-scale specification of multidisciplinary systems (F) to a certain simplex-wholeness of (N) in the particular case where a situation-system can be framed from an affording reality.

While our situation-system paradigm posits direct phenomenological sensing as problem-situation prerequisite for pedagogical issues, the situation in engineering has so far been limited to cognitive observation, i.e. not direct except at certain times when our role as teacher-researcher enables us direct feeling. Despite the many techniques to check knowledge and models interoperability issues in a project-system situation, only few deals with the remaining difficulty of transitioning between problem-oriented and solution-oriented systems-thinking. Another difficulty, and not the least, is to satisfy the interdisciplinary continuous-discrete hybridity of knowledge, skills and models, underlining once again the orchestrator's simplex capacity for heuristic management. In that direction,

we shown in (Bouffaron, 2016) the interest to distribute the project-system multidisciplinary assets around an in-silico co-modelling and co-simulation bus<sup>14</sup> enabling whole-system modelling (Garcia Jr, 2009) by co-execution of all the specialized models in each of their respective environments under a discrete-event orchestrator, which we intent should ideally be the situation-system control model of (Figure 13) and its related refinements. The system-in-the-loop proof-of-concept at TRL5 has been performed by request-report data-driven co-interoperation of both in-silico models and in-situ components according to operational scenarios by the mean of an open communication platform between the in-silico co-simulation operating platform and an in-situ platform emulating a critical situation-system in process-control (Figure 2.1, in (Dupont et al., 2019)). Nevertheless, even if a transition to our situation-problem of the in-silico collaborative architecture could take the advantage of operating separately in asynchronous (|knowledge|model|exchange) and synchronous mode (system|model|execution), the overall modeling process remains focusing from |F via |N to |F.

Thus, to be congruent with the situation-system-in-the loop process depicted by figure 3, i.e. from |N throughout |F to |N, we intent to take benefit of AIPL as melting-pot of complementary approaches to enable system-project engineering assets to share, on one hand a knowledge-based in-silico platform as before, and on the other hand an in-silico model-based platform, itself connected to an in-situ sensing platform enabling each person to dynamically frame a certain reality while being orchestrated collaboratively to define a system-situation. In alignment with the others tools and models already interoperating<sup>15</sup>, current works should also make executable the situation-system model, possibly in case of the chosen systems-thinking architecting tool<sup>16</sup> by the means of a simulator plug enabling to run the model by command line, and to retrieve the model inputs / outputs to make it evolve. This in-situ in-silico interoperability enables de facto measurements by direct phenomenological sensing via the in-silico bus of the homeostasis of the human group (green model, figure 14) carried out by the learner-teacher group (figures 14 and 15, in green and red). This phenomenological sensing of the designated reality can be augmented by coupling intelligent communication technology to an ambient-like environment. Advanced information and communication instrumentation related to indoor-air quality-control enhanced by ambient computer technology gives us the opportunity to "see directly" an expanded phenomenological source of the environment of our system-situation. A sensors platform<sup>17</sup> has been installed to enable the measurement of the concentration of some ambient air components, enabling carbon dioxide, humidity and temperature data to be communicated through a networking infrastructure<sup>18</sup> to the AIPL Ethernet network (Figure 15, left), which additionally provides measurable properties for requirements and models checking issues.

This in-situ in-silico interoperability enables to envision added specifications of ( $\Psi$ cE) prescribing to (|SScE) to refine the previous situation-system model, e.g. related to H<sub>2</sub>O-flowing (Figure 15, red curve). The water vapors in the calculation of  $f_{O_2}^m$  come from breathing but the evaporation of sweat (mainly composed of water) by the skin and its sweat glands is a mechanism of heat loss when the temperature of the air is too excessive. The human body is also a source of heat with an average temperature of 37° Celsius, in addition to other thermal sources of a technical nature such as computers or normal room heating. As the fourth basic need is related to human thermoregulation and thermal comfort, different indices could be used to estimate this comfort by measurement and calculation, such as PMV and PPD thermal comfort indices (Predicted Mean Vote, Predicted Percentage of Dissatisfied respectively) or Humidex (Parsons, 2014). But like to human breathing, we intend to introduce a hybrid homeostasis of thermal comfort with sound mathematical<sup>19</sup> and physiological basis. As written in section 4, human breathing can be addressed and then described or even simulated through different levels of organization according to followed trajectories. Thus, the first, more macroscopic one was to follow the air in and out of the human occupant. The second is more microscopic (molecular level) and makes it possible to establish, following the example of the matter balance proposed in section 4, an energy balance, the one required for each human occupant to ensure well brain activity (Shulman & Rothman, 2005) and more generally the second basic need relating to nutrition (Stipanuk & Caudill, 2013). The S-Propagator operator in the theoretical framework of MTIP (Chauvet, 2002) enables, if necessary and provided that the required data are available and/or attainable, to explore various levels of organization of the sources and sinks involved in the propagation of the functional interaction framed as essential for the targeted situation-system. That points out again how our situation-situation paradigm combined with MTIP might enable to rationally contain the intricate connectivity of all these situations. Note, for instance in (Figure 19, middle), the possible interlinking of the physico-physiological thermal comfort specification with the breathing situation-system specification.

---

<sup>14</sup> <https://site.chiastek.com>

<sup>15</sup> IBM® Rational® Rhapsody®, Matlab® Simulink®;

<sup>16</sup> <https://www.iseesystems.com>

<sup>17</sup> <http://www.libelium.com>

<sup>18</sup> <https://lora-alliance.org>

<sup>19</sup> [https://ptaff.ca/humidex/?lang=en\\_CA](https://ptaff.ca/humidex/?lang=en_CA)

This in-situ in-silico interoperability enables also, on another side (Figure 15, right), wholeness-requirements specifications of ( $\text{SScE}$ ) to ( $\text{ScE}$ ) prescribing to maintain this essential physico-physiological situation-system architecture all along the refinement process when applying a technical architectural pattern to specify an homeostat-like respondent-system for control issues. This architectural paradigm acquired from previous works (Figure 15, in (Dobre, 2010)) takes advantage of digital technology to increase the "hardware-software" interoperability of the instrumentation towards a certain "human-artefact" ambient interactivity in order to filter inwards actions and observations as well as outwards requests and reports. It should be noted that the related form of embedded "technical intelligence" should reflect the dynamics of the framed situation-system as control requirements specification to ( $\text{CcE}$ ), implying for instance co-specification with ( $\varphi\Psi\text{cE}$ ) to embed homeostatic behavior into an intelligent actuation and measurement pattern (Figure 15, right bottom, red and green circles).

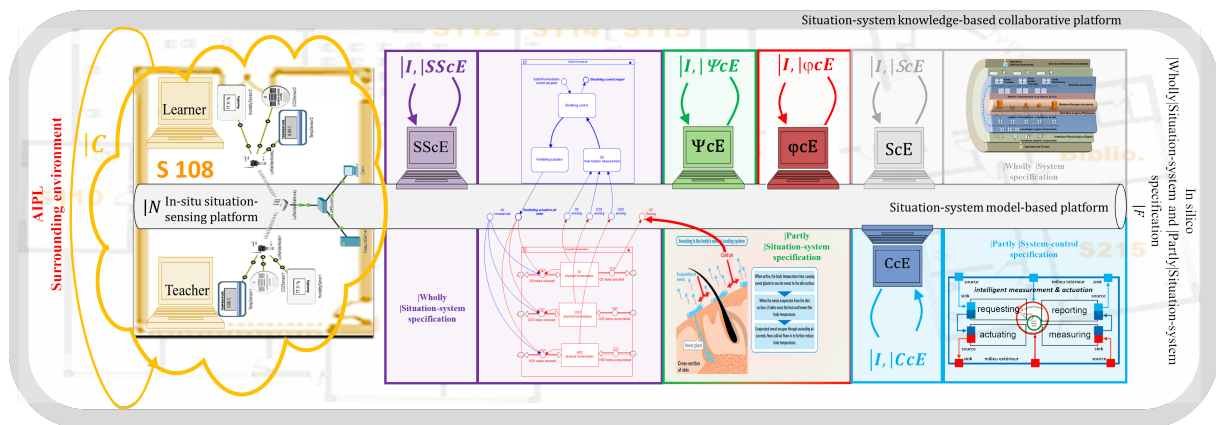


Figure 15: Architectural pattern of intention of a collaborative platform of in-situ situation-system specification

This in-situ in-silico interoperability raises also the framing extension of the situation-system to the AIPL area where the engineering situation is located, or even to the remote working situation. The interdisciplinary orchestration described in § 3.3 leads us to think about the knowledge-flowing between the architect-orchestrator ( $\text{ScE}$ ) and the various experts belonging to different worlds of know-how (Vodovotz & Billiar, 2013). Thus, we suggest a transposition of the MTIP triplet {source|functional\_interaction|sink} to contain on the semantic level the exchange togetherness (centripetal content) with regard to the targeted system-situation in order to avoid any dispersion (centrifugal content). As wrote by (Grothendieck, 1986), "things of the Universe never tire of speaking for themselves and revealing themselves, to the one is sensitive to hear", the  $\text{ScE}$  system-architect can, when perceiving the system-situation from his own experience, identify certain experts in order to better understand it by making him perceive what he does not see, because he does not know enough about it. Thus, an exchange qualified as elementary between the system architect and one of the experts in a two-time description/prescription process, in analogy to breathing (inhalation/exhalation), could be transposed to the elementary mechanism of a source interacting with a sink, where the ( $\text{ScE}$ ) "source" expert (description) triggers a "sink" expert, here in physiology ( $\Psi\text{cE}$ ), so that the latter returns a prescription as illustrated in (figure 16). As in integrative physiology, this first interaction (as well as the one in return) must not only be carried by the right physical quantity (in order to ensure a right triggering of sensory perception, here visual and/or auditory) but must also ensure on the semantic and disciplinary level relevance and intelligibility with regard to the targeted situation-system in the meaning "to do the right job right". The orchestration of multidisciplinary knowledge leads to the deployment by the system-architect of different disciplinary fields we qualified each by a color (green for physiology, for example), which could be likened by a certain analogy to the refraction of the prism when passing through white light revealing its various colors by qualifying each field of knowledge. The orchestration of multidisciplinary knowledge leads to the co-optation by the system-architect of different disciplinary fields that we qualified by a color (green for physiology, for example), which could be likened by a certain analogy to the refraction of the prism when passing through white light revealing its various colors. And this same orchestration leads these experts to focus on the same reality through the situation-system and to send back their own partial representation falling within their field of knowledge, like a refracting optical diopter. Indeed, the resulting focus by all the experts may be an image of the integration process that gives rise to an interdisciplinary solution, such as a mechanism for the recomposition of white light from its constituents. This on-going integrative-physiology based interpretation of our heuristic process strengthens the simplicity capability to be assigned to a human orchestrator only able to be sensitive to an affording reality simplex-wholeness. This in-progress integrative-physiology based interpretation of our heuristic

process intends to strengthen the simplicity capability to be assigned to a human orchestrator we argue only able to be sensitive to an affording reality simplex-wholeness.

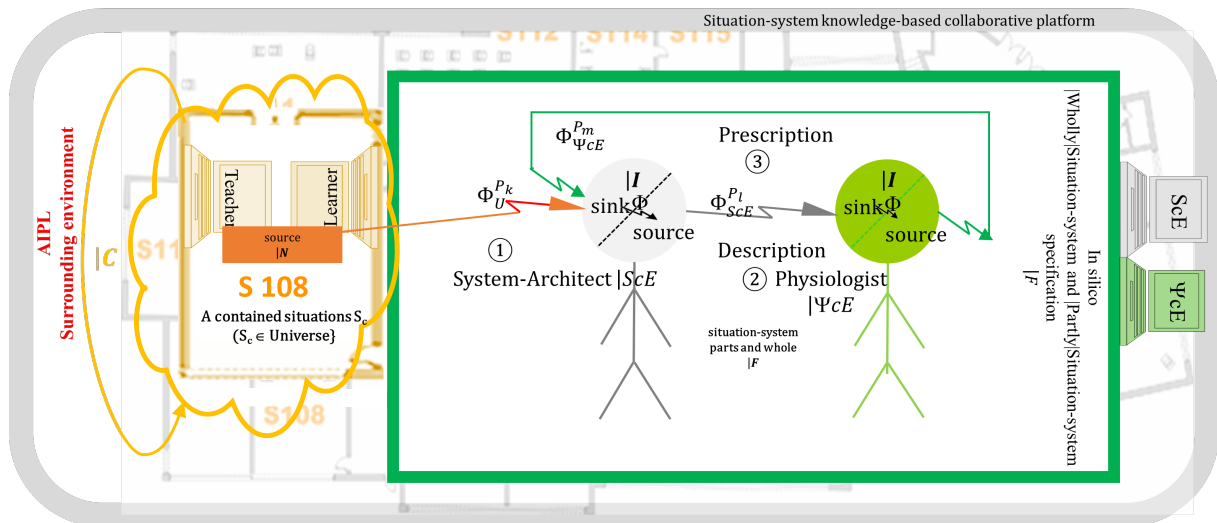


Figure 16: Elementary physiological-cognitive process of description/prescription between |ScE and |ΨcE triggered by a phenomenological sensing coming from a situation perceived by its simplicity

Achieving this scientific perspective in the case of a frameable system-situation could bridge the technical and human-centered disciplines in the model-based system-engineering loop (Boy & Narkevicius, 2014), despite a certain lack of openness of system-centered tools for the standardized exchange of co-simulation models. The impact throughout the system-project would be the co-optation of multidisciplinary skills to make visible the phenomena of interest, in addition to the operational (CONOPS) and design requirements of the stakeholders.

## 7. Conclusion

Taking advantage of feedback from teacher-researchers and system-engineering practitioners on a shareable problem-situation, the learning situation as an archetypal case-study of indoor-air quality control, we launched a collaborative scientific project to make the framing of a system-situation (Lawson, 2015) a topic to be explored. We noted that the resulting understanding from the assessment of a situation-problem as system-wholeness does not necessarily highlight occupant breathing as primary need, while it is manifestly the simplex-wholeness to be framed. This observation invited us to examine the process of capture, analysis and synthesis as a system of a containable situation of interest, e.g. our particular case study.

Thus, we first revisited Rosen's modelling relationship by combining it with the precepts of perception-action and simplicity of (Berthoz & Petit, 2006)(Berthoz, 2009) in order to experiment then an interdisciplinary orchestration of the relevant multidisciplinary expertise to designate and to define the essential simplex-wholeness of this contained natural system on which to base the system-wholeness of the targeted situation and then the related control response. Proof of concept of this situation-system paradigm is provided in the framework of integrative physiology and then system dynamics to specify an occupant hybrid-oxygenation model as basic encapsulation for all situations to be integrated as a system prior to any technical solution. An important result is the oxygen molar fraction which may be a right candidate to be controlled in order to ensure/contain breathing togetherness, by a certain analogy with a gluon (Gell-Mann, 1995). Its physico-physiological nature, enabled by measurable physical quantities, ensures in our paradigm the togetherness of the situation-system. In this direction, we outline the perspective of encapsulating a hybrid homeostasis of lower priority thermal comfort around the more vital hybrid homeostasis of breathing.

Although quite mature throughout a robust scenario-based model-checking process as well as in others research and training scientific works, these experiments do not yet take sufficient advantage of the possibility of direct phenomenological sensing in situ. We examine in perspective the interest of coupling an in-silico collaborative specification platform based on executable models with an in-situ ambient platform to "put into simplex-situation" all the interoperating elements of the situation-system. To some extent, we overcome the artefactual boundary between natural and formal domains at this scale of complexity since each human asset is himself a simplex-wholeness from which we have distinguished for our collaborative specification process the requested knowledge from the acting inference to define by detour a partial response to be checked before interdisciplinary integration. We discuss in perspective the orchestration cognitive trajectories that could result from this augmented situation-system paradigm. By doing so, the modeling of a respondent system to this type of containable situation-system,

including design alternatives from this essential architecture-wholeness, would result from the concurrent execution of in-silico models in their own modeling environments with in-situ operating components.

These works and their perspectives point in the direction of a "design for unexpected and resilience" (Valckenaers & Van Brussel, 2015)(Levalle & Nof, 2017) if one accepts that the personalization of this type of application must not be subordinated too early by an a priori prescription of reality, as required in case of large-scale systems applications. In other words, with regard to the well-admitted control paradigm as discussed in (Pétin et al., 2006), these works contribute to see more to control more as system-wholeness.

## 8. References

- Ahtisham, Y., & Jacoline, S. (2015). Integrating Nursing Theory and Process into Practice; Virginia's Henderson Need Theory. *International Journal of Caring Sciences*, 8(2).
- Aizier, B., Lizy-Destrez, S., Seidner, C., Chapurlat, V., Prun, D., & Wippler, J.-L. (2012). 1.6. 1 xFFBD: towards a formal yet functional modeling language for system designers. *INCOSE International Symposium*, 170-183.
- Allegro-Daniel, B., Faisandier, A., & Morel, G. (2016). *Systems thinking and engineering in action*. Bureau du Réseau Figure.
- Allegro-Daniel, B., & Smith, G. R. (2017). Mind mapping systems thinker's attitudes facing a sepsis problem. *Proceedings of the 59th Annual Meeting of the ISSS-2015 Berlin, Germany*, 1.
- Berthoz, A. (2009). *Complexity*. Odile Jacob.
- Berthoz, A. (2014). *Complexity: Biologically Inspired Principles for Complex Systems* [Plenary talk]. 5th International Conference on Complex Systems Design and Management, Paris, France.
- Berthoz, A. (2012). Neural basis for the decision. A cognitive neuroscience approach. *Annales Médico-psychologiques, revue psychiatrique*, 170, 115-119.
- Berthoz, A., & Petit, J.-L. (2006). *Phenomenology and physiology of the action*. Odile Jacob.
- BKCASE Editorial Board. (2019). *The Guide to the Systems Engineering Body of Knowledge (SEBoK): Vol. 2.0. R.D. Adcock (EIC)* (The Trustees of the Stevens Institute of Technology). R.J. Cloutier. <http://www.sebokwiki.org>.
- Boardman, J., & Sauser, B. (2008). *Systems thinking: Coping with 21st century problems*. CRC Press.
- Boardman, J., & Sauser, B. (2013). *Systemic Thinking: Building Maps for Worlds of Systems* (Wiley). John Wiley & Sons, Inc.
- Boardman, J., Sauser, B., John, L., & Edson, R. (2009). The conceptagon: A framework for systems thinking and systems practice. *IEEE International Conference on Systems, Man and Cybernetics*, 3299-3304.
- Bombled, J.-P. (2014). *The very complex world of emergences*. Deuxième Colloque International du GREC-O sur l'Expérience de la Complexité, Le Mans, France.
- Bouffaron, F. (2016). *Executable Model Based System co-Specification: Application to critical process* [Phd Thesis]. Université de Lorraine.
- Boy, G. A. (2019). Human Systems Integration: A Mix of Human-Centered Design, Systems Engineering, Ergonomics, HCI and Artificial Intelligence. *INCOSE Human Systems Integration conference*. INCOSE Human Systems Integration, Biarritz, France.
- Boy, G. A., & Narkevicius, J. M. (2014). Unifying human centered design and systems engineering for human systems integration. In *Complex Systems Design & Management* (p. 151-162). Springer.
- Brier, J., Rapanotti, L., & Hall, J. G. (2004). Problem Frames for socio-technical systems: Predictability and change. *Proceedings of the 1st International Workshop on Applications and Advances of Problem Frames*, 21-25.
- Cabrera, D., & Cabrera, L. (2015). *Systems Thinking Made Simple: New Hope for Solving Wicked Problems* (Odyssean Press).
- Cannon, W. B. (1929). Organization for physiological homeostasis. *Physiological reviews*, 9(3), 399-431.
- Chauvet, G. (1993a). An n-level field theory of biological neural networks. *Journal of mathematical biology*, 31(8), 771-795.
- Chauvet, G. (1993b). Hierarchical functional organization of formal biological systems: A dynamical approach. I. The increase of complexity by self-association increases the domain of stability of a biological system. *Philosophical Transactions of the Royal Society of London*, 339(1290), 425-444.
- Chauvet, G. (1993c). Hierarchical functional organization of formal biological systems: A dynamical approach. II. The concept of non-symmetry leads to a criterion of evolution deduced from an optimum principle of the (O-FBS) sub-system. *Philosophical Transactions of the Royal Society of London*, 339(1290), 445-461.
- Chauvet, G. (1993d). Hierarchical functional organization of formal biological systems: A dynamical approach. III. The concept of non-locality leads to a field theory describing the dynamics at each level of organization of the (D-FBS) sub-system. *Philosophical Transactions of the Royal Society of London*, 339(1290), 463-481.
- Chauvet, G. (1999). S-Propagators: A formalism for the hierarchical organization of physiological systems. Application to the nervous and the respiratory systems. *International Journal Of General System*, 28(1), 53-96.
- Chauvet, G. (2002). On the mathematical integration of the nervous tissue based on the S-propagator formalism I: Theory. *Journal of integrative neuroscience*, 1(01), 31-68.



- Chauvet, G. (2005). *The mathematical nature of the living world : The power of integration*. World Scientific.
- Chauvet, G. (2006). A new paradigm for theory in integrative biology—The principle of auto-associative stabilization : Biochemical networks and the selection of neuronal groups. *Journal of integrative neuroscience*, 5(03), 381-415.
- Cloutier, R., Sauser, B., Bone, M., & Taylor, A. (2014). Transitioning systems thinking to model-based systems engineering : Systemigrams to SysML models. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 45(4), 662-674.
- Dillenbourg, P. (2011). *Trends in orchestration. Second research & technology scouting report*.
- Dobre, D. (2010). *Contribution to industrial-process interactive-aided control modeling* [Phd Thesis]. Université Henri Poincaré-Nancy 1.
- Ducrocq, A. (1960). *General logic of systems and effects*. Dunod.
- Dupont, J.-M., Mayer, F., Bouffaron, F., Lieber, R., & Morel, G. (2019). System-centered Specification of Physico-physiological Interactions of Sensory Perception. In *Automation Challenges of Socio-technical Systems* (ISTE-Wiley, p. 29-79). Frédéric Vanderhaegen, Choubeila Maaoui, Mohamed Sallak, Denis Berdjag.
- Edson, R. (2008). *Systems thinking. Applied. A primer*. Analytic Services.
- Fanmuy, G., Fraga, A., & Llorens, J. (2012). Requirements verification in industry. *Complex systems design and management conference*.
- Forrester, J. W. (1968). Industrial dynamics—After the first decade. *Management Science*, 14(7), 398-415.
- Fusaoka, A., Seki, H., & Takahashi, K. (1983). A description and reasoning of plant controllers in temporal logic. *Proceedings of the Eighth international joint conference on Artificial intelligence-Volume 1*, 405-408.
- Garcia Jr, J. S. (2009). Executable and Integrative Whole-System Modeling via the Application of OpEMCSS and Holons for Model-based Systems Engineering. *INSIGHT*, 12(4), 21-23.
- Gell-Mann, M. (1995). *The Quark and the Jaguar : Adventures in the Simple and the Complex*. Macmillan.
- Giré, A. (1988). *Opened theory of systems : Epistemological drafts* (L'interdisciplinaire).
- Gouyon, D., Bouffaron, F., & Morel, G. (2014). Specifying some key SE training artifacts. *Complex Systems Design & Management*, 207-218.
- Grothendieck, A. (1986). *Récoltes et Semailles : Réflexions et témoignage sur un passé de mathématicien*. Université Paris 6, Grothendieck Circle.
- Gunter, C. A., Gunter, E. L., Jackson, M., & Zave, P. (2000). A reference model for requirements and specifications. *IEEE Software*, 17(3), 37-43.
- Hall, J. G., Jackson, M., Laney, R. C., Nuseibeh, B., & Rapanotti, L. (2002). Relating software requirements and architectures using problem frames. *IEEE joint international conference on requirements engineering*, 137-144.
- Herman, I. P. (2016). *Physics of the human body*. Springer.
- INRS. (2012). *Reference body for occupational risk prevention in France* (N° ED6126). <http://www.inrs.fr/dms/inrs/CataloguePapier/ED/TI-ED-6126/ed6126.pdf>
- Jackson, M. (1995). *Software Requirements and Specifications : A lexicon of practice, principles and prejudices*. Addison-Wesley.
- Jin, Z. (2006). Revisiting the meaning of requirements. *Journal of computer science and technology*, 21(1), 32-40.
- Koestler, A. (1978). *Janus : A Summing Up*. Calmann-Lévy.
- Krob, D. (2014). Architectural elements of complex systems. In *Complexité-Simplexité* (OpenEdition Books). Berthoz. A et Petit J.L.
- Kuras, M. L. (2006). *A Multi Scale Definition of a System* (Technical report MTR 06B0000060). MITRE.
- Kurtz, C. F., & Snowden, D. J. (2003). The new dynamics of strategy : Sense-making in a complex and complicated world. *IBM Systems Journal*, 42(3), 462-483.
- Lawson, H. B. (2015). Attaining a systems perspective. In *Software engineering in the systems context* (I. Jacobson and H. Lawson). College Publications.
- Le Moigne, J.-L. (1990). *Complex systems modelling*. Dunod.
- Levalle, R. R., & Nof, S. Y. (2017). Resilience in supply networks : Definition, dimensions, and levels. *Annual Reviews in Control*.
- Li, D., Menassa, C. C., & Kamat, V. R. (2017). Personalized human comfort in indoor building environments under diverse conditioning modes. *Building and Environment*, 126, 304-317.
- Louie, A. H. (2009). *More than life itself : A synthetic continuation in relational biology* (Vol. 1). Ontos verlag.
- Louie, A. H. (2011). Essays on more than life itself. *Axiomathes*, 21(3), 473-489.
- Mayer, F. (1995). *Contribution to manufacturing engineering : Application to pedagogical engineering at manufacturing training center AIPL*. [Phd Thesis]. Université Henri Poincaré - Nancy I.
- Mayer, F. (2018). Exploring the notion of situation for responsive manufacturing systems specification issues. *16th IFAC INCOM*.
- McFarlane, D. (2003). Product identity and its impact on discrete event observability. *European Control Conference (ECC), 2003*, 121-132.
- Mella, P. (2009). *The Holonic Revolution, Holons, Holarchies and Holonic Networks, The Ghost in the Production*

*Machine*. Pavia University Press.

Michael, J., Cliff, W., McFarland, J., Modell, H., & Wright, A. (2017). *The core concepts of physiology: A new paradigm for teaching physiology*. Springer.

Millot, P., Debernard, S., & Vanderhaegen, F. (2011). Authority and cooperation between humans and machines. In *The Handbook of Human-Machine Interaction: A Human-Centered Design Approach* (CRC Press). Guy A. Boy.

Morel, G., Bouffaron, F., Nartz, O., Mayer, F., Marangé, P., Levrat, E., & Panetto, H. (2014). Towards an iterative learning of systems engineering based on models. *10ème Conférence Francophone de Modélisation, Optimisation et Simulation, MOSIM'14*.

Morel, G., Panetto, H., & Mayer, F. (2015). Workshop No. 3 : Manufacturing Systems Engineering : Fundamental Issues and Case Studies. *15th IFAC Symposium on Information Control in Manufacturing*. 15th IFAC Symposium on Information Control in Manufacturing, Ottawa, Canada.

Morel, G., Pereira, C. E., & Nof, S. Y. (2019). Historical survey and emerging challenges of manufacturing automation modeling and control : A systems architecting perspective. *Annual Reviews in Control*, 47, 21-34.

Nadin, M. (2012). Prolegomena : What Speaks in Favor of an Inquiry into Anticipatory Processes ? Mihai Nadin. In *Robert Rosen—Anticipatory Systems Philosophical, Mathematical, and Methodological Foundations* (second edition, Vol. 1). Springer.

Nazaroff, W. W. (2013). Four principles for achieving good indoor air quality. *International journal of indoor environment and health*, 23(5), 353-356.

OFSP. (2019). [https://www.aerer-les-ecoles.ch/upload/downloads/Abstract\\_FR.pdf](https://www.aerer-les-ecoles.ch/upload/downloads/Abstract_FR.pdf). [https://www.aerer-les-ecoles.ch/upload/downloads/Abstract\\_FR.pdf](https://www.aerer-les-ecoles.ch/upload/downloads/Abstract_FR.pdf)

Olesen, B. W. (2012). Revision of EN 15251 : Indoor environmental criteria. *REHVA Journal*, 49(4), 6-12.

Parsons, K. (2014). *Human thermal environments : The effects of hot, moderate, and cold environments on human health, comfort, and performance*. CRC press.

Penalva, J. M. (1997). *Modelling by systems in complex situation* [Phd Thesis]. Paris 11.

Pétin, J.-F., Morel, G., & Panetto, H. (2006). Formal specification method for systems automation. *European Journal of Control*, 12(2), 115-130.

Ponto, C. F., & Linder, N. P. (2011). *Sustainable Tomorrow : A Teachers' Guidebook for Applying Systems Thinking to Environmental Education Curricula*. Association of Fish & Wildlife Agencies.

Pouvreau, D. (2014). On the history of Ludwig von Bertalanffy's "general systemology", and on its relationship to cybernetics-Part II: Contexts and developments of the systemological hermeneutics instigated by von Bertalanffy. *International Journal of General Systems*, 43(2), 172-245.

RAE. (2014). *Guide to atmospheric testing in confined spaces*. [https://www.raesystems.com/sites/default/files/content/resources/Application-Note-206\\_Guide-To-Atmospheric-Testing-In-Confined-Spaces\\_04-06.pdf](https://www.raesystems.com/sites/default/files/content/resources/Application-Note-206_Guide-To-Atmospheric-Testing-In-Confined-Spaces_04-06.pdf)

Rondeau, E., Lepage, F., Georges, J.-P., & Morel, G. (2015). Measurements and Sustainability. In *Green Information Technology. A sustainable approach*. (Mohammad Dastbaz, Colin Pattinson and Babak Akhgar, p. 29-59). Elsevier.

Rosen, R. (1985). *Anticipatory systems : Philosophical, mathematical, and methodological foundations*. Pergamon Press.

Rosen, R. (1991). *Life itself: A comprehensive inquiry into the nature, origin, and fabrication of life*. Columbia University Press.

Sausser, B., Boardman, J., & Verma, D. (2010). Systemics : Toward a biology of system of systems. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, 40(4), 803-814.

Shulman, R. G., & Rothman, D. L. (2005). *Brain energetics and neuronal activity : Applications to fMRI and medicine*. John Wiley & Sons.

Sillitto, H., Dori, D., Griego, R. M., Jackson, S., Krob, D., Godfrey, P., Arnold, E., Martin, J., & McKinney, D. (2017). Defining "system" : A comprehensive approach. *INCOSE International Symposium*, 27, 170-186.

Stipanuk, M. H., & Caudill, M. A. (2013). *Biochemical, Physiological, and Molecular Aspects of Human Nutrition-E-Book*. Elsevier health sciences.

Valckenaers, P., & Van Brussel, H. (2015). *Design for the unexpected : From holonic manufacturing systems towards a humane mechatronics society*. Butterworth-Heinemann.

Vodovotz, Y., & Billiar, T. R. (2013). In Silico Modeling : Methods and Applications to Trauma and Sepsis. *Critical care medicine*, 41(8), 2008.

von Bertalanffy, L. (1968). *General Systems Theory*. G. Braziller.

Werber, B. (2000). *The encyclopedia of relative and absolute know*. Albin Michel.

Wiener, N. (1948). Cybernetics. *Scientific American*, 179(5), 14-19.

Zask, J. (2008). Situation or context ? *Revue internationale de philosophie*, 3, 313-328.

Zaytoon, J., & Riera, B. (2017). Synthesis and implementation of logic controllers—A review. *Annual reviews in control*, 43, 152-168.

