SPRINGER BRIEFS IN APPLIED SCIENCES AND TECHNOLOGY · POLIMI SPRINGER BRIEFS

Ingrid Paoletti
Massimiliano Nastri *Editors*

Material Balance

A Design Equation

POLITECNICO
MILANO 1863

Springer

SpringerBriefs in Applied Sciences and Technology

PoliMI SpringerBriefs

More information about this subseries at http://www.springer.com/series/11159
http://www.polimi.it

Ingrid Paoletti · Massimiliano Nastri
Editors

Material Balance

A Design Equation

POLITECNICO
MILANO 1863

Springer

Editors
Ingrid Paoletti
Department of Architecture,
Built Environment and Construction
Engineering (ABC)
Politecnico di Milano
Milan, Italy

Massimiliano Nastri
Department of Architecture,
Built Environment and Construction
Engineering (ABC)
Politecnico di Milano
Milan, Italy

ISSN 2191-530X ISSN 2191-5318 (electronic)
SpringerBriefs in Applied Sciences and Technology
ISSN 2282-2577 ISSN 2282-2585 (electronic)
PoliMI SpringerBriefs
ISBN 978-3-030-54080-7 ISBN 978-3-030-54081-4 (eBook)
https://doi.org/10.1007/978-3-030-54081-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Chapter 1
The Material Balance Manifesto. Scientific Approach and Methodologies

Ingrid Paoletti and Massimiliano Nastri

Abstract This introductory chapter examines the contents and processes of the Material Balance principle, according to the relations of equilibrium that account for streams by which energy is produced, exchanged, transformed and consumed (i.e. with the application of the "law of conservation of mass"): the analysis focuses on the relations established by the "closed systems", the "unsteady state system" and the "mass balance system" until the mechanical and physiological observation. The examination investigates the elaboration as a practice of sensitive design based on the organic composition of the artificial apparatus (as systems, components and materials described as "programmable pro-active structures") and how the production, consumption and distribution activities have a direct relation with nature (mainly considering the effects of pollution controls). The study of the Material Balance Model provides a framework for analyzing alternative methods of resource and residuals management, with the aim of providing measures of performance (as guides for the technological research and for the environmental design) and of developing the new approaches to calibrate productivity and eco-efficiency. On this basis, the scientific research is intended to "model" and to visualize the conditions posed by the environmental reality of reference, through devices able to assume the modalities of experimentation and simulation: the work on Material Balance implies the objectives to incorporate environmental issues both in production efficiency models and in pro-active eco-efficiency research methods, involving the incorporation into technical design and building processes. This approach considers the development of technical elaboration of the environmental reality and the anticipation of the environmental outcomes (limiting the conditions of consumption and accumulation caused to the productive and constructive operations). Moreover, it focuses on the functional, productive and material optimization with the support of new forms of calibration and material densities, morpho-typological sizes and structural performances (with

I. Paoletti · M. Nastri (✉)
Material Balance Research Group, Architecture, Built Environment and Construction Engineering—ABC Department, Politecnico di Milano, Milan, Italy
e-mail: massimiliano.nastri@polimi.it

I. Paoletti
e-mail: ingrid.paoletti@polimi.it

I. Paoletti and M. Nastri (eds.), *Material Balance*,
PoliMI SpringerBriefs,
https://doi.org/10.1007/978-3-030-54081-4_1

less material and wasted energy), with the use of “digital/virtual design” procedures, “productive/constructive customization” technics and “executive design” methods.

Keywords Material balance principle, processes and physical relations · Declination of material balance to mechanical and physiological characteristics · Technological research, environmental design and calibration of eco-efficiency in transformation processes · Procedures of knowledge, unveiling and manipulation of reality · Technical elaboration and anticipation of environmental outcomes · Functional and material optimization and “productive/constructive customization” technics

1.1 A Design Equation Coming from Engineering

The *Material Balance*, as for the *Mass Balance* principle, is a consideration of the *input*, *output* and distribution (of materials, energy and/or substances) between streams in a process or stage. The *Material Balance*, on its semantic model, deals with material and/or energy quantities as they pass through processing operations. According to this principle, the *balances* are statements on the conservation of mass (and they are fundamental to the control of processing, particularly in the control of yields of the products) showing:

- the relations of equilibrium that account for streams by which energy is produced, exchanged, transformed and consumed;
- the quantitative account of the redistribution of material and/or energy that occurs when anything happens;
- the balancing “volume reconciliation” to ensure the exact account of volumes of *in-* and *out-of-scope* source which maintains along the supply chain, provided that the volume or the ratio of sustainable material integrated is reflected in the product. In particular, considering the *output*, no (physical, chemical) difference exists between *in-scope* and *out-of-scope*;
- the challenging complexity of after-use material and/or energy streams.

The *Material Balance*, as a principle, deals with the application of the law of conservation of mass which can be compared to an “accounting” for material, according to the basic theories of Ayres and Kneese (1969). Their study (on comprehensive analysis and management of residuals and pollution) determines a fundamental reference on the consideration of the “residuals-generating materials flows” (to the mass balance principle) and of the concept of pervasive (pollution) externality. On this basis, the principle of the *Material Balance* considers that *if waste assimilative capacity of the environment is scarce, the decentralized voluntary exchange process cannot be free of uncompensated technological external diseconomies unless all inputs are fully converted into outputs, with no unwanted material residuals along the way and all final outputs are utterly destroyed in the process of consumption.*

The *Material Balance* contemplates the ratio between the quantities of materials that enter and leave any system or process which is based on the principle of the "law of conservation of mass" (this law states that matter is neither created nor destroyed in the process and the total mass remains unchanged): so the process can be defined as one or a series of operations in which materials are carried out and a desired product is result in the end, where the system can be defined as any arbitrary portion of a process to consider for analysis and the system boundary must be fixed in each problem. Specifically, the *Material Balance* is articulated through some main typologies as:

(a) the "closed systems", where process considers that materials are placed into the system at the beginning of the process, held for a period of time (known as "residence time" or "retention period") during which the required physical and/or chemical changes are occurred. Then, products are removed all at once after this time and no masses crossed the system boundary during this time, proposing the equation:

$$\text{Input (Initial quantity)} = \text{Output (Final quantity)}$$

(b) the "unsteady state system", where process considers that not all of the operating conditions remain constant with time, and/or the flows in and out of the system can vary with time, hence the accumulation of materials within is explained by the equation:

$$\text{Input} - \text{Output} = \text{Accumulation}$$

(c) the "mass balance system", where process considers, according to the "law of conservation", that matter can be transformed into other matter or energy but can never vanish: all *inputs* used in the production processes are resulting in an equivalent residual or waste. This process is widely used in engineering, chemistry, environmental impact assessment and complementary in energy, population and other major complex systems, often linked to entropy: here the *input* passed in the system (*through design*, with the materials used in building components, elements and whole constructions, as a *generation* activity) and the resulting *outputs* includes consumption (of raw materials and energy) and accumulation (of waste) as explained by the equation:

$$\text{Input} + \text{Generation} = \text{Output} + \text{Consumption} + \text{Accumulation}$$

Moreover, the *Energy Balances*, inside the *Material Balance* conception, are used in the examination of the various stages of a process, over the whole process and even extending over the total production system from the raw material to the finished product. On this basis, material and/or energy quantities can be described by material and/or energy balances, which are statements on their conservation (in respect of the "law of conservation of mass") as expressed through:

$$\text{Mass In} = \text{Mass Out} + \text{Mass Stored}$$

Just as mass is conserved, so energy is conserved in processing operations. The energy coming into a unit operation can be balanced with the energy coming out and the energy stored:

$$\text{Energy In} = \text{Energy Out} + \text{Energy Stored}$$

which can be articulated through the relation:

$$\text{Raw Materials} = \text{Products} + \text{Wastes} + \text{Stored Materials}$$

also deepened through the relation (where Losses are the unidentified materials):

$$\text{Raw Materials} = \text{Products} + \text{Waste Products} + \text{Stored Products} + \text{Losses}$$

The materials have to be considered whether they are to be treated as a whole, a gross mass balance, or whether various constituents should be treated separately and if so what constituents. The energy takes many forms (such as heat, kinetic energy, chemical or potential energy, but because of interconversions it is not always easy to isolate separate constituents of energy balances) which can be calculated on the basis of external energy used (according to the product or to raw material processed). The energy consumed in production includes *direct energy* (used on the farms, in transport, in factories and in storage, selling) and *indirect energy* (which is used to actually build the machines, to make the packaging, to produce the electricity and the oil and so on).

The material and energy balances make it possible to identify and quantify previously unknown losses and emissions, expressing how:

- the balances are useful for monitoring the improvements made in an ongoing project, while evaluating cost and benefits;
- the raw materials and the energy in any manufacturing activity are not only major cost components but also major sources of environmental pollution, and inefficient use of raw materials and energy in production processes are reflected as wastes.

The declination of the *Material Balance* may be articulated, then, from the mechanical point of view, which implies the balanced and optimized formulation between:

- the acquisition and application of the requirements and related parameters, according to the functions and performance expected from the systems, components and materials;
- the composition, physical, chemical and material calibration, with respect to the expected stresses and performances (as a result of *mass customization* modes), reducing the use of materials for product development.

At the same time, the declination of the *Material Balance* from a physiological point of view is expressed with respect to:

- the application of stimuli, stresses and loads (physical and mechanical, environmental and sensorial), to which corresponds the “automatic” reaction (in “active” or “passive” form) by systems, components and materials according to the specific morphological, functional and performance modification capabilities;
- the combination of “sensory” equipment, devices and actuation criteria by systems, components and materials, having “intelligent” and “technical” properties (whether in part or integrated form) which enable them to react to induced impulses.

The elaboration is clarified as a practice of *sensitive design* focused on the organic composition of the artificial apparatus, its articulations and surface extensions (in the form of *bioreactive artificial bodies*) which involve as sensory receptors with respect to the information received in order to proceed with movements and geometric and physical, dimensional and connective variations, as expressed by the *balance information* through the relation:

$$\text{Input Information} = \text{Learned Information} + \text{(Re)Actions}$$

The complexity of the physical balance system results from the difference between the energy put into the “dense network sensing” of “bodies” related to systems, components and materials and the energy used, as through the relation:

$$\text{Total Body Energy} = \text{Energy Stored} + \text{Energy Intake} - \text{Energy Output}$$

The declination of *Material Balance* with respect to physiological characteristics leads to the elaboration of systems, components and materials described as “programmable pro-active structures” reacting based on input values also generating, as products, bio-reactions, bio-energy and/or bio-mass (which can also be used to produce energy, i.e. electricity). These products are developed according to:

- the responsive and reflexive approaches which provide a series of mediated environmental reactions;
- the responsive interaction with sophisticated reflexive capabilities to interpret and to react to environmental loads.

This *Material Balance* concept observes how the production, consumption and distribution activities have a direct relation with nature, which provides raw materials to the economy for its production and consumption activities:

- the residuals from both the production and consumption processes usually remain and they usually render "disservices" (such as waste and pollution). Although, some of these residuals from production and consumption activities are ultimately returned to nature and are recycled (and not all emission of residuals causes pollution damage because of assimilative capacity of the environment);
- the energy taken out of the environment reappears somewhere else in the economic system, even though it might have a different form and appear as waste products (Lauwers et al. 2009).

The early approaches dealt with pollution respect of productivity and efficiency values and measures focused upon the effects of pollution controls upon (macro and micro) economic and social scales (i.e. consequences of integrating the "conservation laws" of materials and energy into the microeconomic models of production, consumption, and general equilibrium; Krysiak and Krysiak 2003). The *Material Balance* model provides a useful framework for analyzing alternative methods of resource and residuals management, i.e. in industrial and agricultural performance measurement systems, where the pollutant factors are on the rise and therefore many conventional methods of performance measurement have proven incompatible with the "material flow conditions" (Ausubel and Sladovich 1989).

Coming now at the design perspectives, the most important one for our purpose, the study gives an interpretation of the *Material Balance* equation in order to support a statement and a model to develop innovation, as research group, that could foster an agenda and consequent actions for the coming years.

Specifically, on this basis, the orientation is aimed at:

- developing a new approach to calibrate creativity and eco-efficiency (Arabi et al. 2017);
- providing measures of performance that can serve as guides for the technological research and, particularly, for the environmental design;
- adjusting traditional methods of production in order to integrate environmental concerns and social values into the technical and economic efficiency measures.

The activity, research and application, according to the principles of the *Material Balance* is a cognitive practice aiming at re-balancing our activity on the planet.

As a cognitive practice, the activity aims at replacing the phenomenal "real event", modeling the conditions posed by the environment, through experimentation and simulation.

The perspective at the design and research level focuses on the outcomes of the *Material Balance* equation, for the transformation of contemporary architecture (at an expressive, morpho-typical, functional and constructive level) with respect to different factors.

First of all the interdisciplinary acquisition of knowledge, processes and technologies from other sectors (especially those of advanced experimental and industrial nature) which can be adapted to the development of new systems, components and materials.

In this regard, the activity of the research group is proposed in the form of *agency* (or "exchange structure"; Davidson 2002) aimed at a *technology push* essentially supported by the performance requirements achieved by the functional needs of architecture, which can be identified as the main "engines" of innovation promoted by production potential (Flichy 1995, tr. it. 1996; Sobrero 1999).

Secondly the aim is containing the physical, material and energy resources for systems and components construction: through the development of advanced processes and devices, capable of including the globality of parameters, variables and constraints for the optimization of results.

Third, the calibration of shape and density with respect to the actual performance required.

Therefore, on this basis, working with a Material Balance Design equation means recognizing a new approach to resources, materials, energy and production can be able to invert the environmental decline of the anthropocene.

Moreover, the Material Balance Design practice implies that the resources extracted from the environment should eventually become wastes and pollutants, considering that recycled materials are energy consuming and imperfect, therefore this process cannot fully compensate and that waste is equal in mass to the difference between total raw material *inputs* to the process and useful material *outputs*.

However, in this scenario the products are more complex and this leads to an increase of *input* mass and wastes. The process wastes far exceed the mass of materials that are finally embodied in useful products (Villalba Méndez and Talens Peiró 2013). The emissions could be reconstructed as a subsystem of a comprehensive *production-cum-abatement technology* when treated as *inputs* in production functions (Pethig 2006). Moreover, according to *Material Balance*, the "emission function" is treated as a production *input*, as a production function with material and non-material *inputs* and bounded marginal product of the material *input*, then as a well-behaved production function with emissions as an *input* (Ebert and Welsch 2007).

The study on *Material Balance* for Design implies the attempts to incorporate environmental issues both in production efficiency models and in pro-active eco-efficiency research methods, and so involving the incorporation into technical design and building processes (Coelli and Lauwers 2007). In particular, the methodological orientation in the study, research and application activities focuses on the possibilities of supporting sustainable development in the construction sector, assuming the need to contain energy consumption and to reduce polluting emissions compared to the use of solutions capable of establishing high "environmental performance".

In this regard, the methodological orientation is articulated through the elaboration of conceptual and operational apparatus referring to the fundamentals and needs of environmental sustainability.

The “eco-efficiency” of the transformation processes, for which the design, production and construction elaboration (understood as an *environmentally conscious design* activity) is determined, in a global way, both in the interaction with the equilibrium of the ecosystem and in the acquisition of the appropriate levels of environmental and settlement quality (Slessor 1997).

The paradigms of sustainable development are defined with respect to the consequences of environmental impacts (caused largely by the management activities, especially energy management, of buildings) and aimed both at protecting the environment and bio-ecological balances, and the conservation of non-renewable resources (materials and energy).

The interactive articulation of contents, procedures and objectives with respect to the determination of the conditions of balance with the environmental system (in general, with respect to resources, constraints and contingency of phenomena), is identified as a system defined by “constructed” conditions (according to the “method of complexity”; Morin 1977, tr. it. 2001).

In the following chapter a detailed analysis will be developed on the fold a *Material Balance* for architecture and design. In particular these aspects will be taken into consideration:

- the technological culture and the procedures of knowledge, unveiling and manipulation of reality, through the development of the activities of technical elaboration of the environmental reality and the activities of anticipation of reality and environmental outcomes with the aim of limiting the conditions of *consumption* and *accumulation* caused to the productive and constructive operations (Par. 1.2);
- the procedures of functional, productive and material optimization, according to the analysis and support of new forms of calibration and material densities, morpho-typological sizes and structural performances with less material and wasted energy and the criteria related to “digital/virtual design” procedures, “productive/constructive customization” techniques and “executive design” methods (Par. 1.3).

1.2 Technological Culture and Procedures for Knowing, Revealing and Manipulating Reality

The activity of study, research and design according to the *Material Balance* principles is carried out as a process that makes use of the faculties of “manipulation” of reality and processes that interact with the environment proper to the “technological action” (Fadini 2000, p. 47) through the “manipulation” (including virtual) of the physical and procedural, productive and constructive aspects (Nacci 2000, p. 296). Specifically, the “manipulation” of reality (physical and immaterial), in the characteristics of the generation and in respect of both management and limitation of the conditions resulting from *consumption* and *accumulation*, is determined:

- as an operation both "poietic" (in the Aristotelian sense), as a practice based on the assumption and interpretation of data and notions learned from reality and the environment and, on these foundations, addressed to action through forecasting and planning methods (Gehlen 1978, tr. it. 1983), and "autopoietic", as a practice based on experiential acquisition for the purposes of action (Maturana and Varela 1984, tr. it. 1992);
- as an expression of the ability to "give form" (according to the "constructivist" position; Borutti 1997) and to "manifest" reality through the adoption of "calculating" and predictive tools and practices (Cacciari 2000, p. 15) (Fig. 1.1).

The "manipulation" of physical reality, according to the optimization and management of the contents related first to *generation* and then to *consumption* and *accumulation*, is proposed as an instrumental and "finalized" activity, typical of the *homo faber*, aimed at the development of procedures and operating methods for the realization according to the conceptual and design, productive and constructive, environmental and energy balances (Arendt 1958, tr. it. 1964, pp. 220–221). Therefore, the activities of study, research and application according to the *Material Balance* principles, in accordance with the specific "finalized instrumentation" of the *homo faber*, involve either the formulation of the cognitive and operative modalities for the

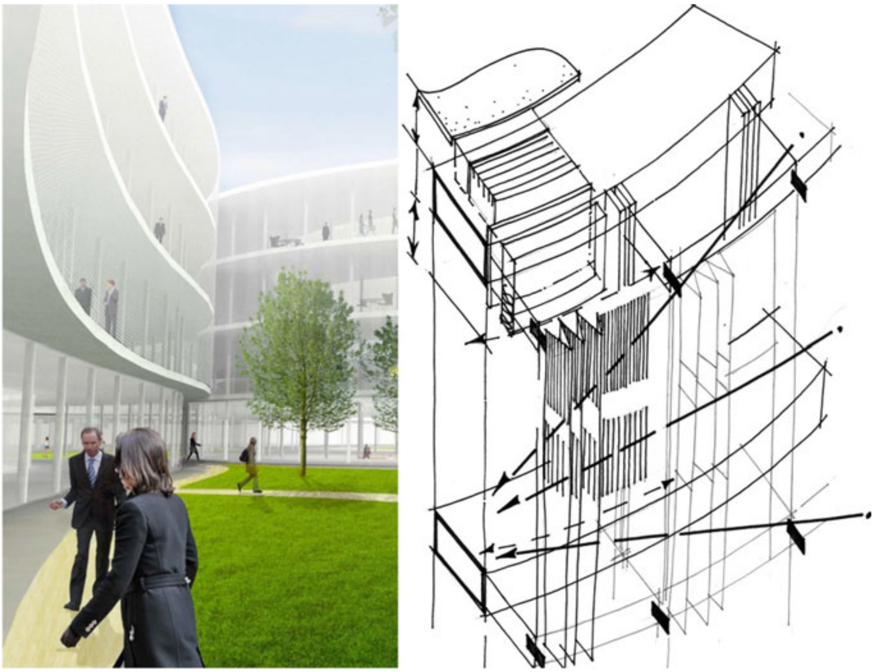

Fig. 1.1 Preliminary analysis and design of the morpho-typological, functional and environmental constitution of the façade and shading devices (Massimiliano Nastri, Università Commerciale "Luigi Bocconi" of Milan; concept design of the "Campus Bocconi". Study of the envelope systems)

intervention towards reality and in respect of resources, balances and eco-systems (Jonas 1974, tr. it. 1991), the extension of the criteria of "possession of the sense of reality" (Leroi-Gourhan 1955, tr. it. 1961, pp. 75–76), either the formulation of the "executive dexterity", as an "operational" application of the experience (i.e., as an acquisition of the technical-manual practicality proper to the *jongleur* described by Gillo Dorfles 1965, p. 86) aimed at making visible and "manipulating" phenomenal reality (Leroi-Gourhan 1964, tr. it. 1977, pp. 379–384) (Fig. 1.2).

The principles of the Material Balance Design are outlined with respect to the procedures of investigation, exploration and "systematization" of the environmental, productive and constructive reality of reference (Popitz 1995, tr. it. 1996). The reality of reference, in which the conceptual orientations, the methods of knowledge and operational intervention are configured, is understood as a "technically organized" context (or "technically conditioned"; Galimberti 1999) and structured overall by technique.

These techniques determine the rational way of "access" and "understanding" of the physical, phenomenal and environmental reality: in these terms, the activity of analysis, elaboration and execution with respect to reality is available as a method of knowledge, as a "disposition of fabrication" and as a work of "unveiling" the physical and material, performance and potential contents of the reality under study. In other

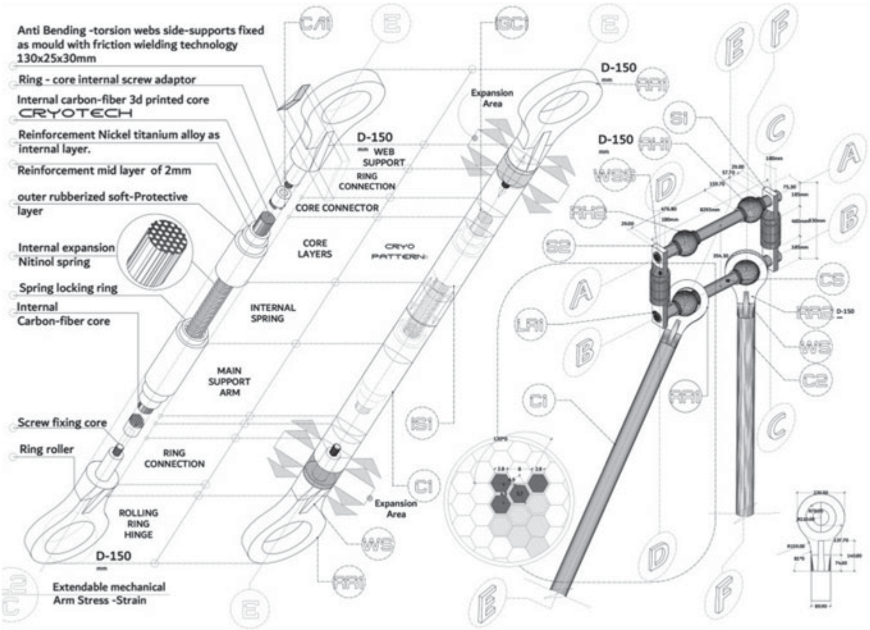

Fig. 1.2 Extendable 3D hinged Mechanical Arm. Self Deployable Structure: executive design of the inflatable skin which activates the structure to self-deploy using the "origami" manner for two main passes for each support (© Courtesy of Mohamed Ahmed Mahfouz, Home Is Mars. Mechanical extendable Arm)

words, in the reference and application of Martin Heidegger's theory on technique, the activity of study, research and application is affirmed as an ability to "dispose" what is offered and made possible by the reality and as an ability in the *conduction* of knowledge, procedures and means towards *production* (1953, tr. it. 1976) (Fig. 1.3).

The disciplinary, operative and experimental approach of the *Material Balance* is thus structured in the concreteness of the reality, where the activity of analysis, elaboration and execution takes place on the basis of the link between "science" (that is, knowledge) and "power" (Galimberti 1999, p. 61), by supporting:

- the formulation of the characteristics of anticipation and forecasting with respect to the conditions of *consumption* and *accumulation* resulting from the *generation*, as a "Promethean" expression of the contribution due to *téchne*;
- the "revelatory" and "productive" expression, as a "way of unveiling" the environmental reality (in the Heideggerian perspective) which consists both in 'knowing the "truth of things", in order to bring it to light' (Spengler 1931, tr. it. 1992; p. 79), and in "making happen in presence" and "leading out" the knowledge from reality itself (Bufalo 2011, p. 28);
- the implementation of the Heideggerian "unveiling" as a capacity to "arrange in new relationships" what is offered and made possible by the environmental reality, as a capacity or "dispositive force" in the *conduction* (i.e., in the articulation and fine-tuning) of knowledge, procedures and means according to the design and construction objectives aimed at limiting the conditions of *consumption* and *accumulation*;
- the elaboration of results, products and "artifacts" as the "unveiling provocation as téchne" (Mazzarella 1993), understood as a practice that aims to examine the "internal functioning of things" (Deutsch 1997, tr. it. 1997, p. 12) (Fig. 1.4).

Therefore, *Material Balance* is carried out in accordance with the principles of the work of "unveiling" (outlined by Martin Heidegger), aimed both at "making in presence" and "leading out" knowledge from reality, and action, as "production" towards the environmental reality ("used" by the *téchne*), understood in "manipulable" and "calculable" form (Cacciari 2000). The formulation of the operative activity, aimed at the intervention towards the environmental reality, involves the anticipation and the simulation aimed at exercising, at the moment of the concrete action, the management and the direction of the productive and constructive operativeness (Fig. 1.5).

The adoption of the *Material Balance* design strategy is determined according to the procedures aimed at anticipating the outcomes and consequences within the environmental context, in order to reduce the conditions of *consumption* and *accumulation* due to production and construction, management and use up to disposal. In this regard, the scientific framework calls into question the support of the technological culture of design aimed at stimulating the approach based on the set of knowledge related to the analysis and anticipation of reality, bearing in itself the "component of planning and therefore of calculating forecast" (Cera 2007, pp. 68–69). On this basis, the design activity is constituted through:

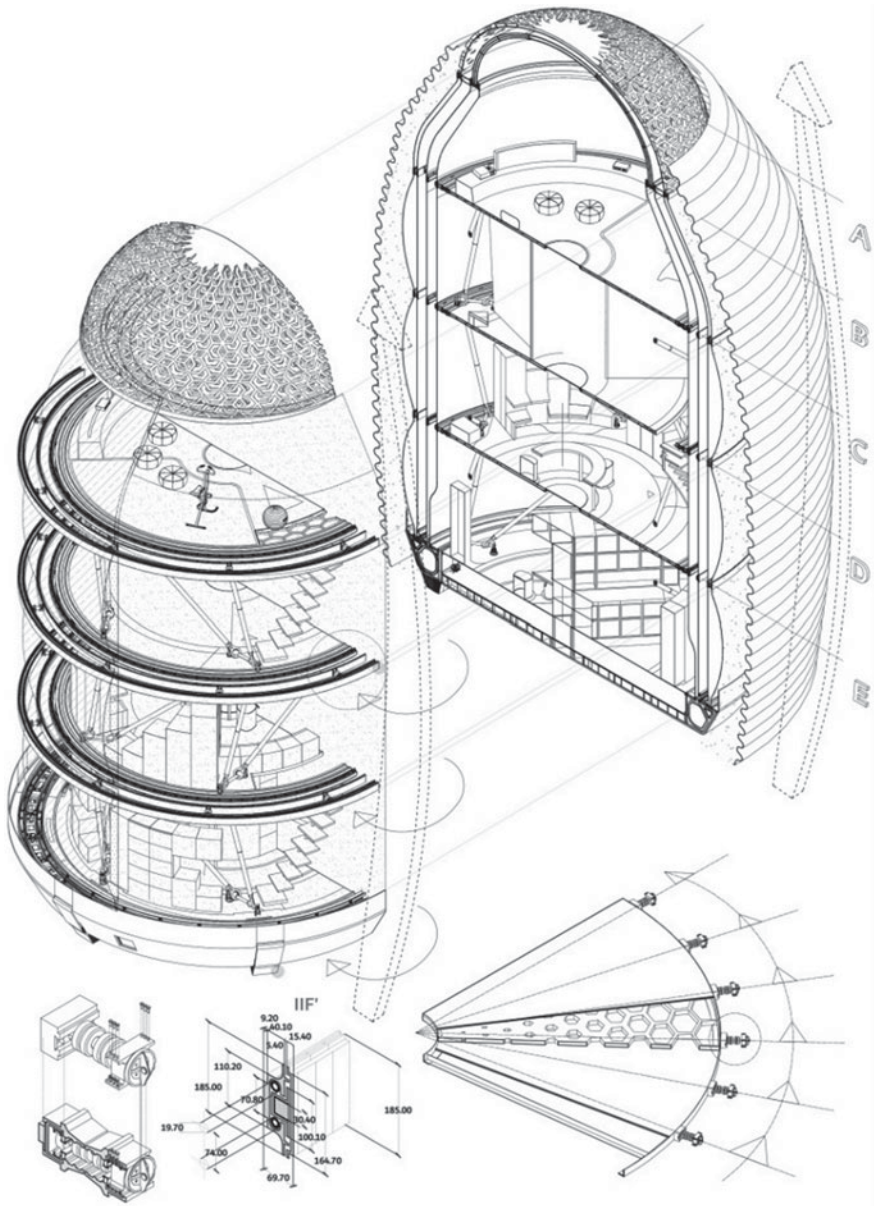

Fig. 1.3 Development of the tower of the Martian colony showing the multi-layered building envelope consisted of 3D-printable regolith and the internal based inflatable skin that helps in triggering the deployment of the mechanical compressible structure (© Courtesy of Mohamed Ahmed Mahfouz, Home Is Mars. Interior of the Martian colony)

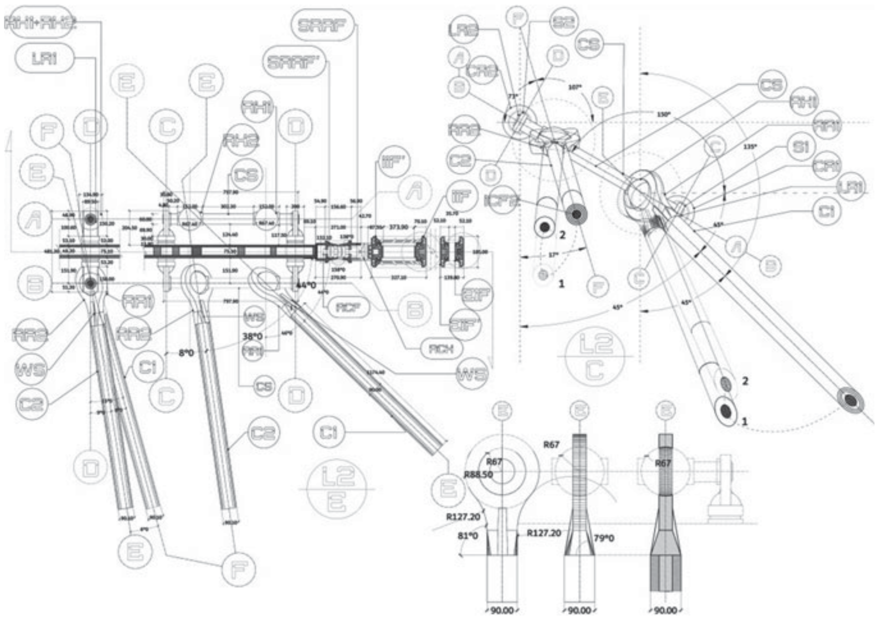

Fig. 1.4 Study of the yet complex 3D-hinge function which can perform a limited 3D-XYZ axis rotation with three axial movements rotation around its axis and rotation while following the deployment path. The ring hinge is reinforced by dual side web to reduce the side stresses such as bending and horizontal sheer forces (© Courtesy of Mohamed Ahmed Mahfouz, Home Is Mars. 3D hinge system)

- the integration of the contents and methods oriented towards forecasting and "optimization of the results according to the adoption of analytical procedures" (Asimow 1962, tr. it. 1968 3rd ed., p. 10);
- the practices of "projection" and simulation (in an experimental way, to perform tests and checks), for which the activity is defined as a technical procedure of "rational forecasting" (with a "temporal" and, therefore, "Promethean" function) to arrange, organize and anticipate the outcomes and consequences within the environmental context, arriving at the definition of a model of reality not yet existing, whose informative, decisional and forecasting aspects appear (Nastri 2018);
- the practices of "artificial reproduction" (in a simulated form) of the contents, data and procedures to be examined and with respect to which to arrange the criteria for productive and constructive intervention, also foreseeing possible critical and unforeseen situations;
- the practices of "modelling" (provided with heuristic function), for which the knowledge of the properties of reality (according to the characteristics of the "modelled" domain) allows to formulate forecasts (on "modelled" phenomena). The cognitive and operational processes take place as a practice of "modelling"

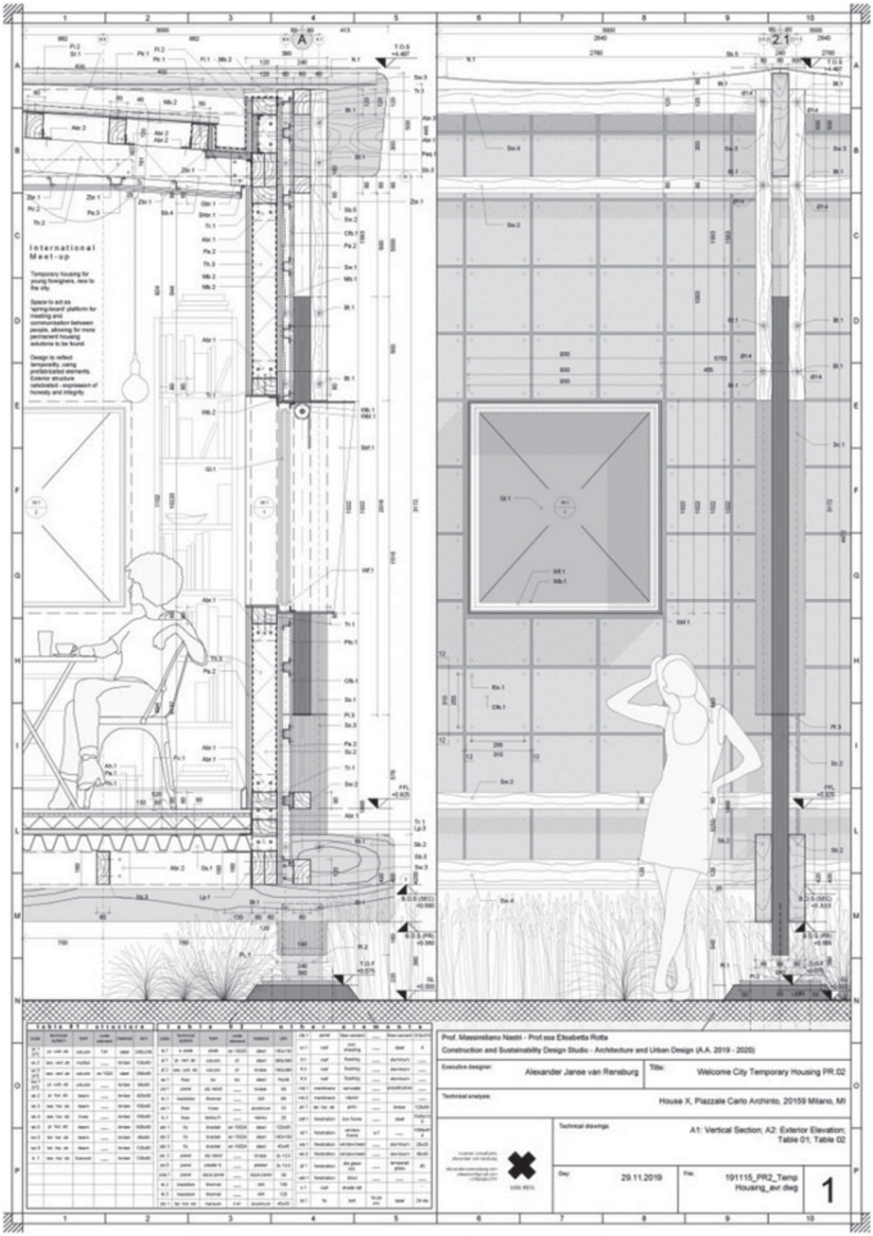

Fig. 1.5 Executive elaboration and construction simulation of the technical interfaces (through the development of construction drawings), according to the typological and connective arrangement of the elements and joining devices (© Courtesy of Alexander Philip Janse van Rensburg, Welcome City Project, Milan)

through the formulation of "interpretative models", through the activity of organization and intelligible reproduction of reality and of the environmental context: these are defined as the totality of the "possible determinations", that is, as a result of a "construction", a representation and a "planned configuration" with respect to which to proceed at an experimental and simulative level (Borutti 1991, 1997);
- the practices of "manipulation" and "exploratory forecasting" aimed at structuring and simulating reality, so that the elaboration processes propose the "construction of a real-world analogue that can be subsequently manipulated in order to discover its functioning under new circumstances" (Waddington 1977, tr. it. 1977, p. 202) (Fig. 1.6).

1.3 Functional, Production and Material Optimization Procedures

The adoption of the *Material Balance* principles is determined within the *digital fabrication* procedures in the experimental design, production and construction scenario, aimed at the development and execution of complex building systems and architectures defined by overcoming the limits related to feasibility conditions (physical, dimensional and morpho-typological).

The activity, through the use of operational methodologies acquired and transferred from industrial sectors characterized by the use of advanced technologies, considers the development of cognitive, technical-scientific and applicative guidelines for the realization of optimized systemic and compositional solutions, coordinated in the design, production and construction phases in a way related to the increase of economic, management and environmental effectiveness.

The adoption of the *Material Balance* principles, according to the use of digital production systems, considers:

- the elaboration and realization of products of reduced mass, able to favour the containment of energy resources (during the production and management phases), and the composition of models and prototypes able to re-elaborate traditional solutions;
- the design, production and executive elaboration of systems, components and elements with high morphological and connective complexity, according to customized solutions, without the constraints due to traditional methods of realization.

The study, research and application activity observes the potential and prospects established by the *digital fabrication* procedures, according to the opportunity to develop technical solutions with calibrated geometric composition, with the help of multiple materials and determined according to the "physical transformation" of requirements and performance (Fig. 1.7).

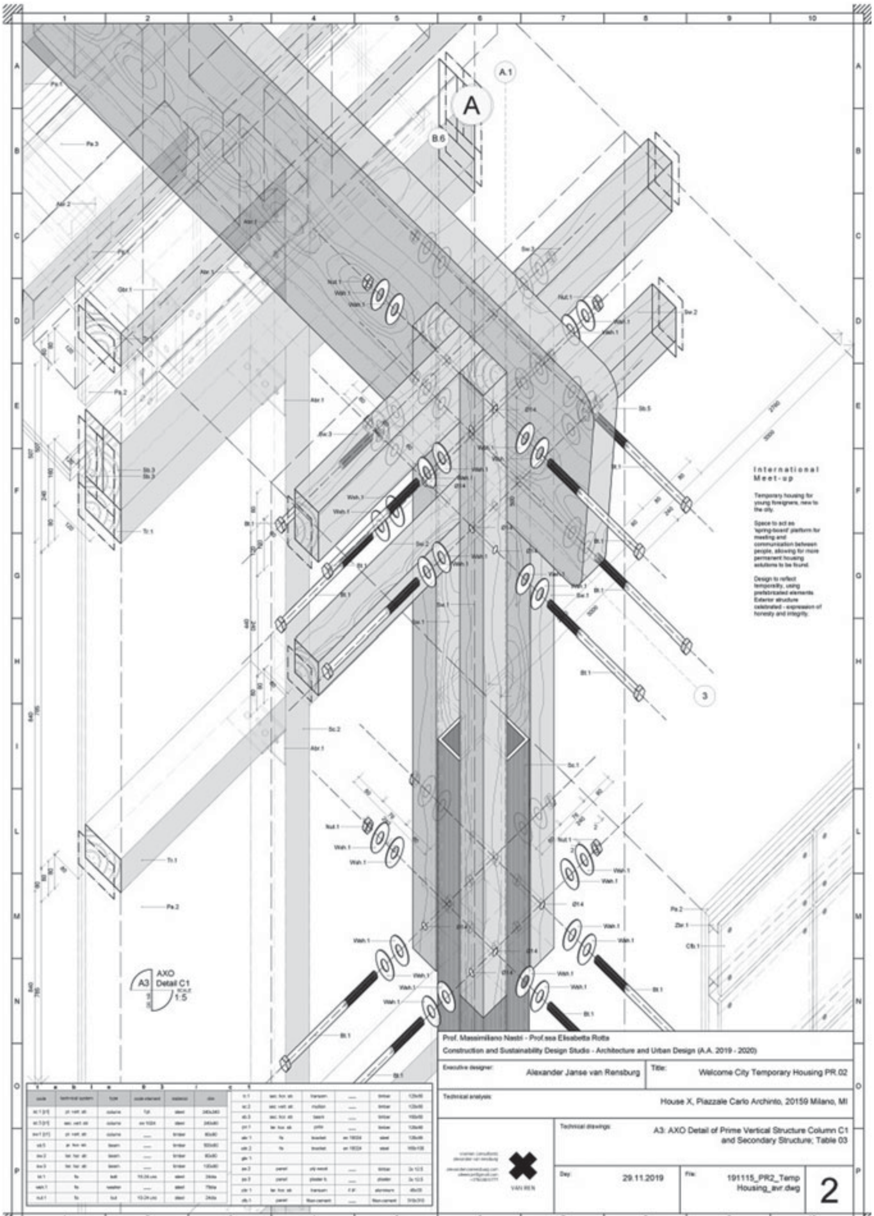

Fig. 1.6 Design and construction simulation of the technical interfaces (through the development of assembly drawings), according to the arrangement of the sequences and joining devices (© Courtesy of Alexander Philip Janse van Rensburg, Welcome City Project, Milan)

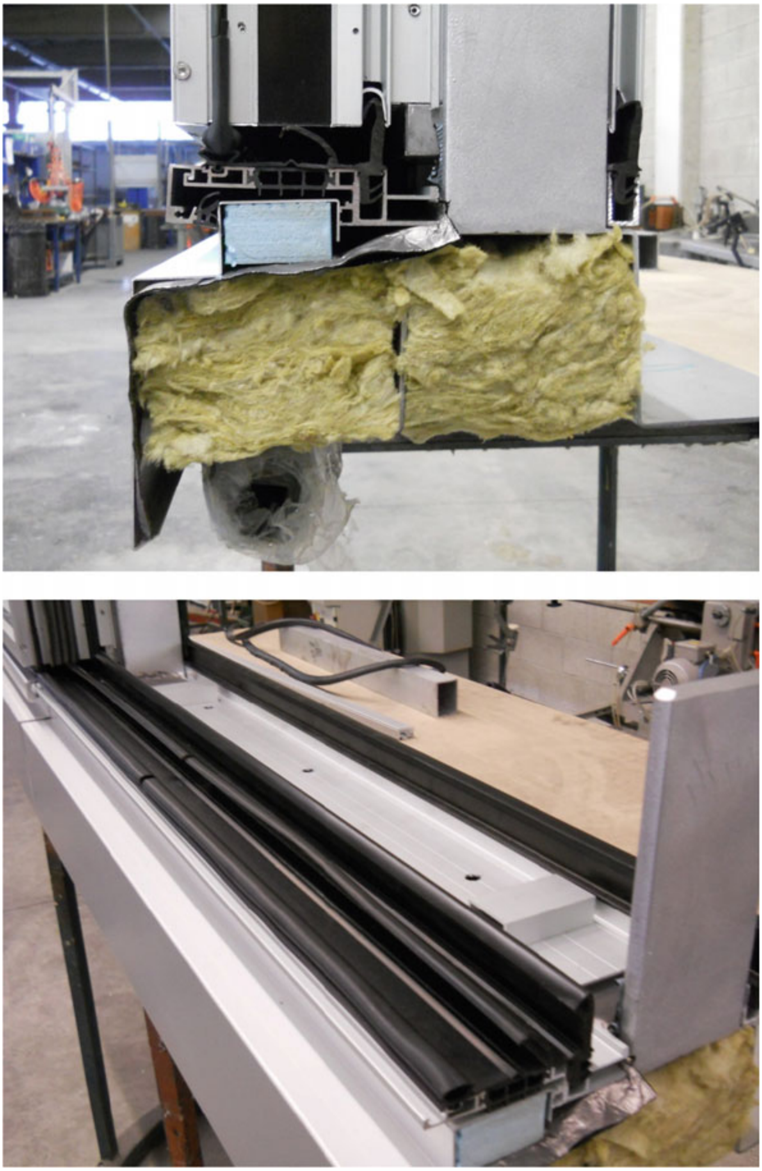

Fig. 1.7 Physical modelling, connective experimentation and construction simulation of components and technical interfaces of prefabricated façade system in the laboratory (Massimiliano Nastri, Tecnet Tower, Milan; executive design of the building envelope)

In this respect, the operational procedures under consideration include:

- the development of the three-dimensional digital configuration of building systems, components and technical elements, subsequent optimization according to requirements and printing in 3D modes;
- the development of three-dimensional and complex geometry solutions of integrated typology, examining the possibilities of avoiding critical conditions due to the combination of elements and joining devices according to traditional solutions;
- the optimization of the production lines, in order to reduce the quantities of material (calibrated with respect to the actual functional needs), to avoid the production waste and to limit the use of energy resources and polluting emissions.

These activities consider the *topology optimization* procedures concerning geometric and physical calibration (i.e., according to the finite elements calculation method), oriented to the development of specific performance conditions according to the integration and application of *additive manufacturing* procedures. Specifically, the technical-scientific contribution includes the methodological guidelines established by the three-dimensional digital configuration and subsequent optimization according to the requirements and content resulting from the environmental and energy analysis. In this regard, the operating procedures under examination include:

- the functional and structural development of the building systems, components and technical elements through the simulation and the virtual modeling;
- the development of the numerical parameters relative to the models, foreseeing the calibration of the models with the results of the tests focused on the material characterization;
- the interaction between the production parameters and 3D printing processes, in order to calibrate the physical composition through the identification and optimization of the parameters, aimed at providing and meeting the conditions of balance between costs, quality and reduction of both energy and materials consumption;
- the development of the building systems, components and technical elements optimized with respect to the actual climatic and environmental stresses (i.e., thermo-hygrometric, lighting and acoustic needs and comfort requirements in interior spaces), through the conception of new perspectives both of compositional and functional articulation (in *free-form* mode), and of physical and material stratification (Fig. 1.8).

Material Balance principles are oriented to the examination of materials with respect to their processes of change from “stable entities” to “designable entities” (according to the characteristics of “changed physicality”, which the experimental research tends to transform into “dense” and “interface of intelligent systems”) according to a specific “performance program” (Altomonte 2004, p. 42). The elaboration towards the materials as “designable entities” is addressed with respect to the outcomes of solutions in which functions tend to become “complex” (in a “controlled” and “managed” way) and combined (in *solid state* form), realizing multiple performances through the correlation of different agents.

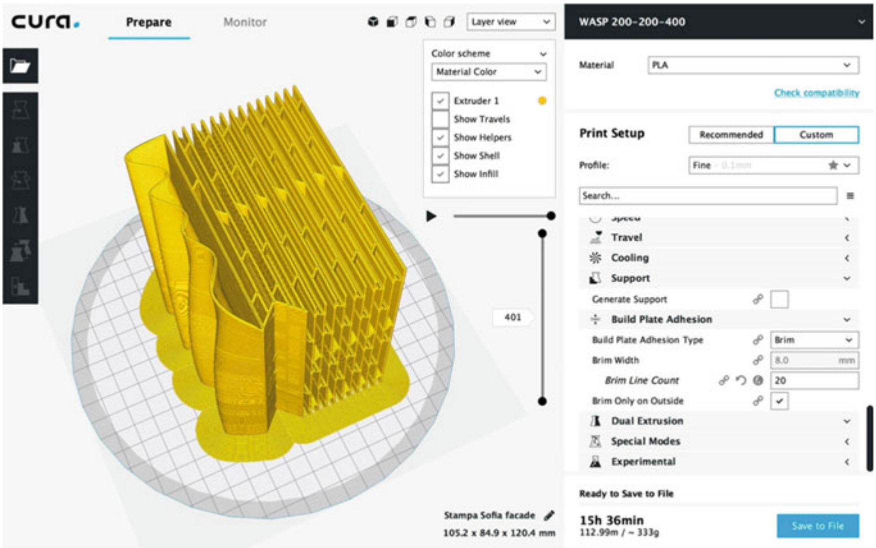

Fig. 1.8 Study of 3D-printed façade system which actively participates in housing thermal comfort conditions, thanks to its customable and optimized shape made to host installations and to regulate solar radiation: the façade is assembled with light manageable components printed in recyclable PET-G, reducing waste and costs in every stage of LCA (© Courtesy of Sofia Peviani, Additive manufacturing design potential for sustainable architecture)

This by means of: the integrative possibilities of the functions, where relations and (physical, performance) interfaces between individual parts and materials in a system or component are arranged; the elaboration of the building systems, components and materials conceivable in custom made form, with the action towards the contents and data in order to perform certain functions and without having to adapt to the limits imposed by the original and predetermined properties; the elaboration of the building systems, components and materials with respect to their ability to react to environmental stimuli, according to "passive" or "active" regulation processes induced by multiple loads (electrical and chemical, thermal and lighting) that modify, through alterations in the physical or chemical structure, the physical and functional arrangement; the development of the building systems, components and materials integrated with "natural" systems, up to the form of *naturoid* organisms, i.e., as "machinations" which aim to reproduce, manage and metabolise natural processes, according to the criteria of "active understanding" (Negrotti 1999, 2000) (Fig. 1.9).

The activity is outlined according to the procedures aimed at the "transformation" of what has been acquired and disposed by the environmental reality, according to the references around the cognitive and operative elaboration understood as "transformative act" and "metamorphosis" (Warner 2004).

The activity, as a "transformation" of the contents and data acquired by reality, takes place as the generative" practices (with regard to generation and consumption contents), defined as technological processes through which to act on the material

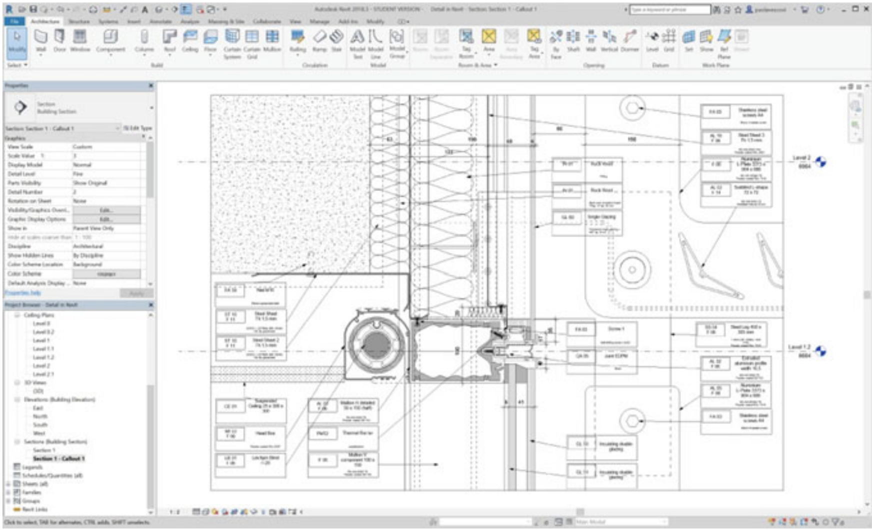

Fig. 1.9 Executive design of the shop drawing reworked through the application of Revit, providing a high detail comparable to that originally executed in AutoCAD. Parametrization of the system: automatic reference to the detail section through the provision of call-out, elaboration of customized components saved in the software libraries for subsequent applications, automatic change of the geometric model by varying the associated parameters, dynamic insertion of materials, dimensions and codes (© Courtesy of Paola Vescovi, Future Façades and Executive Design. Parametric and Dynamic Methodologies for Technical Processing of Advanced Building Envelopes)

aspects, i.e., which show the potential for mutation in compliance with specific physical characteristics. This is done through strategies aimed at incorporating, within the design, production and construction processes, the capacity to preserve (or intensify) performance and rebalancing relationships (Southwick and Charney 2012) and the "regenerative" practices (as action towards content acquired by accumulation), defined as technological processes by which an attempt is made to reproduce or renew the initial state and properties of a substance or a material.

The activity of cognitive and operational processing is aimed at the reproduction of the properties following the loss of functionality, total or partial, supporting the techniques of "re/generative" resilience, "dynamic adaptation" and "metamorphosis" (with particular attention to the *eco-mimesis* processes) (Fig. 1.10).

1.4 A Backcasting Approach

In conclusion we should think that the possibility to go deep in the process thanks to computational tools, digital fabrication, scientific knowledge, technical culture and applied methods can help us to set where we would like to be in the future and have a "backcasting" approach, setting the roadmap to arrive at that desired result.

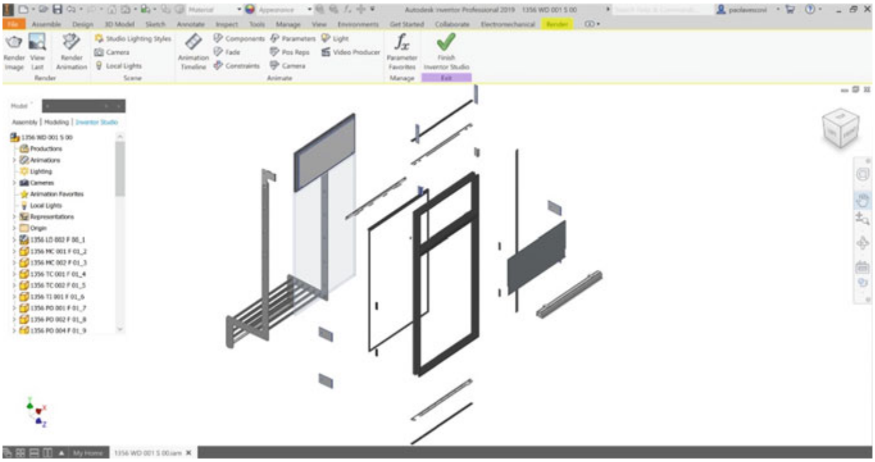

Fig. 1.10 Configuration of the façade panel processed in Inventor starting from the Revit model. Inventor environments applied for the executive design of fabrication drawings and assembly drawings: detailed modelling of three-dimensional components in Inventor Part, mounting of the single elements of the panel in Inventor Assembly, layout of the graphic-descriptive panels provided with automatic dimensions and codes in Inventor Drawing (© Courtesy of Paola Vescovi, Future Façades and Executive Design. Parametric and Dynamic Methodologies for Technical Processing of Advanced Building Envelopes)

In the field of future studies the traditional *forecasting* approach is still dominant, where the idea is to make previsions on mainstream trends. However, in complex systems, it will hardly generate solutions that could be long lasting. In architecture a more interesting approach, is *backcasting*, intended as a method to analyze future with the focus on a preferable scenario. The fundamentals of this approach were outlined by John B. Robinson on the nineties but they remain still today meaningful as they concern less with a possible, plausible or probable future and more with the construction of a progressive knowledge, a physical feasible scenario, a set of skills, which starts from a future end-point to the present (thus “back casting”).

This result should be identified in the three main ambits of university mission that is the first sector—education, the second sector—research—and the third one—the impact on society of our activities.

To leverage the level of knowledge is today a need that cannot be postponed to have a more informed society, to contrast populism and have a democracy of technology and materials, accessible, transparent and caring to our environment.

The idea of this is to put the architectural project at the center of debate as a complex phenomenon, able to build a synthesis of scientific, social, political and cultural points of view, in a period where the anthropocentric perspective has radically changed our approach to the environment, to construction, to technology and materials, given their impact and effects on scarcity of resources.

Here is where architecture and design can give a real contribution to the debate, in a variable, multicultural, trans-disciplinary and fast changing society.

The question is not to anticipate the future but to build it.

References

Altomonte S (2004) L'involucro architettonico come interfaccia dinamica. Strumenti e criteri per una architettura sostenibile. Alinea, Firenze
Arabi B, Munisamy Doraisamy S, Emrouznejad A, Khoshroo A (2017) Eco-efficiency measurement and material balance principle: an application in power plants Malmquist Luenberger Index. In: Annals of operations research, vol. 255. Springer, pp 221–239
Arendt H (1958) The human condition. The University of Chicago, Chicago (tr. it. Finzi S, Vita activa. La condizione umana. Bompiani, Milano, 1964)
Asimow M (1962) Introduction to design. Prentice-Hall, Englewood Cliff, NJ (tr. it. Mancuso M, Principi di progettazione. Marsilio, Venezia, 1968, 3rd ed.)
Ausubel JH, Sladovich HE (1989) Technology and environment. National Academy Press, Washington, D.C., pp 36–39
Ayres RU, Kneese AV (1969) Production, consumption, and externalities. Am Econ Rev 59:282–297
Borutti S (1991) Teoria e interpretazione. Per un'epistemologia delle scienze umane. Guerini & Associati, Milano
Borutti S (1997) Costruttivismo e progettualità. Una prospettiva epistemologica. In: Nardi G (ed) Aspettando il progetto. Milano, Angeli, pp 28–43
Bufalo R (2011) Tecnica e filosofia nel pensiero del novecento. Note per una discussione. Il Contributo, n. 1, gen.-apr., pp 9–40
Cacciari M (2000) Salvezza che cade. In: Cacciari M, Donà M, Arte, tragedia, tecnica. Cortina, Milano, pp 3–65
Cera A (2007) Sulla questione di una filosofia della tecnica. In: Russo N (ed) L'uomo e le macchine. Per un'antropologia delle macchine. Guida, Napoli, pp 41–115
Coelli T, Lauwers L (2007) Environmental efficiency measurement and the materials balance condition. J Prod Anal 28:3–12
Davidson CH (2002) Tra ricerca e pratica: il trasferimento di tecnologie, l'osservatorio tecnologico e l'innovazione. In: Sinopoli N, Tatano V (eds) Sulle tracce dell'innovazione. Tra tecniche e architettura. Angeli, Milano, pp 158–168
Deutsch D (1997) The fabric of reality (tr. it. Frediani S, La trama della realtà. Einaudi, Torino, 1997)
Dorfles G (1965) Nuovi riti, nuovi miti. Einaudi, Torino
Ebert U, Welsch H (2007) Environmental emissions and production economics: implications of the materials balance. Am J Agr Econ 89:287–293
Fadini U (2000) Sviluppo tecnologico e identità personale. Linee di antropologia della tecnica, Dedalo, Bari
Flichy P (1995) L'innovation technique. La Découverte, Paris (tr. it. Guareschi M, L'innovazione tecnologica. Feltrinelli, Milano, 1996)
Galimberti U (1999) Psiche e techne. L'uomo nell'età della tecnica. Feltrinelli, Milano
Gehlen A (1978) Der Mensch. Seine Natur und seine Stellung in der Welt. Akademische Verlagsgesellshaft Athenaion, Wiesbaden (tr. it. Mainoldi C, L'uomo. La sua natura e il suo posto nel mondo. Feltrinelli, Milano, 1983)
Heidegger M (1953) Die Frage nach der Technik, in Vorträge und Aufsätze. Günther Neske, Pfullingen (tr. it. Vattimo G, La questione della tecnica, in Saggi e discorsi. Mursia, Milano, 1976, pp. 5–27)
Jonas H (1974) Philosophical essays. From ancient creed to technological man. Prentice-Hall, Englewood Cliffs, NJ (tr. it. Bettini G, Dalla fede antica all'uomo tecnologico. Il Mulino, Bologna, 1991)

Krysiak FC, Krysiak D (2003) Production, consumption, and general equilibrium with physical constraints. J Environ Econ Manage 46:513–538
Lauwers L et al (2009) Justifying the incorporation of the materials balance principle into frontier based eco-efficiency models. Ecol Econ 68:1605–1614
Leroi-Gourhan A (1955) Les hommes de la prehistoire, Bourrelier, Paris (tr. it. Spagnol Vaccari E, Gli uomini della preistoria. Feltrinelli, Milano, 1961)
Leroi-Gourhan A (1964) Le geste et la parole. I. Technique et language. Albin Michel, Paris (tr. it. Zannino F, Il gesto e la parola. I. Tecnica e linguaggio. Einaudi, Torino, 1977)
Maturana HR, Varela FJ (1984) El árbol del conocimiento. Las bases biológicas del enten-dimiento humano. OEA, Santiago (tr. it. Melone G, L'albero della conoscenza. Garzanti, Milano, 1992)
Mazzarella E (1993) Ermeneutica dell'effettività. Prospettive ontiche dell'ontologia heideggeriana. Guida, Napoli
Morin E (1977) La Méthode. La Nature de la Nature. Éditions du Seuil, Paris (tr. it. Bocchi G and Serra A, Il metodo. 1. La natura della natura. Cortina, Milano, 2001)
Nacci M (2000) Pensare la tecnica. Un secolo di incomprensioni. Laterza, Roma-Bari
Nastri M (2018) Téchne e poíesis. Cultura tecnologica ed elaborazione esecutiva del progetto. FrancoAngeli, Milano
Negrotti M (1999) From the artificial to the art: a short introduction to a theory and its applications. Leonardo 32:183–189
Negrotti M (2000) Artificiale. La riproduzione della natura e le sue leggi. Laterza, Roma-Bari
Pethig R (2006) Non-linear production function, abatement, pollution and materials balance reconsidered. J Environ Econ Manage 51:185–204
Popitz H (1995) Der Aufbruch zur artifiziellen Gesellschaft. Mohr, Tübingen (tr. it. Auletta G, Verso una società artificiale. Editori Riuniti, Roma, 1996)
Slessor C (1997) Eco-Tech. Sustainable architecture and high technology. Thames & Hudson, London
Sobrero M (ed) (1999) La gestione dell'innovazione. Strategia, organizzazione e tecniche operative. Carocci, Roma
Southwick SM, Charney DS (2012) Resilience. The science of mastering life's greatest challenges. Cambridge University Press, New York
Spengler O (1931) Der Mensch und die Technik. Beck, München (tr. it. Gurisatti G, L'uomo e la tecnica. Contributo a una filosofia della vita. Guanda, Parma, 1992)
Villalba Méndez G, Talens Peiró L (2013) Materials balance models. In: Fischer MM, Nijkamp P (eds) Handbook of regional science. Springer, pp 1009–1028
Waddington C H (1977) Tools for thought. Paladin, St. Albans, Herts (tr. it. Sala V, Strumenti per pensare. Un approccio globale ai sistemi complessi. Mondadori, Milano, 1977)
Warner M (2004) Metamorfosi, in Eds., Focus. Fondazione La Biennale di Venezia, Venezia, pp 15–29