Reference Model for Innovative Product Development in Construction: A Stages Proposal based on Comparative Analysis

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***Abstract*--The houses for the low income residential construction sector are one of the most prominent niches in the building construction sector in Brazil. However, the construction process continues to handcraft, which creates many errors and quality problems. To reach greater efficiency, it is necessary to have large-scale production with repeatability, standardization, high productivity and an accurate management system. The final product of the construction is a unique building, not in serial production. What makes it a project management model widely used nowadays is its unique product through a specific design. However, these management models are generic, for all kinds of activities and sectors, and it does not refer to innovation and industrial environment. Meanwhile, the construction industry needs a model for developing its innovative approaches for the best project management practices, relevant management and the peculiarities of the industry. The reference models suggest that the product can develop by dividing into stages. That division is a way to deal with the complex process of development and aims, in addition, to establish control points to ensure increased design efficiency. The purpose of this article is to generate, from the comparison of the models mentioned, a preliminary proposal phase for new reference model for innovation in construction.**

I. INTRODUCTION

The construction process in Brazil remains handcrafted, using concrete made on site, a masonry laid brick by brick, plaster, finish and hand paint and other things. It is prone to quality errors. The quality deviation means a budget deviation, and the majority of construction enterprise transfer the cost to sales price.

Recent studies published by [3] Strategy for Full Social and Economic Potential in Brazil showed that between 2003 and 2011 the construction sector increased its production cost (labor: 85% and materials 70%). It identified that, among others, low productivity is one of the main challenges of the sector to overcome.

According to the study carried out by FGV [4] on Taxation, Industrialization and Technotogy in Construction, in the short and long terms projections point to favorable growth for the activity in the next 10 years. Nevertheless, there are alerts that if the low productivity does not change, the favorable scenario will compromise any effort aiming forward progress.

In the search for a profitable business, many companies adopt the strategy to build smaller apartments, without floor, tile and other items to keep the low construction costs under control. The inefficiency and the lack of innovative process reflection is visible by mismatching the budgeted cost and the completion cost always higher than estimated.

In 1989, the respected professor Sabbatini classified the construction process as follows:

- Traditional: based on craft production of manpower, low mechanization and high waste;
- Rationalized: planning and control as a main principle, and focus on waste elimination and productivity increase. Production process and cost flow controlled;
- Industrialized: intensive use of elements produced in fixed installations and later adapted to the site, based on principles of organization, planning and control, low waste, productivity increase and cost reducing.

In 2013 [2], knowing the Sabatini statements bring the following conclusions:

- The industrializations are associated with industrial facilities and production plants;
- The productivity increase could made by rationalization with more advanced stages of industrialization
- To obtain the benefits of those stages, racionalization and industialization, plannig is the foundation
- On site assemble operations is necessary, once the components are from industrial plants.

Nowadays, there is a construction system linked with the industrial management process. The precast concrete is a strong trend, and the large quantities of units made in the US, Europe and Asia reinforce the technical and economic viability.

In Brazil, the precast industry already had some technical reference standard made by the Technical References of the Brazilian Standards Association - ABNT.

Reference [6] identifies some peculiar characteristics of construction sector that hinder the implementation of the concepts and tools for manufacturing models:

- Civil construction is nomad as operates in various sites;
- Their products are unique and non-serial;
- Erection sites centered on production, not the line production concept in a fixed place;
- Weather affects on production performance;
- Intensive low skill labor uses and high turn over;
- Little technical specification;
- Your product is almost uniquely bought in the customer's life;
- Low accuracy compared with other industries.

Against this background, it is clear that it is necessary that the companies in the construction sector should structure to develop new technologies in pursuit of industrialization.

Considering the best practices for managing their innovative projects and product development process.

II. THEORETICAL BACKGROUND

A. Reference models for the management of product development process

The product development management – PDP has as its main objectives; control and quality assurance in the process of product development, linking all professionals involved from the design phase of a product to market and production processes.

The definition proposed by [9] establishes PDP as a set of activities in a logical sequence in order to produce goods or services that have value to a specific group of customers. The authors [9] state that:

"The product development process consists of a set of activities which seeks the basis of market needs and the possibilities (...), considering the competitive strategies (...). Reaching the design specifications for a product and its production process, in way to manufacturing and be able to produce it. "

Reference [9] states that the "reference model" is essential to the product development process because it:

- Determines the ability of companies to control the PDP and interact with the market and with sources of technological innovation.
- Includes strategic management, operational management and the development cycles of problem solving, improving and learning, considering the entire product life cycle.
- Structure the operational steps and activities of project development.
- The formalization of the PDP management model enables everyone involved to have a common view of the process.

Accordingly [7] the "reference models" is suitable for both in training, as well as, to updating professionals as the ideal model for the implementation of improvements in the process of developing products businesses.

Essentially the PDP comprises several stages, namely: idea generation, previous research, even development, pilot series and the launch of the product on the market. There is no established rule for the division of the stages of the PDP, also the boundaries between one and another are not clearly identified and known, but the purpose of each stage is to perfom the tasks.

Reference [9] the PDP split into three macro-stages: pre-development, development and post-development. These macro-stages subdivided into stages that detail and specify activities within the process. These stages require resources and time to execute and transform inputs into outputs, for example, customer requirements in the final product. The Fig.1 briefly presents the reference model [9].

The *pre-development* macroprocess includes the *product strategic planning* stage. Such stage defines which products to develop, which are not and which markets will focus. It is still in the planning stage that the project scope is in definition, taking into account the economic viability and the organization's ability to run the project. The *development* of the macro process consists of five stages: *informational design, conceptual design, detailed design, preparation for production and product launch.*

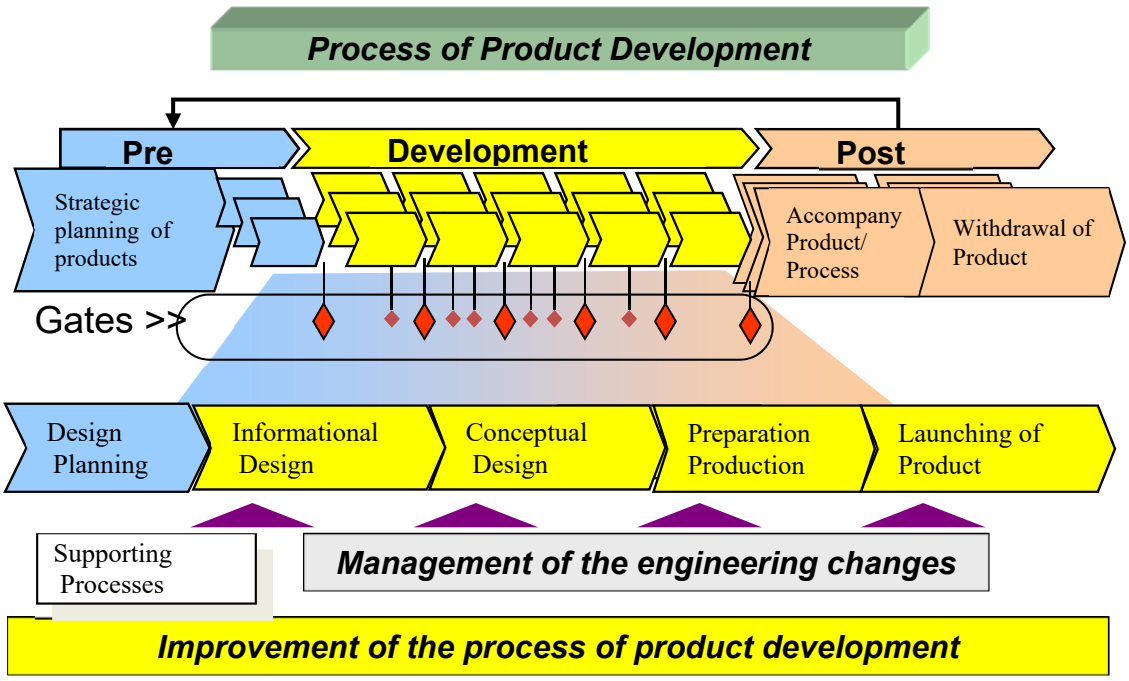

Fig. 1 - Product Development Process [9]

During the stage of *informational design* is necessary information about the project, according [8] this stage turns the output of the previous stage design specification, in addition to detailing product requirements.

In the *conceptual design* is when the descriptions started as product modeling itself, with the functions that the product must present, regardless of how it will be structured such functions. Then they proposed possible solutions for product functions and made the schematic arrangement of the product.

In the *detailed design* stage the necessary tests establishment, including support materials, product packaging design is also stated. This stage has three cycles: detailing cycle, acquisition cycle, and optimization cycle. Concurrently with the detail design stage occurs the *production preparation* stage. There are the development of product manuals and instructions for technical assistance, and information to vendors and staff training and manufacturing devices. It is at this stage still occurs the production of a pilot lot or pre-series.

At last, the development of macro process comes the *product launch* stage, when in addition to document best practices, there are marketing activities, sales, product distribution logistics arrangement, the customer service and after service and technical assistance. So the product can be released into the market. The post-development macroprocess contains two stages, namely: Stage in which follows up the product and process, an assessments of customer satisfaction and technical product performance, the audit processes, and enrollment lessons learned.

B. Stage gates for innovation - Process for new product development

The stage-gate has been developed and first suggested by Robert G. Cooper (McMaster University) in his book Winning at New Products, published in 1986. The stage-gate development process divides into stages separated by gates. At each gate, the continuity of the development process led by a manager or by a committee. The decision based on information available at the time, including business cases, risk analysis, availability of necessary resources such as money, people with skills, among others.

As [1] the model uses tools when dealing with the development of new products. Gates or decision points are located at points of most beneficial development for decision-making. The production areas, located between gates are: 1. Idea generation; 2. Establishment of viability; 3. Test; 4. Validation; 5. Product launch.

Within each stage, a series of multifunctional activities is performed, and this cross-functional team should be coordinated by the project manager. In Fig. 2 one can see the 5 stages and 5 decision-making points to the commercial launch of the product.

Stage 1 - Preliminary investigation - This stage is considered to be a preliminary investigation of the project scope including a non-exhaustive work.

Stage 2 - Detailed investigation - This stage comprises a detailed investigation, both technical and commercial project scopes to build the business case of the project.

Stage 3 - Development - At this stage, there is the development of the product, including its production and operation processes.

Stage 4 - Validation and testing - In this stage are made technical tests for the resilience and quality reliability.

Stage 5- Full production and market launch – After the several testing procedures and the validation the full production process carried out and market launch planned.

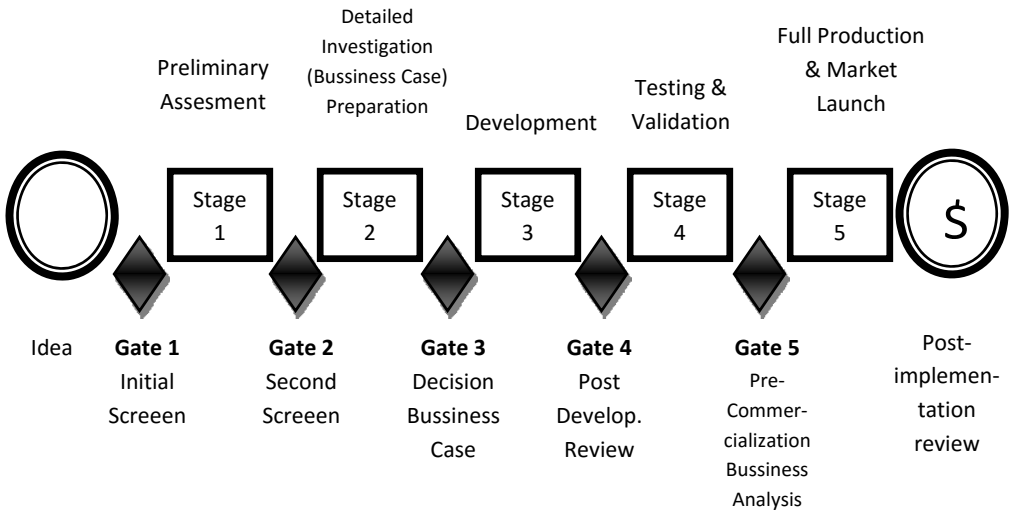

Fig. 2 - The stage gate system [1]

C. Project management framework

The formalization of studies on the project management discipline was through the Project Management Institute, Inc. [5], which came about in the 60s, founded by five volunteers and headquartered in the US. For dissemination of good practices related to the project management discipline, PMI launched in 1987 the first version of the Guide to the Project Management Body of Knowledge (PMBOK® Guide, or simply PMBoK)

The project life cycle defines the stages that connect the beginning of a project to its end. It is in the early stages, according to [10], the mission and objective of the project are determined, including strategies for driving.

During the planning stage, the inherent activities seek to identify, determine and mature the project scope, as well as, collect information from numerous sources, and the viability of the project is analyzed. As the project progresses, it is common for new information, risks and costs are added, implying that occur several feedbacks that serve to further scrutiny. If the impact of this new information throughout the project life cycle to be meaningful, it is possible that the planning phase and even the initiation phase, needs review.

The stage control and monitoring take place concurrently with the execution stage, aims to monitor and keep under control what is running, so that potential problems or deviations identified in time and that the necessary corrections implemented. The main prerogative of this stage is to monitor and measure project performance regularly, pointing variations or otherwise, regarding the project management plan.

In the closing stage, there is the formal completion of all project activities; at this stage it is checked whether all groups of processes needed for project closure were completed. It is also at this stage that all contracts entered into by virtue of the execution of the project begin to be.

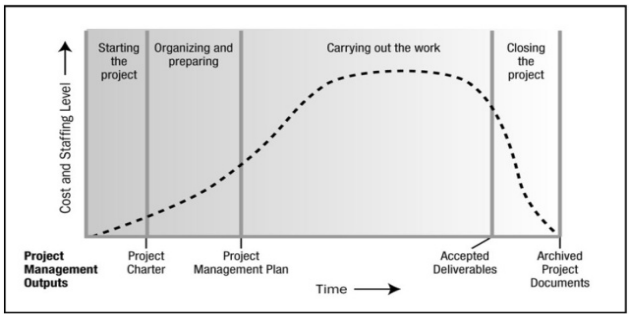

Fig. 3 Project life cycle [5]

D. Reference model for the management of integrated building design process

The Brazilian researcher [7], considering the problems related to lack of quality buildings areas caused by informal design process. She presents in her doctoral thesis a "Reference model for the Integrated Design Process Management Building", formulated with the aim of clarifying of this process in order to assist in understanding and to formalize the practice. This study goes into detail of the project process for building and project management and process modeling to end providing a "reference model".

The proposed "reference model", called Management of Integrated Building Design Process - GPPIE, compared with published models was shown, according to the assessment [7] is more comprehensive. The GPPIE decomposed into three macrostages (Fig.4):

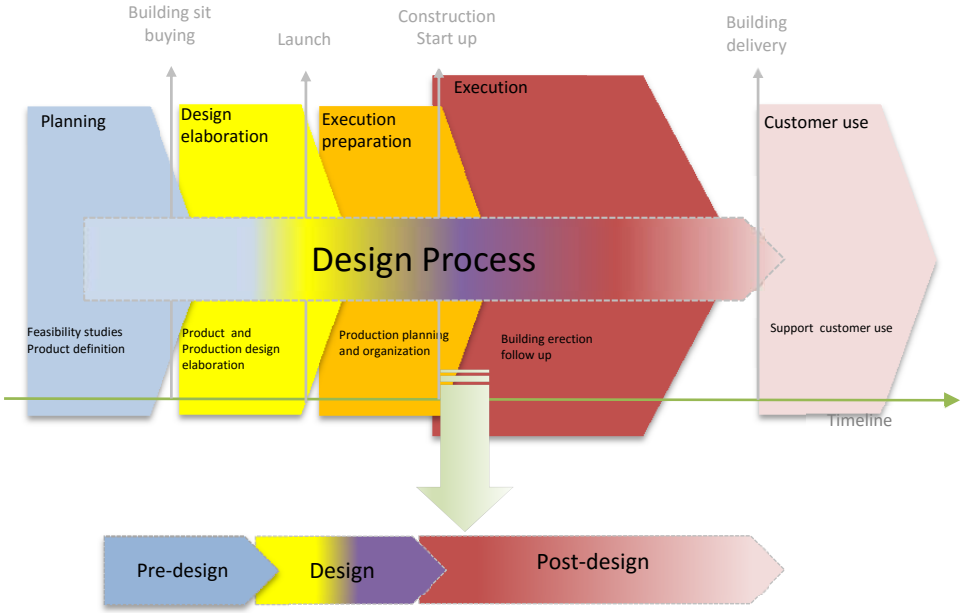

Fig. 4 Macro stages GPPIE – adapted from [7]

Pre-projection - the first microphages corresponds to the stage of project planning. It involves the preparation of the plan of the development project, the main result of the stage.

Projection - involves the development of product-building projects encompassing architectural, foundations and structures, building installations and projects for production involving formwork, slabs, masonry, waterproofing, vertical coatings, construction site. It breaks down into five stages called: informational design, conceptual design, preliminary design, cool design, detailed design, and projects to production. The main results of each stage are respectively the design specifications,

Post-projection - involves monitoring the construction of the building and monitoring of use. The main results of each stage include, respectively, the feedback from projects from the work and evaluation of post-occupation satisfaction. The macro stages are also decomposed, and the eight stages as shown in Fig. 5, as listed: 1. Planning of the project; 2. informational design; 3. Conceptual design; 4. Preliminary design; 5. Legal design; 6. Detailed design - the product and production; 7. Civil works support; 8. Custom utilities support.

III. METHODOLOGY AND TECHNIQUES

Based on the models mentioned in this article, it expected the example of ROMANO doctoral thesis [7] take the first step to migrate the black box model towards a transparent box in which can see and know operation way, therefore better manage it.

It can consider the stages and macro stages as the first level of detail management process as shown in Fig.7.

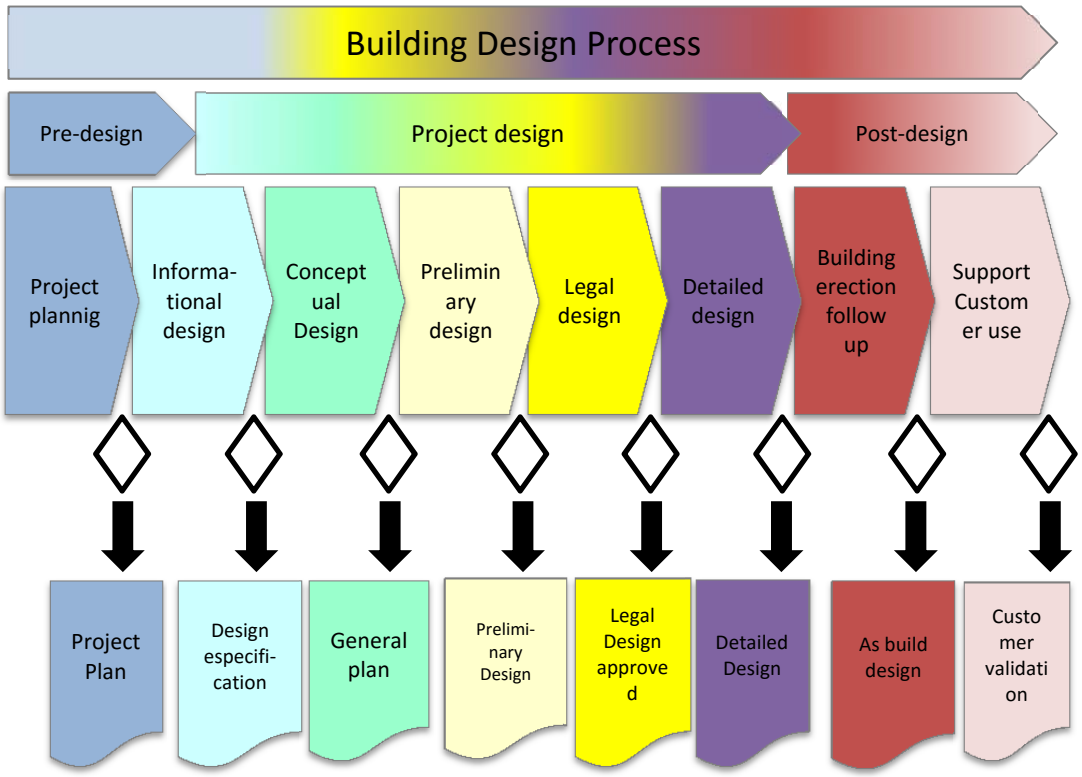

Fig. 5 - GPPIE stages –adapted from [7]

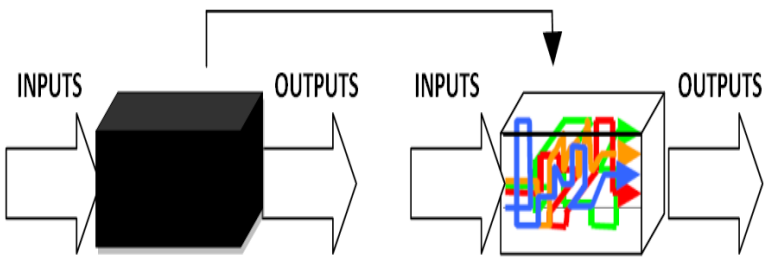

Fig. 6 The process of black box to the transparent box [7]

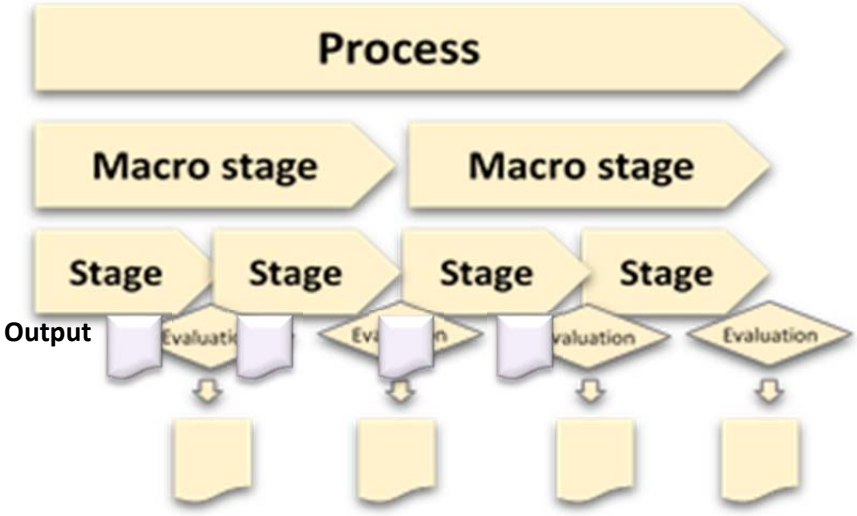

Fig. 7- Graphical representation of reference model [x]

In practical terms, there were comparisons between stages proposed by the authors cited in the theoretical framework (item 2). The basic principle is to compare its overlapping stages through a comparative table. From this framework, suggest a staged structure for the new model, still in generic level to cite the main outputs or deliveries.

IV. ANALYSIS

It has noticed that there is identity between the stages and stages that somehow focused on projects (PMBOK) trend to be more general and therefore summarize and group stages of other models.

Initiation, planning, and execution are terms that aptly sum up the purpose of the other phases, which do not occur in phases monitoring and control, and closure. The design's approach is lacking in a stage with a view to the post-project or production support or monitoring of production, as proposed by Rosenfeld [9]. The same deficiency is noticed in the Cooper model [1], without stages for production support.

Cooper's toolgates approach in its innovation perspective Step 4. Validation and testing, reinforces the formalization of processes to ensure quality given the unprecedented nature of the products and projects that managed by this provision. This also occurs in the proposed [9], in that respect stages of prototyping and validation. However, are aspects that do not stand out at the level of the phases and on a deeper level of the model. Both the proposed by [1] and [9], are guided in the typical processes of the manufacturing industry.

Already the Romano´s GGPIE model brought a more aligned to the construction industry language, and even more specific for buildings. What makes it better suited to the industry process with regard to technical jargon and business peculiarities in the present study?

An important aspect of the management present in the PMBOK, is the concept of delivery, each project stage marked by the delivery of one or more "deliverables".

PMBOK	Cooper, 2001	Romano, 2003	Rozenfeld et al., 2006
Initiation	Stage 1 – Preliminary investigation	1.Planning of the project	Pre-development – informational design
Plan	Stage 2 – Detailed investigation	2.Informational project 3.Conceptual design 4.Preliminary design 5.Legal project	Development – conceptual design Detailed design
Execution	Stage 3 - Development	6.Detailed design – the product and production	
Control and Monitor	Stage 4 – Validation an Testing	7. Civil works support	
Closing	Stage 5 – Full production and market launch	8.Custom utilities support	Post-development – preparation for production and product launch

Fig. 8 - Comparison of the stage of the models studied [Authors]

V. PROPOSED STAGES TO REFERENCE MODEL

Each model has different objectives and stages can complement each other to create a hybrid model. Thus, from the comparative analysis of the models was possible to structure a proposal stage to a "reference model" for developing innovative products to construction. Although generic and embryonic, this model can be the basis for detailed studies that sector organizations can create specific templates for the reality.

The simple division of this complex process has been already an important step in establishing control points to ensure increased design efficiency.

A. 1st Stage: Initiation

It is the initial stage of development of the construction product. It begins with ideas and market information such as research commissioned and / or performed by the directors, observations of competitors, improvement needs, customer feedback, and so on.

As in Stage 1, Stage Gates [1], has become a generic scope, for the results of high level from a non-exhaustive work

The fundamental questions that this stage should answer are:

1. Are product specifications and targets bringing a proposal interesting business for the company?
2. Has the company provided the human and financial resources, to develop the next step?

The new product project proposals revealed from these activities evaluated with attractiveness analysis technique (based on analysis of concepts of value and considering market factors and competitive strategy of the company).

Based on PMI, expect the following outputs for this stage:

- Objectives and justification - research competitors, improvement needs, customer requirements, etc.;
- Preliminary scope and possible solution - assumptions, product characteristics, etc.;
- Declaration of benefits;
- Targets of the product: cost, expected return, release date, final specification of the product, etc.;
- Preliminary risk business;
- Definition of the development team;
- Budget for development;
- Attractiveness analysis (preliminary business case).
- Review preliminary technical feasibility

At the end of this stage also sets up a timeline with key milestones of the project, which were based on the "reference model". It begins thus the application of project management concepts that must accompany all development.

B. 2nd Stage: Conception design

It is to complement the guidelines previously obtained with a detailed definition of the technical characteristics of the product. This activity is performed by a multifunctional team which consists of quality engineers, process, design, marketing, and others led by development coordinator.

Having equivalent to the stage of preliminary engineering studies (architectural draft) mentioned by [7], plus other aspects, this stage is for the analysis and evaluation of all information received for selection and recommendation.

The stage is for the design and representation of provisional technical information detailing the building and its elements. Preparation of rough estimates of cost and time of service.

The fundamental questions that this stage should target are as follows:

1. Are we freezing a viable concept?
2. Have we a viable way to build concept?
3. Have we enough resources for the next stage?

The team should have to worry about forming a plan for prototyping new technologies, identifying the elements and systems to be prototyped. Being able to include the identification of the certifying bodies of the technology, the strategy of manufacturing and assembly of the prototype, the tests to perform and possible patents to develop.

Potential suppliers and strategic partners for the development of new technologies should be identified and where appropriate already involved in the current project.

Thereby have the following deliveries expected for the phase:

- Multifunctional team - civil works, process design, provide back, marketing, etc.;
- Plan prototyping - identification of prototypes, certification bodies, fabrication strategy, assembly, testing and patents;
- Preliminary engineering studies and conceptual projects - draft of architecture and complementary disciplines;
- Preliminary concepts and product structures;
- Make or buy analysis and hiring critical suppliers;
- Identification of suppliers to be developed - strategic partners;
- Update and monitoring targets of the product;
- Product-specific costs;
- Estimation of capital investment – purchase of machinery, training staff, etc.;
- Resources allocation and plan for next phase;
- Evaluation of different concepts for the product;
- Process simulation.

Once defined the technical characteristics are generated concepts and their primary product structures and bill of materials - BOM. These structures, providing a foundation for decisions make or buy and cost forecast, for the latter may use the philosophy of activity based costing.

This whole set of information is the basis for evaluation of alternative concepts for the new product, which feeds back the requirements of this stage, generating a series of scenarios that will be targeted simulations.

C. 3rd Stage: Development and homologation

Product design and process: In this stage is realized the detailed product by the same multifunctional team plus now in specific areas experts. Similar product information were retrieved and used by the team.

Following the line of the stage of detailed design [9] made, were the necessary tests, support material of creation and provided documentation and approval of the product.

The three cycles: detailing cycle (create and refine systems and components - output: projects and prototypes), acquisition cycle (development of suppliers) and optimization cycle (assessing the systems and components and to set up and document the process and product).

As in previous stages, this responds to the fundamental questions:

1. Are we committed that the project will meet the requirements?
2. Is the level of risk acceptable to make the changes in the organization and make the investments?
   - Deliveries suggested for the stage:
   - Engineering and architectural design (basic and executive);
   - 3D BIM modeling;
   - Structure of final product;
   - Specification and purchase of new machinery / equipment / tools;
   - Training plan;
   - Definition of agreements with suppliers;
   - Up to date management system;
   - Final budget product.

In parallel, there were constructions of prototypes that aimed to get different types of design verification. By organizational proposal we grouped the deliveries of the prototyping process in product homolgation and process homologation.

Homologate product: Used assumptions and these rules in regulations (ISO example, QS, NR, etc.), following the product test program, the process plan of the prototype control plan for the prototype, the items to be purchased and external services for its construction.

The following carried out by planning, manufacturing and assemblying of the prototype, which tests and an evaluation of the results performed. Apply here the experimental design techniques, riding up to the final report of the tests.

Based on this report and taking in hand the possible failures raised during the product design FMEA is completed and the product approved. On the homologation, there is compliance with product guidelines through review meetings with the teams involved in its development.

Deliveries listed to homologate the product are:

- Testing laboratories and field tests;
- Test program for the product;
- Prototyping;
- Approval / certification of external bodies.

Homologate process: With the approved prototype part of the definition of an internal schedule of product deployment in the enterprise. They are detailed construction plans, control plans and verify the capability of the processes. At the end of the pilot production, the flaws in the manufacturing process are evaluated and appropriate measures are taken up to eliminate tem.

These failures compared with those provided for in the process FMEA and evaluates the effectiveness of corrective actions derived from this analysis, generating new risk indices. At the end of this effort, the process approved in a meeting with the entire team.

D. 4rd Stage: Launch

The objective of this stage is to place the product on the market, together with the result of the previous stage, aiming at the acceptance of potential customers.

Reference [9] verification of the financial feasibility study of the premises is also a stage of goal. The suggestion deliveries to the stage are:

- Installation / deployment of machines, tools and new equipment;
- Construction and adaptation of manufacturing processes;
- Training and update documents;
- Marketing and sales campaigns;
- Review of operating costs;
- Pricing of new products;
- Correction of errors detected in the approval;
- New product performance monitoring.

E. 5th Stage: Closing

In this last stage is suggested deliver:

- Verification of compliance with the targets (goals) of the project;
- Lessons learned archiving.

VI. CONCLUSION

The proposed “reference model” for developing innovative products for the housing construction sector described in this article brings an approach that blends typical theories for the manufacturing industry (product development, innovation management) with generic models (PMI) and models [7] specifically for the construction.

Which brings certain unknown, incipient and fragile issues to the proposal. It should consider it as a preliminary proposal, which lacks depth and development.

The building for housing construction has its own dynamic and yet so refined approach, with regard to the

management of innovation and product development, as the manufacturing industry, will certainly benefit from the studies that concern the subject of this article. The hope that this study will serve as a basis for future detailed studies and that sector organizations can create specific templates for their reality.

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