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Challenges in Implementing Innovative Building Technologies: Housing Case Studies in South Africa

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Abstract

South Africa has come a long way in addressing the housing backlog for the poor and has even taken further steps by providing a regulatory environment for energy efficient houses. The benefits of including energy efficiency are increasingly becoming realized, not only due to reduction in pollution but due to the additional electricity crisis affecting most South Africans. Many challenges, however, lie ahead with finding a balance between eradicating informal settlements and providing energy efficiency measures, taking into account the escalating cost of building materials. The South African regulatory environment provides for the implementation of innovative building technologies (IBT). However, the uptake of these IBTs to assist in fast delivery of houses and social infrastructure is very slow. The aim of this paper is to report on an investigation carried out on a few case studies where IBTs have been used in housing developments, by collating the data from the projects, analysing the challenges and making recommendations. The major challenge identified in the implementation of the IBTs is the construction cost. Cost analysis and comparisons are made in the paper, and it is apparent from the results that the construction costs of IBTs compare favourably with convectional construction. However, for single story units, the cost for implementing IBTs are not significantly reduced. On availability of more data, it is recommended that a more detailed life cycle cost be performed. In addition, a Housing Innovation Maturity Model is proposed in order to unify the understanding and interpretation of "*innovation*" in housing.

Keywords: Innovative Building Technology, Housing Innovation Maturity Model, Life Cycle Cost

1. INTRODUCTION

South Africa is a country with significant socio-economic development. However, the majority of South Africans have limited or non-existent access to basic infrastructure, services, education, primary health care, housing and socio-economic opportunities. At present, the urban housing backlog exceeds 2.4 million houses (SA Government, 2019), with many families living in squatter housing. Over the last twenty years, there have been significant housing innovations in South Africa. Notable examples include the introduction of standardised panel walling systems, light-weight steel and modular foundation technologies. All these systems have been approved by the certification body Agrèment SA, and are commonly referred to as “Innovative Building Technologies (IBT)”. The use of the word “innovation” has been interpreted as any building technology which is developed, without the use of South African National Standards. These innovations have basically changed what houses are made of, how the houses are constructed, how they perform, their cost, durability and how they are perceived by housing beneficiaries.

If the current rate of housing delivery by South African government is about 180,000 per year, the eradication of the housing backlog will entail delivery of an estimated four million houses in a period of more than 30 years. The government, through the National Department of Human Settlements, has prioritised the delivery of homes and has developed a number of programmes aimed at provision of sustainable human settlements. These include the Urban Regeneration Programme aimed at the eradication of backyard informal settlements, and the fast tracking of housing delivery through the use of IBTs. The intent of government is not only on quantity but improving the general quality of life of all its residents by providing sustainable quality homes. Thus, innovation in housing has important economic ramifications for the country. However, there are challenges in implementing the government strategy on IBT and these are related to the following issues:

- Innovation, like in any other industry, requires high initial capital outlay. This initial cost would inevitably increase the production cost of the product, although the cost will subsequently reduce as sales increase.
- There is still a misunderstanding of cost, i.e. cost of actual house construction compared to the Life Cycle Costing (LCC). LCC would include the costs associated with the initial design, production costs, actual house construction cost, maintenance or operational costs and decommissioning costs. However, although a house is the largest expenditure in most household budgets and is usually the most valuable asset a

family owns, most end-users (i.e. House beneficiaries and developers) are not interested in LCC but actual cost of construction. This is in contrast to the fact that most houses, including social houses, are built with a life expectancy of 50 years or more. The components which are used in house construction have much shorter life spans, with, for example, roofs requiring replacement within 15 years. This means that during the life of a typical new house, much of sub-components may need to be replaced two or three times before the end of the design life. In addition, the housing beneficiary may also want to perform major alterations, depending on the dynamics of the family. Thus maintenance and running costs add a further dimension which need to be taken into account in costs analysis, thus justifying LCC.

- Other general benefits are not well understood by both the developers and the beneficiaries. For instance, the South African Government has committed itself to achieve reductions in green-house gas emissions. This is in line with their signing the Kyoto Protocol according to which then Department of Minerals and Energy had set targets of energy usage reductions. In addition, South Africa has been experiencing an electricity shortage crisis resulting in unprecedented levels of national load shedding, affecting business, industry and households. Although the low income sector is currently not the main consumer of electricity, it presents a significant source of future demand growth as income levels rise. Other benefits also include the general improvement in health and productivity, possibilities of creating jobs both in the manufacturing plant and on-site, contributing to mitigation of climate change by reducing carbon dioxide (CO_2) greenhouse gas emissions (Conradie, 2014), and ensuring that sustainability is achieved in housing delivery.

If the above benefits are realised, the result will be a fast delivery of quality houses in South Africa. The aim of this paper is to report on an investigation carried out on a few case studies where IBTs have been used in housing developments, by collating the data from the projects, analysing the challenges and making recommendations. The major challenge identified in the implementation of the IBTs is the cost. Cost analysis and comparisons are made in the paper, and it is apparent from the results that the “construction cost” of IBTs compare favourably with convectional “Brick and Mortar” construction for multi-family residential units. However, to have a common understanding and consistent approach to housing innovation, a Housing Innovation Maturity Model proposal is presented in the paper, using successful concepts which have been adopted in information technology.

2. LITERATURE REVIEW

The use of the words “Innovative Building Technologies” is sometimes interchanged with the words “Alternative Building Technologies”. The intent is however the same, i.e. the use of “non-conventional” building technologies where South African National Standards are not available to assess the performance of these products against the performance requirements of the building regulations. Internationally, the concept of building performance, which implicitly promotes innovation, is used. It is recognised that houses impact on health, safety and welfare of beneficiaries, and the CIB (2003) defines performance-based building as:

> “Performance-based building considers the performance requirement throughout the design life of the building and its components, in terms that both the owner and the users of the building understand, and which can be objectively verified to ascertain that requirements have been met. The requirements are concerned with what a building or building component is required to do and not with prescribing how it is to be constructed”.

In the CIB definition, it is clear that the whole life cycle is considered and the end-user performance requirements are taken into account. The “**how**” part of construction is not prescribed, which then promotes the use of innovation in construction. Throughout the world there are many other definitions of high performance buildings. The NIBS (2008) has the following definition for high performance buildings:

> “High performance buildings, which address human, environmental, economic and total societal impact, are the result of the application of the highest level design, construction and maintenance principles – a paradigm change for the built environment”.

The South African regulations (NBR, 1997) are based on a similar performance-based approach. However, meeting the functional requirements of the building regulations can be complied by meeting the “Deemed-to-comply” standards, “Rational assessment” by a competent person or by meeting the “performance requirements” of Agrèment SA (2010). It is on the basis of meeting Agrèment requirements that the products are called “Innovative Building Technologies”. However, to have a consistent approach to innovation, which does not necessarily exclude the use of conventional building materials in an innovative way, there is a need to review and define what is referred to as IBT, and this approach has to be based on the concept of building performance.

The nature of innovation and the benefits arising out of the use of IBTs in the complex government housing production value chain poses a challenge in the roll-out and mass scale customisation of houses in South Africa. The one main bottom-line attribute being used for the adoption of IBTs is the “construction cost”, and if this cost is within the subsidy quantum, then other issues such as social acceptability are then considered. Government is currently providing a subsidy quantum to poor households an amount of R110,000, excluding variations (SA Government, 2019). Although construction costs often determine both the rate and degree of substitution of conventional “brick and mortar” construction by IBTs, the additional improvements and benefits associated with these technologies need to be taken into account (Burger, 2004).

New technologies, in construction or any other industry, are often introduced at a premium cost to cover the initial capital costs of development, certification costs etc. However, end-users are hesitant to pay for the higher price for a new innovative product, because the value of the increased functionality is difficult to assess, particularly where the innovation is embedded in the structural integrity of the walling, roofing system or foundation system. These technological improvements are mostly realised by the home builders and the professional team as they immediately get an improvement in productivity, reduction in waste etc., all of which are invisible to the housing beneficiary. Unless the innovation is part of finishes of the product, the housing beneficiary thus has uncertainties about the use of new technologies in their houses.

This study therefore attempts to respond to some of the following research questions, which have thus far not been critically and analytically answered, and are relevant to the uptake of IBTs in the housing industry:

- How should “innovation” in construction be described?
- Do IBTs offer more cost effective construction products compared to traditional, conventional “brick and mortar” construction, during construction?
- How durable and what is the design life of houses constructed using IBTs?
- Do IBTs reduce operating costs (Life Cycle Cost) over the life of the buildings compared to conventional construction? Do housing beneficiaries have an interest in reducing operating costs in the long term or are rather interested in short-term cost savings? Considering the current, and possibly future energy crisis, do housing beneficiaries appreciate the present value of energy savings over the design life of the houses?
- Are the IBTs easy to maintain, re-model and will the products be locally available during the design life of the house?

- Does the National Home Builders Registration Council (NHBRC) provide a warranty for a house constructed using IBTs? If so, in the event of structural defects and unavailability of the home builder, will the NHBRC be in a position to fix the house and or provide the Housing Consumer with the same product? If the house is replaced with conventional materials, what happens to the loss of "potential" long term savings?
- Considering the boom-bust cycles in the construction industry, is there a willingness by construction companies to invest in long-term innovation and the further training of their employees?
- The low-income house construction is now being dominated by small and medium size home builders, is there adequate capacity and resources resources to invest in innovation in house construction?

3. RESEARCH METHODOLOGY

This research was based on case studies of real projects being implemented on the ground, and collating data from certificate holders of IBT. Due to the confidentiality nature of the projects, the names of the projects will be excluded in this paper. A certificate holder is a company whose product has been certified for "fitness-of-purpose" by Agrèment South Africa. Agrèment certification of a building system ensures that the product meets the performance requirements of the building regulations (NBR, 1997). The Agrèment performance requirements for walling systems include:

- Structural Safety and fire resistance. Providing adequate resistance to static and dynamic actions, intentional and unintentional abuse and accidental actions;
- Structural Serviceability. Ensuring there is adequate resistance to loss of function, damage and avoidance of user discomfort;
- Structural Durability. The ability of the product to perform at the required level for the design life, typically thirty to fifty years;
- Energy Efficiency. The extent to which the building envelope optimises the amount of energy required to achieve a required level of indoor climate control;
- Condensation. Avoiding health problems caused by excessive moisture in the air, resulting in formation and growth of algae. This is commonly observed in southern coastal condensation problematic areas; and

- Acoustics performance between indoor rooms and between houses.

The case studies investigated were based on single and double storey houses, and the results were extrapolated to have an understanding of multi-storey residential units. The information collated included the type of building technology (i.e. the product materials used, availability of manufacturing plant locally), Agrèment certification and construction cost per square metre of walling system. The research also utilized secondary data sources involving desktop surveys, literature surveys and Internet searches together with one-on-one interviews with innovators.

The delimitation of the research is summarised as:

- Logistics was not considered in the analysis. It is noted that the dynamics and construction costs may differ if the product is to be constructed in a province far from where the manufacturing plant is located;
- Due to the limited data available, it is recognised that the LCC is the better approach to compare the cost, but for the purpose of this research, which is supported by the requirement needs of the end-user, only construction costs are considered;
- Only the construction costs of the walling system per square metre are considered. This cost included production, material and implementation (labour) costs only. The indirect cost implication of the weight of the walling system on the subsequent structural bearing elements and the foundation is analysed.
- The implications of the energy usage is not considered. This will be relevant if LCC analysis is being conducted.

The key questions highlighted in Section 3 were critically analysed and used to provide responses as to why IBTs are not being implemented at a faster rate.

4. RESEARCH FINDINGS

In this section, the research findings based on the construction cost of the IBTs are presented. The cost comparison is based on projects which have implemented IBTs single and double storey houses. The projects utilised either blocks or panels as the building system. Examples of IBT blocks are shown in Figure 1 (a), (b) and (c). The product descriptions and the price comparison *per square metre* for an external wall are presented in Table 1. The costs shown in the table include labour, materials, plaster and or rhinolite. The costs exclude the logistics costs which may be significant depending on geographic location of the project relative to the production plant, and were obtained from the innovative product suppliers.

(a): Polystyrene (b): Lightweight concrete (c): Wood chips & cement

Figure 1: Typical Blocks (Samples obtained from IBT Suppliers)

Table 1: Construction cost comparison as provided by IBT Suppliers

Product Description	**Cost (R/m^2)**					**Weight (kN/m^2)**
	Labour (R/m^2)	**Materials (R/m^2)**	**Plaster and or rhinolite**	**Total (R/m^2)**	**Cost Ratio**	
Light-Weight Concrete Masonry 150 mm thick *blocks* laid on thin bed mortar	R30	R302	R85	R417	0.74	0.63
Lightweight interlocking *panels* comprising a 75 mm polystyrene beaded concrete core encapsulated by cement fibre board	R22	R455	R35	R512	0.91	0.48
200 mm *blocks* using biodegradable wood chips combined with lime cement	R75	R400	R75	R550	0.98	1.57
Light-Weight Concrete Masonry 150 mm thick wall *panels* laid on thin bed mortar	R15	R483	R75	R573	1.02	0.63
150 mm special aerated mortar with no stone	R30	R222	R75	R327	0.58	2.65
220 mm standard conventional brick	**R92**	**R206**	**R265**	**R563**	**1.0**	**4.10**

From Table 1, it is apparent that the cost of constructing a square metre of wall using IBT blocks compare favourably to the 220 mm standard conventional brickwork, with one case showing about 42% cost saving. This is shown in the table as cost ratio (= total cost of construction using IBT divided by the equivalent cost using conventional standard brickwork). However, the average cost saving for IBT panels is not significant, with even one panel system costing more than the conventional brickwork.

In understanding the cost savings, it should also be noted that there are further cost savings/increases which have not been factored in the table. These costs are attributable to:

- Possible reduction of rubble removal;
- Reduced material handling time and associated cost;
- Overall time savings on site (Preliminary and General Costs); and
- Overtime costs, overhead cost related to more people.

One of the major reasons why the IBTs cost are still high is due to the high capital outlay as mentioned earlier. The special aerated mortar technology has been in existence for more than twenty years and this is reflected in the reduced production and implementation cost, where the cost of the final product is about 58% of the brickwork cost, as shown in Table 1.

The most important impact on cost reduction in using IBT is related to the construction of multi-storey residential units. This is reflected in Table 1 by comparing unit weight of the products per square metre, as shown in the last column of the table. The weight per square metre of a 220 mm brickwork is about 4.10 kN/m^2, assuming a density of 1900 kg/m^3. All the IBTs show a significant reduced weight per square metre compared to brickwork. The weight of "*light weight concrete*" to brickwork is about 15% and for "*interlocked polystyrene beaded panels*" is about 12%. This is a huge reduction in weight. From an engineering point of view, this will result in reduced sizes of supporting structural elements such as beams and columns, and subsequent reduced foundation costs. However, these costs can only be realised in multi-storey buildings, at least more than 4-stories. For these multi-storey buildings, foundation cost saving can be in the order of 15-20%.

Another result from the analysis presented in Table 1 is the high cost of panels compared to the blocks. This is due to high set-up costs in the manufacturing plant. However, the labour costs on site are lower. Of interest to note is that panels have a highly reduced time of construction, which can be more than ten times quicker than brickwork construction. If time is of essence, the cost of construction using panels will be much more favourable than blocks, later alone brickwork.

5. DISCUSSION AND RECOMMENDATIONS

5.1. Redefining Innovation in Housing

For industry consistency in defining innovation in housing, in this section a proposal is presented on a new approach developed along the similar lines of the Capability Maturity Model (Paulk et.al. 1994). Innovation in housing usually occurs when a new technology or process replaces another conventional product in the performance of a particular set of processes or functions for end-user or housing beneficiary. New technologies and processes can be considered as successful substitutes for conventional building products if they offer value to the beneficiary by providing the following:

- Functionality i.e., enhancing or adding function such as appearance, or energy efficiency;
- Productivity i.e., reducing the costs of inputs such as labour, materials equipment, as they relate to the final product (the house or a building component); and/or
- Systemic efficiency, i.e. reducing the cycle time of construction.

Based on the literature review, the National Building Regulations, Agrèment performance requirements and the definitions of high performance buildings, a framework for a "Housing Innovation Maturity (HIM)" model is presented. The model is similar to the Capability Maturity Model developed by the Software Engineering Institute (Paulk, et al, 1994; Saieidian and Kuzara, 1995), and provides for incremental product and process improvement to encourage innovation in house construction. At present there are no methodological mechanisms to analyse and improve processes in house construction.

According to Paulk et al (1994):

> "A maturity level is a well-defined evolutionary plateau toward a mature process. Each maturity level provides a layer in the foundation for continuous process improvement. Each level comprises a set of process goals that, when satisfied, stabilize an important component in the construction process. Achieving each level of the maturity framework establishes a different component in the construction process, resulting in an increase in the process capability of the organization."

The proposed Housing Innovation Maturity model is presented in Figure 2. The characteristics of each level of the maturity model are described briefly below.

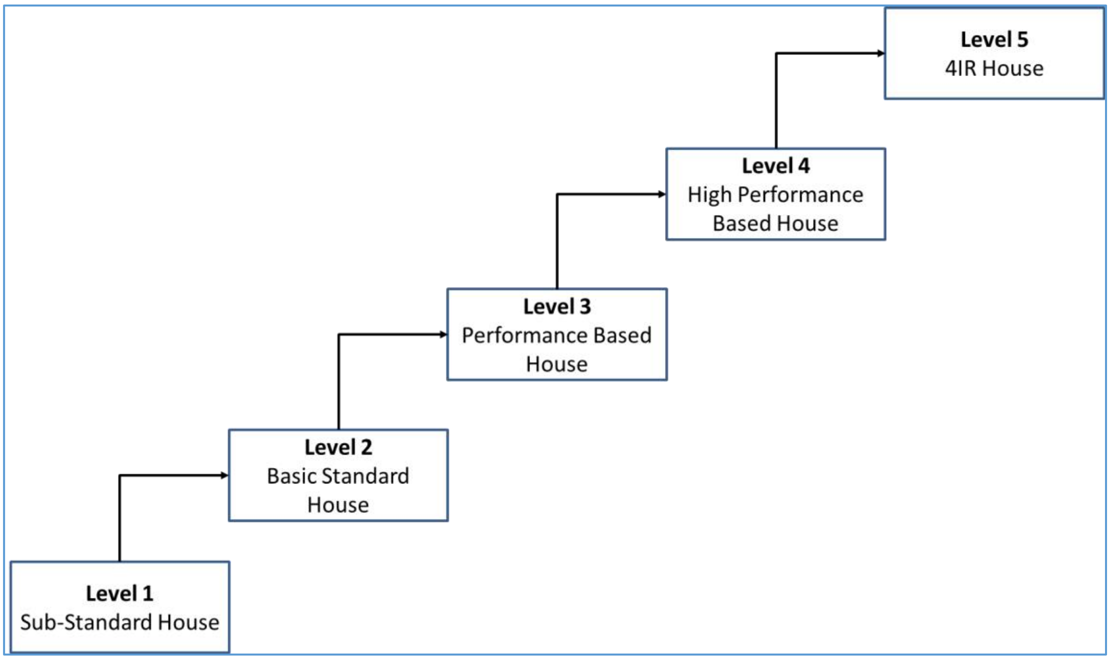

Figure 2: Housing Innovation Maturity ("HIM") Model

Level 1: Sub-Standard House

At this level, house construction is haphazard, with very little adherence to specifications; high cost of construction, poor quality product, aesthetically unattractive and characterless. The location of the house maybe associated with unsafe environment, inadequate social infrastructure to support schools, jobs, transport etc. The functional design is inadequate and lacks adequate space for bathrooms, kitchen, storage space and poor sound insulation. Over the design life, energy consumption is inefficient and the houses have high maintenance costs. The LCC for these houses are very high.

Level 2: Basic Standard House

As basic design and quality management control is applied, housing products become consistent with improved quality due to house constructors becoming more and more experienced, and hence developing certain "recipes" about how things are done. The minimum standards stipulated in the National Building Regulations (NBR, 1997) and the National Housing Norms and Standards (SA Government, 2019) are just met. House constructors can also make realistic delivery and financial commitments, based on the results of previous projects. As such, house constructors can track quality and functionality as well as time and costs.

Level 3: Performance-Based House

At level 3, both management and engineering activities are documented, standardized and integrated into the business of the house constructor. Houses constructed at this level exceed the expectations of the beneficiaries. The construction costs are affordable, there is social acceptability of the product and there is construction process improvement with reduced waste. The house can easily be remodelled and upgradable at minimum costs. Quality and functionality of all projects are well tracked. In fact most of the house constructors who build these houses will have quality management systems in place.

Level 4: High-Performance House (Innovation)

Houses at this level, exceed the expectations of the end-user and are associated with low LCC, flexibility of space in homes, very low environmental impact (e.g. waste, carbon dioxide emissions), comfort factors are high (i.e. air quality, sound insulation, natural light), renewable energy products using solar and wind power are utilised and water recycling is a norm.

Level 5: 4IR House

At the highest level (level 5), the *entire* house supply chain is focused on continuous process improvement. The houses at this level are based on Building Information Modelling (BIM), Artificial Intelligence (AI) to control the houses and the building elements/components are premanufactured in the factory.

The above proposed Housing Innovation Maturity (HIM) Model is still conceptual and not yet quantified. The next level of the research is to determine objective and measurable performance criteria which would enable a house to be positioned at the relevant HIM level. Only houses falling at Levels 4 and 5 would qualify to be referred to as “innovative”.

5.2. Cost Analysis Discussion

In Section 4, an analysis of cost of construction using IBTs and conventional brickwork was made. The cost savings were not significant. However, when all factors are taken into account, there is possible huge cost savings using IBTs. Interviews with some of the innovators indicated the following as inhibitors to innovation:

- The perceived high cost of construction is limiting the uptake of the IBTs;

- Challenges in getting financial support in setting-up or upgrading the manufacturing plants;
- Unsustainable streamline of projects, which leaves the manufacturing plant idle for months/years. When the plant is restarted, the start-up costs are high, resulting in higher cost of the final product (house). Such disruptions are very rare in the conventional brick manufacturing process, which keeps the costs of conventional building materials relatively stable.
- The innovations still need acceptability by local market to be successful, despite some of the innovators having managed to penetrate markets outside South Africa;
- Architects and engineers are not innovative and a number of them are ignorant about innovations in construction.
- The procurement phase is currently a major inhibitor to innovation in housing. Necessary preconditions to overcome this include an innovative brief, a preferential contract that demand innovation, and a competition between only innovators.

On the other hand, interactions and interviews with end-users and beneficiaries, including developers, points to one thing – the construction costs of IBTs must be lower than conventional brickwork. They are not interested in Life Cycle Cost (LCC), or other beneficial considerations such as energy efficiency and thermal performance. The disparity between the expectations of the end-users and the innovators must therefore be closed. To partly address this, the following recommendations are proposed:

- Government must adopt a unified approach to innovation. The HIM model proposed in this paper allows for incremental growth and attainment of high performance houses. This model does not exclude the use of conventional building materials and products that are used in a more innovative approach but will be expected to comply with minimum requirements of Level 4;
- The concept of using LCC should be embedded in government policy on innovation, and in the allocation of the subsidy quantum;
- All IBTs envisaged for human settlements projects should undergo rigorous approval processes, starting from the product conceptualisation to acceptance by the end user (Developer; beneficiary etc.);
- Thorough feasibility studies should be conducted before any IBT can be used in a specific area/province; and

- Beneficiaries and other end-users must be well educated and informed about the benefits of IBTs and the quality of the products built using IBTs. This requires a partnership between the key stakeholders in the housing value chain, i.e. Agrèment SA, NHBRC and the Government.

6. CONCLUSIONS

The housing backlog in South Africa is still unacceptably high compared to other countries. Although the regulatory environment promotes the use of IBTs in building, very few innovators have manged to take advantage of this. In this paper, a proposed Housing Innovation Maturity model was presented. This model provides a gradual improvement/quality in the product and process. Houses built at Level 4 are the houses exceeding performance expectation and fulfil the requirements of housing innovation.

An analysis of cost construction using IBTs has also been presented in the paper, where it has been demonstrated that the costs are comparable to the brickwork costs. However, if all the LCC are taken into account, the use of IBTs promise to show considerable cost savings. Furthermore, the cost of IBTs are more favourable for multi-storey residential units compared to single/double storey houses. This is due to the reduced weight of the IBTs, which has a favourable effect on the supporting structures. Reduced foundation costs can be estimated to be in the order of 15-20%. Further research is thus recommended to provide objective performance criteria for the Housing Maturity Model, and how LCC can be incorporated in the allocation of housing subsidy by government.

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