Product platform considerations on a project that develops sustainable low-cost housing for townships

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Abstract

Construction companies in Denmark are often working with profit margins as little as 1-3% in situations where they deliver high-end buildings to the local market. Even though customers are willing to pay a premium price for high quality, construction companies earn very little on their products. Consequently one Danish company took the decision to produce sustainable low-cost houses and to sell them to developing countries that have township housing programmes. But why would this company believe it could make a profit in the low-cost housing segment abroad, when there is almost no profit in the high-end segment at home? As the research described in this article shows there are three main reasons for their optimism: 1) The successful introduction of a product platform for low-cost houses, 2) a modular approach to the design of low-cost houses, and 3) the application of requirements management as described by INCOSE. 1) to 3) have been studied using action research on a case project.

The case company´s success contributes to people currently living without decent housing by providing insulated, low-cost houses based on the latest technology. The fact that those low-cost houses are solid gives their new owners the possibility to take a loan out on their building which is expected to contribute to more businesses being started up and thereby strengthening the domestic economy. As a consequence of this, additional research is needed in how to further optimise the economy of sustainable low-cost housing based on life cycle considerations. Moreover, it has to be examined how the experience gained can support in maximising the high-end segment in countries like Denmark.

Key words: Low-cost housing, product platform, construction industry, practical implementation, action research

1. Introduction

This section will introduce the trend of population growth and the concept of product platforms which are core to the business opportunity of the research case detailed in this paper.

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1.1 Population growth in developing countries

It is estimated that about 1.6 billion people around the world live in sub-standard housing and over 100 million are homeless. If no serious action is taken the number of slum dwellers is expected to rise from one billion people today to two billion within the next 30 years (Habitat for Humanity, 2013). This leaves many developing countries with a problem that is hard for them to overcome. South Africa is one of the countries that are taking action, as it tries to solve its housing problem by means of a centrally planned housing programme. Through this programme, since 1994 more than 2.3 million housing units have been made available to nearly 11 million people, where in 2010 alone about 219.000 housing units have been made. The goal for the coming years is to create 220.000 housing units a year. Despite such a tremendous number of erected units, the housing backlog has grown from 1.5 million units in 1994 to 2.1 million units today. This means that 12 million South Africans – a quarter of the population – are still in need of a better shelter (Ministry of national housing and social amenities, 2011).

Inspired by the housing programme of the South African government, the case company described in this article examined whether and how it would be possible to contribute to the housing problem of developing nations with its knowledge and technology. After a careful examination of the National Housing code (2009), the decision was taken to develop a low-cost product platform that could co-exist with both the existing, high-end and re-insulation panel product platforms and to make an offer to the South African housing programme.

1.2 Product platform definition and strategy

The product platform concept has widely been discussed in literature, where accordingly a number of definitions have been introduced by e.g. Muffatto and Roveda (2002). Halman et al. (2009, page 151) for example, refer to McGrath's definition of a product platform: "a set of subsystems and interfaces that form a common structure from which a stream of related products can be effectively developed and produced". The authors base their research on this definition, as it incorporates both the physical and economical aspects of a platform concept. An overview of the product platforms that exist in the case company can be seen in Figure 1.

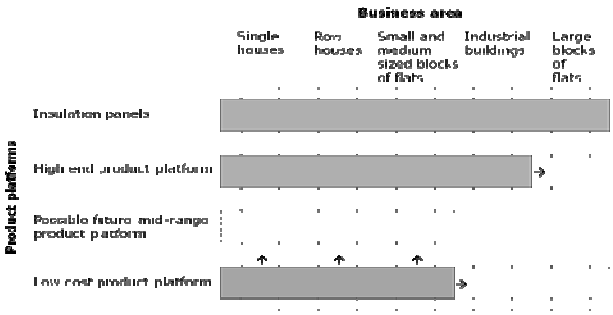


Figure 1: The product platforms that exist in the case company

As illustrated in Figure 1, the insulation panels aim to cover all business segments, while the other two product platforms address only parts of the market, but still keeping the possibility

of expanding open. The reasons for believing in the success of a product platform that did not even exist at the time the offer was made were:

- The product platform approach had been rooted in the organisation and the staff of the case company had been trained in product platform thinking for several years
- The successful implementation of requirements management in the case company
- All the desired European safety and product approvals had already been received
- The technology the case company wanted to use had successfully been tried out in several buildings in Denmark (see Figure 2 for an example)
- The senior staff have a long history of successfully executed building projects

The above listed points indicate that a strong base had indeed been established which made it possible for the case company to continue building upon. At the same time the case company was also aware of the main obstacles that had to be overcome. To begin with, the government subsidy for a 40 m2 stand-alone house only amounts to 55.706 ZAR (= 4.926,87 € using exchange rates from December 25th 2012) (Coetzer, 2010), which is considerably less than what a house based on the high-end product platform costs. Moreover, unskilled labour is to be used, whereas the usual approach of the case company is one of automation and efficiency in combination with a skilled work force. There is also a risk of facing problems using the local building materials with unknown properties and quality. However, the management of the case company had full confidence in being able to produce 40 m2 low-cost houses at a price that did not exceed the government subsidy. Working with unskilled labour and having to use local building material were treated as risks. Therefore, risk mitigation plans were made for those two points as described in the PMBOK (2008).

Figure 2: A building based on the high-end product platform

Studying the situation resulted in the main hypothesis that creating and introducing a platform concept to low-cost markets would support both, developing countries in overcoming their housing problem in an effective manner, and construction companies to improve their performance in the domestic markets. To this end, this article in particular addresses the following aspects:

a) It is possible and beneficial to develop a low-cost product platform that can be used for making low-cost houses
b) It is possible to make several variants of houses based on that low-cost product platform

c) The new knowledge gained by developing and implementing a product platform for low-cost housing will contribute to improved efficiency and reduced prices in the high-end platform

This paper therefore deals with the question on how to successfully introduce a product platform that supports modularity to the low-cost housing segment of the construction industry. To answer this question, after a literature review (Section 2), an explanation of the applied research and design methods (Section 3) and a description of the case (Section 4) will be provided. Section 5 then gives a brief overview on the key observations that have been made when developing the low-cost product platform and building houses. In Section 6 the thereby achieved results have been analysed. A final conclusion is drawn in Section 7, where the most important findings are summarised and recommendations for future research are given.

2. Literature review

Even though the work on the case project was mainly of a practical nature, a lot of knowledge has been drawn from literature, where both academic publications as well as literature from seasoned practitioners have been consulted. Table 1 below gives an overview showing the main references considered for this article and what they cover in the context of this research:

Table 1: Main literature considered in this research

	Ulrich and Tung (1991)	Thuesen and Hvam (2011)	Mortensen et al. (2008)	Simpson et al. (2011)	INCOSE Systems Engineering Handbook (2011)	Huang et al. (2005)	Roy et al. (2003)	This article
Product platform		X	X	X		X	X	
Product platform in construction		X					X	
Product platform in construction – low-cost housing								X
Product variants / family	X		X	X		X	X	X
Modularization of products	X	X	X			X	X	X
Requirements management					X		X	

The concepts of product modularization (Ulrich and Tung, 1991) and product platforms have extensively been discussed in literature. Huang et al. (2005) for example have studied several companies in different industries using product platforms. In addition, Hvam (2011), Mortensen (2008), and Simpson (2011) provide a number of publications on the application

of product platforms, where the approach of using product platforms has mainly been put in the context of consumer electronics, car, aerospace, and software industries. However, at the same time very little theoretical contribution could be found on how to apply product platform principles to the construction industry (Roy et al., 2003). As of today, there are in particular no published attempts to practically implement a product platform which facilitates modularity and product variants for low cost housing in this industry.

3. Research and design methods

The research described in this article makes use of action research (AR) defined by Coughlan and Coghlan (2002) as well as Checkland and Holwell (1998) for creating the needed models and tools. The approach was applied to a case project, where full access to all key people and complete access to all documents relevant to this research, including minutes of meetings in addition to documents containing the future strategy of the case company and its products, existed (Voss et al., 2002 and Yin). In order to cover all parts of the case project's value chain (see Figure 3), including the sub-projects described in Section 4 "Description of case", several interview rounds with key persons from the construction industry and the case project have been conducted.

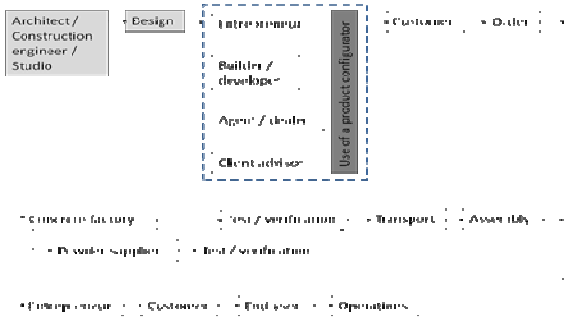


Figure 3: The value chain of the case project

For reasons of comparability and consistency interviews were conducted using a question template from previous research for all participants, resulting in a master document that covered a wide range of different requirements: from functional, non-functional, technical, market and organisational requirements, to requirements towards the project manager and finally to requirements of the stakeholders themselves. This was used to implement requirements management on the case project and was actually (at that time unconsciously) the first step towards a low-cost product platform. During the analysis of the second out of four AR cycles it became clear that requirements management on the case project worked well (Wörösch, 2012), as it significantly contributed to having a clearly defined scope of the case project, its sub-projects, and the different product platforms – the two existing ones as well as the one that needed to be developed.

When linking the requirements of the low-cost product platform to the company and product strategies, modularity of the houses based on this platform could be ensured. In an architectural perspective, a definition of the term modularity that fits well with this research has been described by Ulrich and Tung (1991). The authors refer to "the construction of a building from many instances of standardised components. In manufacturing the term often

refers to the use of interchangeable units to create product variants" (Ulrich and Tung (1991, page 73)). Examples of the hereby achieved modularity will be given in Section 6.

4. Description of case

Despite of operating in construction, the case company is unique within its industry in several aspects. Firstly, it produces sandwich elements and insulation panels from High Performance Concrete (HPC) that are used to build and renovate houses to have greater energy efficiencies. Secondly, the company constantly develops new technologies and products resulting in patents. Therefore, already today, it offers buildings that live up to the European Union's 2020 energy saving requirements, covering the complete value chain (see Figure 3), where responsibility is not pushed down to sub contractors. The uniqueness of this case is reflected in the structure of the case project that consists of four different types of sub-projects, which will in the following section be shortly introduced:

1. Technology development used to develop new insulation and HPC material as well as different mounting systems
2. Product development with the goal to develop new sandwich elements, insulation panels, and jointing in different dimensions
3. Development of low-cost, high-end, and insulation panel product platforms
4. New building projects (such as the erection of 40 m2 prototype buildings in Delft, Cape Town, South Africa)

1) to 4) deliver and share human and financial resources as well as processes, which simultaneously results in constraints, where 4) depends on the success of 1), 2), and 3).

5. Observations

When developing the low-cost product platform and building the houses, a series of key observations, that are further grouped and described in detail, has been made.

5.1 The low-cost product platform

- On a conceptual level there were many elements that could be re-used from the high-end product platform; e.g. the basic methodology when describing a platform structure and how to phrase requirements. Previously, there was not much reuse between the two other product platforms
- A solution for the design of the HPC elements has been found that required only few tools for assembly. Buildings can even be assembled without using power tools, since stable electricity sometimes is absent on some building sites. An assembly where only few tools are needed also makes teaching of staff easier and leaves less room for error
- Even though unskilled labour and no high technology production are being used, many houses can be produced during a year. This is due to the production of only few different kinds of elements, which are strongly standardised and can be used across the product variants. Using unskilled labour and no high technology also changes the

description of requirements from being database and specification focused to being expressed in photographs and drawings wherever possible

- Once the HPC elements with their pre-mounted windows and doors are ready for assembly, a Type 1 house (see Figure 4) can be assembled within one working day. This fast assembly also contributes to the possibility of building many Type 1 houses in the course of a year and at the same time it prevents theft or unauthorised occupation, as the houses are closed in the evenings
- The local building materials (about 99%) can be used without any quality problems. The only exception to the use of local material is a special concrete binder that is sent from Denmark. In result, the use of local material creates domestic jobs and reduces CO_2 emission that otherwise would have been caused by transportation from abroad
- The scalability of the low-cost platform is high. This means that when, for example, the production has to be doubled or halved it can be done relatively fast at low cost
- The price of a 40m2 stand-alone house (basic model) based on the low-cost product platform does not exceed 55.706 ZAR. This means that the case company can continue building the low-cost houses without generating losses and the housing programme can accordingly achieve its yearly targets

5.2 Modularity

Modularity has been achieved in several facets. For the customers this means that they can upgrade their houses with extra rooms, a veranda or a bigger kitchen at a low price at the time of ordering. Upgrading is possible in all situations where the housing programme facilitates a contribution of the end user. Besides, modularity can also be achieved by using additional means; e.g. by giving the customer or resident the possibility to enhance the house by adding a rainwater collector that gathers rain water from the roof facilitating cultivating a garden for the house. Another benefit of achieving modularity is that it also is possible to improve the houses with solar panels for generating power for hot water, lighting, charging computers, cell phones, and other consumption. Also, here the housing programme has to allow this kind of improvement.

5.3 Knowledge transferred back to the high-end product platform

- The high degree of standardisation contributes to a high throughput in production. The high-end product platform needs to be examined for possibilities to increase standardisation and to get away from the current high level of uneconomic flexibility
- The use of prototype elements, drawings, and verbal explanations instead of lengthy documents has been very successful. This method of controlling the scope for a product platform could also be introduced to the other product platforms, which, however, would mean to go away from a systems engineering best practice approach as described in the INCOSE Systems Engineering Handbook (2011). It has to be examined to what degree this could be done while still maintaining sufficient documentation and living up to described processes
- The rather effective way of teaching new local staff and the team, created a very inspiring feeling during the teaching sessions and should further be applied to staff working on the other platforms as well. Flying the key personnel of the case project to

South Africa in order to participate in building low-cost houses could be one way of transferring the new knowledge and a positive team spirit back to Denmark

- This new knowledge gained by developing and implementing a product platform for low-cost housing will contribute to improved efficiency and reduced prices in the high-end platform, as many decisions that had been taken on the high-end product platform have been seriously challenged. An example is the very high focus on the factor cost for the low-cost platform that has never been enforced to such a degree on the high-end product platform

Having summarised the main observations, in the next section the results of implementing a low-cost product platform into the case project are discussed.

6. Discussion of results

By the end of action research cycle two, the research conducted in the case project had given a series of theoretical and practical results. The main results have been listed below.

6.1 High level results of making a low-cost product platform

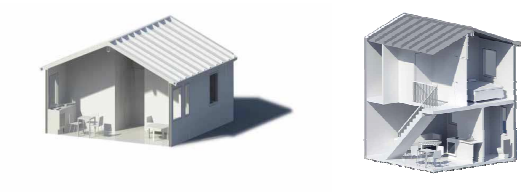
As anticipated, from a technical and process point of view, it was indeed possible to develop the low-cost product platform and build houses based on it within the estimated time. Due to the active use of requirements management, the scope of the new product platform was clearly defined, while market segment-wise there was no overlapping with the existing product platforms. From a societal point of view, building low-cost houses at high speed helps ensuring that more people have decent housing and thereby producing an increase in quality of life. Furthermore, a relatively fast, cheap and secure assembly, contributes to reducing the large backlog in the low cost housing area. Thus, as demonstrated by the case company, local job opportunities together with relevant education and training are created. This increases the standard of living and improves future chances for personal development. Houses made from HPC are solid and have according to Danish Standard (2001) a minimum life expectancy of 50 years, while in practice concrete companies often calculate with 70 or more years. This is much higher than what most housing objects currently have. This longer life expectancy makes it possible for a house owner to take a loan out on their house, which in turn can contribute to starting up financial businesses and thereby to strengthening the domestic economy.

6.2 Results related to the main hypothesis

6.2.1 The low-cost product platform and the use of modularity

The low-cost product platform currently supports three types of houses, of which two will be explained further in this paper. All houses based on this platform can only be ordered in a light or in a dark version. Each of them comes with two different surface structures, a smooth and a brick-like one. Altogether the customer is offered a limited number of choices, as all concrete elements, windows, doors, materials, sizes, and interfaces are completely standardised. This radical standardisation is the main difference from the high-end product

platform, for which more variety and a higher degree of customisation is available. Figures 4 (Type 1) and 5 (Type 2) show two types of 40m2 houses, that are based on this new low-cost product platform.



Figures 4 and 5: Two different 40 m2 buildings made from HPC – Type 1 and Type 2

Modularity on the low-cost product platform exists on two levels. On the element level, the HPC elements are prefabricated and scaled to approximately 1,2m in width. Figure 6 illustrates the conceptual assembly of a Type 1 house based on those elements. On the building level, several variants of the Type 1 and Type 2 house exist. The Type 1 house can be produced as basic 40 m2 model or as one of four variants, where modules like a veranda or extra rooms can be added. Depending on what modules are added, the size of a Type 1 building can go up to 56 m2, as depicted in Figure 7.

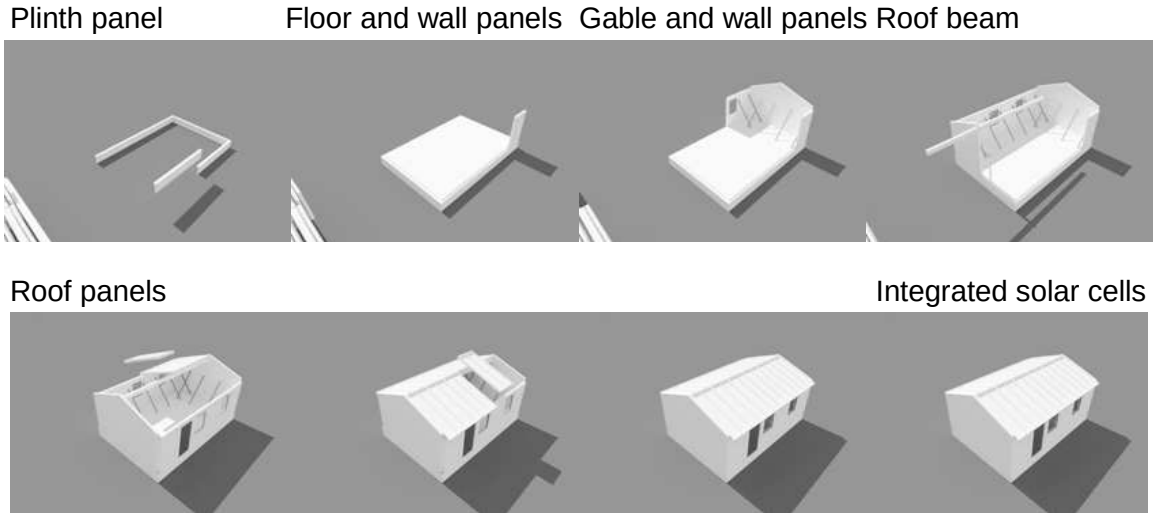
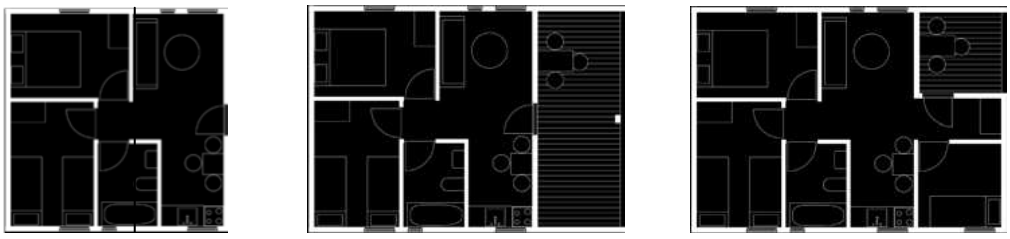
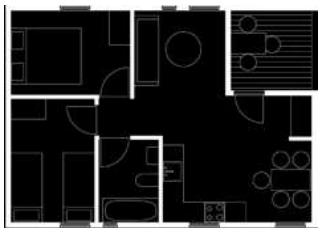
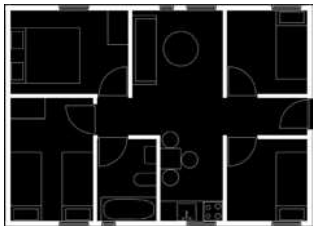


Figure 6: A Type 1 house assembled from prefabricated HPC elements



40 m2 basic model + 2 modules veranda 40 m2 + 2 modules veranda, extra room 50 m2





+ 2 modules veranda, larger kitchen 50 m2 + 2 modules 2 extra rooms 56 m2

Figure 7: The five variants of the Type 1 house (Figures 6 and 7 have been taken from a sales offer to the South African Housing Programme)

6.2.2 Knowledge transferred back to the high-end platform

A lot of knowledge has been gained when making the low-cost product platform. Some of the key learning points were:

- Even though there were only a few choices the customers could make, when ordering a house, the offered variety appeared to be suitable for this market segment. This will result in a review of the high-end product platform, to ensure that customers are not offered an infinite degree of variety and that the financial contribution per variant is high enough. Non-profitable variants should be removed from the platform
- Starting the low-cost product platform from scratch, rather than trying to take the high-end product platform as a starting point for scraping off layers, turned out to be the right decision. In hindsight, it is our belief, that it would not have been possible within the given timeframe to achieve the cost goal per unit using this approach
- This was the third product platform the case company developed. Since the high-end and insulation panel product platforms were well defined and linked to the company strategy, developing a third product platform took considerably less time. The experienced staff and the right software tool support, such as the use of product configuration systems (Bonev and Hvam, 2012), contributed strongly to the fast development of this platform

7. Conclusion

In this article it has been described how a low-cost product platform has successfully been developed and implemented in the low-cost housing segment within the construction industry. The houses based on this platform are built up in a modular approach, where modularity has been achieved both on element and on building level, resulting in buildings which can be delivered in several types and variants. The main difference compared to a coexisting high-end product platform is the high degree of standardisation and the limited number of commercial variants, which has been adapted according to the requirements of this market segment. Besides, the application of requirements management as described by INCOSE has resulted in working descriptions containing much less text, but with more pictures and drawings instead. This positive attempt to use product platforms in the low-cost segment of the construction industry confirmed the main hypothesis of this research (Section 1) and shows that the product platform approach is a valid strategy for meeting the low cost

housing demand of developing countries. Hopefully the described case inspires other construction companies to introduce a product platform concept for their products.

Despite the promising results, further research is needed in the following vicinities: Since there is a high need for decent housing, smart solutions have to be found for quickly producing a high amount of houses, which are cheap and long lasting. If companies find a way of addressing this issue in a profitable manner, they are more likely to participate in this enormous task. At the same time it is important that the applied housing solutions are sustainable, as according to EU, 2010, residential and commercial buildings are responsible for about 40% of the total energy consumption and 36% of the total CO_2 emission in the European Union. Other parts of the world will soon face similar situations to those described above, if there is no sufficient focus on sustainability when producing such a vast amount of buildings. To this end, further research is needed in how product platforms, by means of effective development and production, can further contribute to the low-cost housing segment and to the construction industry in general. Finally, it is necessary to further optimise the economy of sustainable low-cost housing based on life cycle considerations. Once this has been done, it has to be examined how the gained experience can support in maximising the high-end segment in countries like Denmark.

References

Bonev, Martin & Hvam, Lars (2012), Knowledge-based geometric modeling in construction. In: Proceedings of NordDesign 2012

Checkland, Peter and Holwell, Sue (1998), Action Research: Its Nature and Validity, Systematic Practice and Action Research, Vol. 11, No. 1

Coetzer, Pierre (2010), Case study: Molady – an affordable housing solution for the poor, UNDP, Sector Housing and Construction Enterprise Class, MSME

Coughlan, Paul and Coghlan, David (2002), Action research for operations management, University of Dublin, Trinity College, Dublin, Ireland, International Journal of Operations & Production Management, Vol. 22, No. 2, pp. 220 – 240

Danish Standard DS/EN 206-1 (2001)

European Union energy efficiency goal (2012): http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/08/699&format=HTML Press Release of the European Union

Habitat for Humanity (2013) http://www.habitat.org/how/why.aspx

Halman, J.I.M., Hofer, A.P. and van Vuuren, W. (2003) 'Platform driven development of product families: theory versus practice', *Journal of Product Innovation Management*, Vol. 20, No. 2, pp.149–162

Huang, George Q. et al. (2005), The power of product platforms in mass customization, Int. J. Mass Customisation, Vol. 1, No. 1

INCOSE Systems Engineering Handbook ver. 3.2.1. (January 2011), A guide for system life cycle processes and activities, INCOSE-TP-2003-002-03.2.1

Ministry of national housing and social amenities (2011) http://www.housingministry.gov.zw/index.php/component/content/article/67-south-africa-battles-huge-housing-backlog

Mortensen, Niels Henrik et al. (2008), Implementing a product platform in 35 man-days: the visual thinking approach, International Journal of Mass Customization, Vol. 2, Nos. 3/4

Muffatto, Moreno and Roveda, Marco (2002), Product architecture and platforms: A conceptual framework, International Journal of Technology Management, Volume 24, No. 1

National housing code (2009), Technical and general guidelines, volume 2, part 3, Department: Human settlements, Republic of South Africa

PMBOK (2008), A Guide to the Project Management Body of Knowledge (PMBOK guide), fourth edition, Project Management Institute. ISBN 9781933890517

Roy et al. (2003), Construction Management and Economics, Re-engineering the construction process in the speculative house-building sector, Volume 21, 137–146

Simpson et al. (2001), Product platform design: method and application, Res Engineering Design 13, 2-22

Thuesen, Christian and Hvam, Lars (2011), Efficient on-site construction: learning points from a German platform for housing, Construction innovation, Vol. 11, No. 3, pp338-355

Ulrich, Karl and Tung, Karen (1991), Fundamentals of product modularity, DE-Vol. 39, Issues in Design / Manufacture integration, ASME 1991, Sloan School of Management, Cambridge, Massachusetts

Voss, Chris • Tsikriktsis, Nikos • Frohlich, Mark (2002), Case research in operations management, International Journal of Operations & Production Management — Volume 22, Issue 2, pp. 195-219,

Wörösch, Michael (2012), Structuring requirements in a multi-project environment in the construction industry – a life cycle perspective, Technical University of Denmark, Proceedings of the ASME 2012, IDETC/CIE 2012, August 12-15, 2012, Chicago, Illinois, USA

Yin, Robert K., Case study research, Design and methods, Fourth edition, Applied social research methods series volume 5