T.E.S.T – T.echnical, E.conomical and S.ustainable T.ransformation

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Abstract: The problem of the expanding suburbs of the cities, and the increasing number of abandoned office buildings seems to be a challenge for architects. Responding to the demand of spatial and functional urban circumstances, research assumed the redesign of the existing facilities in accordance with the principle of flex-buildings, based on the ability to respond rapidly to changes. In order to support the idea of unlimited transformation of the buildings, research entails the development of bio-degradable panels of integrated façade, that meets the requirements of residential and office functions in terms of lighting, ventilation, and heating / cooling etc. The resulting panels could provide the answer to sustainable and economic transformations of the buildings, do not meet the technical modern requirements.

Keywords: refurbishment, transformation, flexibility, façade, services, bio-composites, Cradle to Cradle

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1.1 Introduction

Definition of Flex-buildings (Heijne 2011), developed by René Heijne and Jacques Vink, assume that these buildings are designed to respond to the constant changes. This type of building must take into account the variability of the in-fills (interiors) and users, that can easily fit them into the existing conditions. Bearing in mind the problem of urban sprawl and the lack of places on the peripheries for the next enormous investments, the role of renovation increases, further justified by the idea of flex-buildings. The most serious problem of objects that adapt easily to changes arises at the stage of initial assumptions - how can you predict the legal and technical aspects over the next 5, 10 or 15 years? There is no clear-cut answer, and assumptions are based on conjecture, always supported on scientific studies. The idea of the building adaptable to the changes was applied in Groothandelsgebouw (Rotterdam) in 1953 (Heijne 2011), where the spatial organization and structure, based on a regular grid of columns, allowed for free play space. However facade elements have been unified and, despite freedom of interior planning, is not possible to fully adjust facade, which affects the cost and the need for countless installations necessary for internal climate control. According to Torben Dahl facade is the third skin – after human skin and clothes (Dahl, 2010, p.58) - and it greatly affects the comfort of indoors. Along with modern facilities installation, such as mechanical ventilation or air-conditioning, climate control problem have been solved. However, in the case of buildings that adapt to functional changes, these solutions are multiplying costs in distribution installation and the existing facade, often unsuited to the requirements of the new features, adds to expenses.

The idea behind the research presented below is to solve the problems of the transformation of existing facilities to new space requirements, develop a fast and inexpensive method to reprogram them, based on the idea of integration of the facade with the services into the bio-degradable panel. Bearing in mind the pressure for architects, as to reduce the energy requirements of buildings and implement the concept of sustainable development, it is anticipated the emphasis on reducing energy requirements and the use of biodegradable materials (Cradle to Cradle). Summary of the work will answer the questions of feasibility in terms of the technological, economic and environmental objectives mentioned above.
2.1 Problem statement

Growing cities cause social division, seizure of green land, increase zoning and transport problem. The problem of the spreading cities, named as ‘urban sprawl’, defines the contemporary city as a single entity depreciates the urban tissue and causing the formation of districts operate periodically, such as on-time work or sleep. This rarefaction causes increased dependence on transport, particularly a car. As a result of the process described above, many buildings become abandon through technical and functional mismatch. In the Netherlands, there are more than 7 million m² in abandoned office buildings. In the Utrecht, where is probably scheduled diploma project location, there are more than 1 million m² (MIRT 2013). The process of reorganization of abandoned objects is a challenge for architects. Nevertheless, often the transformation process turns out to be unprofitable and it is more feasible to arise new building with a specific function, that response to the demographic and spatial changes. The aim of this study is to establish the possibility of restoring abandoned buildings to life and to program them to adapt to unforeseen changes in functional and spatial terms. From the of the construction process and the life cycle of buildings point of view, building elements should be distinguished and specified, to pose the greatest problems in quickly adaptation and respond to change. Structural changes during the transformation process, unless backed by serious arguments, are unreasonable, but then every time it is require to replace the installation, that are necessary to obtain adequate conditions to stay indoors. Chart defining the relationship between the elements of the building (Fig.1) confirms the thesis presented above. While the structure is basically unchangeable and solid, elements of the installation or dividing elements are easily interchangeable. However, the look should be taken to the item guaranteeing protection against both external conditions as the artistic expression of the object - the facade.

![Diagram](image)

**Fig. 1 – (Left) building elements and its durability, presented by line thickness (by Heijne 2011) and author integration proposition (Middle) and (Right)**

Bearing in mind conceptual assumptions, consisting of a rapid adaptation of buildings to the new function, it is postulated to integrate the services in the facades. The integration of this two building elements will provide rapid adaptation to the new requirements, as well will significantly reduce the cost of building and operating.
2.2 Overall design question

Presented below general design question have been constructed to incorporate a doubt on the economic, sociological and energy part of the problem of remodeling of existing facilities.

*How to redesign existing buildings, from area of A12 in Utrecht, to make them functionally flexible and adaptable, and apply Cradle to Cradle idea of re-use keep the future transformations sustainable?*

2.3 Technical research question and sub questions

Presented below question is about specific technical issue, which is the problem of integration of service components in the facade.

*How to design façade that fulfill the different program requirements, in terms of light, ventilation, sunshading, noise, heating/cooling and maintenance?*

Below are presented sub-questions, that refer to the general technical question posted above.

*How to adjust façade elements for the redesign program?*

*How to implement heating, cooling, sunshading and ventilation solutions in the façade panels and reduce number of indoor installations?*

*How to make façade elements adaptable to different types of structures and sizes, as the structure grid, storey height etc.?*

*How to make façade elements easy to install and dismantle?*

*How to implement Cradle to Cradle idea in the design, according to the material aspect and building life cycle, to meet new energetic requirement?*

*How to improve existing process of the recycle method and make it more sustainable and efficient?*

*How to redesign existing buildings to meet new energetic requirements?*

*How to redesign existing building to make them adaptable for future requirements?*
3.1 Research

The following chapters provide a summary of research related to the issue of transformation of objects, based on the integration of the installation on the facade. The research work was divided into three interdependent parts (Fig. 2). The first part (Part A) refers to the materialization and the material properties of the proposed solution - bio-composites, which are fully biodegradable. The idea of Cradle to Cradle will provide the basis to develop material solutions for the issues of environmental costs, associated with replaceable panels. In the second part (Part B) were distinguished two functional blocks of buildings: housing and offices. They were considered according to the optimal spatial divisions, climatic requirements and general conditions, necessary for the proper functioning. The third part (part C) deals with the issues of the facade, as an element of interior and exterior contact. In order to organize the research work have been distinguished aspects necessary for the proper operation of the facility; ventilation, sun shading, light, noise, heating/cooling, maintenance, openings (Fig. 2).

Fig. 2 – division of the research into three interdependent parts – A – material, B – function, space, C - facade

3.2 Scope of the research

Due to the wide possibilities of research, concerning both the material aspect and spatio-functional, the main emphasis was put on Part B, and C- the relation facade - installations - interior climate. Author’s research interests the influence of the legal requirements and spatial evolution of the facade and the possibility of integration of traditional systems that control the climate inside of the outer building layer. The scope of research in its final form will be limited to guidelines, aimed at facilitating the redesign of the existing buildings and adapt it to the new spatial requirements. The new spatial requirements will arise from the urban-architecture and socio-demographic analyzes.
3.3 Methodology

The methodology used to answer the technical question has been divided by specified part. The first part (Part A), that concerns the question of the material, is based on literature research - scientific studies, the manufacturers data and reference design. Part of the second and third (Part B and C) is based both on literature research, reference design and a method of research through design;

the first stage involves representation of the legal requirements, climate and space in order to define the framework and guidelines for research model;

the second stage involves determination of boundary conditions needed to compare selected features. To obtain meaningful results when comparing different functions (housing and offices) was created architectural base model, based on a unified structure (module 30cm) and the layout of the rooms;

The third stage involves the use of specialized programs and diagrams to define the design guidelines.

3.4 Part A – Bio-composites as Cradle to Cradle material

The aim of the research, related to material suitable to the assumptions of flexible buildings, turned out to be a bio-composite. Bio-composite is defined by the inhomogeneous material on the structure, consisting of two or more components (phases) of different properties. Frequently one of the components of is the binder, which ensures its integrity, hardness, flexibility and resistance is compression, and the second, so-called, structural component, that provides most of the other mechanical properties of the composite (Knaack 2007). Bearing in mind the environmental guidelines, from all the available options for research, has been selected bio-composite developed by NABASCO, a part of NPSP (NPSP 2013). The selection criterion was the possibility of biodegradation of individual elements. The composite panel formed by the above-mentioned for architectural purposes, is composed of outer layers of resin binder (based mainly on flex oil) and reinforcement, in the form of natural plant fibers such as flex, hemp or soya beams. The inner layer, constituting the insulator and the construction is usually cork or balsa. An important advantage of composite panels by NABASCO company is able to create 3D forms, without decreasing to the physical or thermal properties of the material. The maximum size of the panel is 3,5 m wide to 14 m height (Fig. 3).
Fig. 3 – picture shows the bio composite panels montage on the Enexis headquarter building in Zwolle. Panels made by NABASCO / NPSP. The maximum panel size, achievable in this particular design was 3.5m wide and 14m height.

Bearing in mind the possibility of rapid assembly and disassembly of the above-mentioned panels can pose the problem of how to join panels. The design goals of NABASCO panels were to be durable and relatively long remain unchanged. Achievable values of thermal composites produced by NPSP is $\lambda$ (0.174 W / mK) (manufacturer’s data). However, this value is based on the production of the panels based on a glass fiber. Due to thermal calculations, bio - composites with cork insulation ($\lambda$ 0.050 W / mK) reach the U -value 0.193 W/m2K with original thickness of 250 mm (Fig. 4).
Production of reinforcement (natural fibers) seems to be a fairly efficient process. Elevation of the ENEXIS company headquarters in Zwolle (NPSP 2013), consumed "several tons of the product" (info based on a conversation with the person responsible for the distribution of material). Assuming an average value of 6 tons of material required for the production, and assuming an average production of 2-3t/1 ha of soybean (Dobek 2008), it takes about 2-3 hectares for the production of the raw material. The most serious problem is the certification of crops, not always corresponding to the quality standards. The most important factor determining the choice of bio-composites suitable material for use in the project is the ability to close the material cycle, thus fulfilling the requirements of Cradle to Cradle ideology. Traditional life cycle of the material (Fig. 5) has been changed by exchanging the raw material of traditional to biodegradable. The end result, in the form of biomass and energy generation (Fig. 6) was by the author supplemented by a process called pyrolysis (Fig. 7). This process involves almost anaerobic biomass combustion, which results in the formation of high-calorie product (biochar) in the final stage of combustion (Lehmann 2009). The resulting mass is rich in coal and can serve as fertilizer for the next crop of plants, from which arise subsequent elements of the facade panels. Another interesting innovation is the use of chicken bones for the production of natural glue - adhesive for panel elements (Odessa 2011). Another possibility is the production of adhesives from molds and fungi (Ecoactive 2013).
Fig. 5 – by author - sketch shows the traditional approach to the building life cycle. The raw material, with big amount of energy, during the process of production turns into the construction material. After dismantle of the building, crushed building material, as a waste goes to the dump.

Fig. 6 – by author - sketch shows the approach to the building life cycle, achieved by NABASCO (NPSP 2013). Raw material, now the plant fibers and wood-based elements, become composite panels and then become main façade elements. After building dismantle, bio-composites are burned as biomass, to provide energy for new material production process.
3.5 Part B– Space, function, services & C– Façade

Part of the research is devoted to the issues of functional and spatial relationship to the facade required the use of a specific actions, involving the stepwise accumulation of data and their implementation in the test model room. Of all the application functions, to develop research were selected two: housing and offices. The selection criterion was the ability to implement these two types selected in the other, defined as private / public. Among the functions such as parking, housing, live / working unit, offices, shopping, hotel, culture, civic, education or sport, it can used dividing and grouped them according to the requirements of climate. Housing may incorporate a subset of the live/work unit or a hotel. Office can include in a set of the function that can stay large number of people, such as culture, education, civic or shopping. Category Sports and parking, despite the public domain, should be considered separately. This paper, contains a sufficient degree of flexibility to be able to be matched to any of the above presented features. Presented below research is divided due to the requirements of the glazing and the light access, hence the panels can be used in all functions.

Integration a services and facade entails the need to combine the properties of both components - specified criteria that had been distinguished to be examined in terms of their implementation in the outer skin of the building. Distinguished were: thermal protection (described in section 3.4 of Part A - Bio- composites as Cradle to Cradle material), protection against noise, maintenance, open / close elements, ventilation, sunshading, light and heating / cooling.
Among the elements outlined above it should be established the basic legal requirements necessary to further the research process;

- Protection against noise - office - interior < 30dB
- Ventilation - housing / offices - 30 m3/h/p
- Light - office / working space - > 500 lx

Facade functions is to protect and connect the interior to the exterior. Regardless of the function of the interior, facade can be divided into three parts; sill - the lowermost, acting as a protective function and to attach utility (installations, radiators, etc.); view - the central part that provides to the user visual contact with the outside, often openable, acting as the interior lightning element; overlight - the highest, often directly available to the user, valuable because of not disturbing the exterior view, the possibility of lightning deep parts of the interior, the possibility to allocate additional installations such as ventilation. Among the specific functions of the interior (house/office), research should follow the requirements of the height location of above mentioned elements (Fig. 8). Grouped results showed that the lower edge of the view should begin at 90/110 cm (110 - in the case of an openable view element). Higher edge of the view should end at 200/220 cm (to allow manual control of overlight). Use of this division can be seen, for example the integrated façade of Capricorn Haus in Düsseldorf. The i-module façade integrates all the elements need to control indoor climate. The management system controls and optimize maintenance planning and energy strategies. Designed by Gatermann + Schossig Architekten, main façade module is divided into two elements – transparent and solid. Transparent allows the user to have contact with outside, the solid controls overheating and contains climate systems (Fig. 9). In the solid element were applied heating/cooling and ventilation systems. The overlight serves as an extra insolation element (i-module 2012).
Fig. 8 - by author - sketch shows the distribution and requirements of the panels based on - Part A - availability, security and visibility; Part B - destination interior; office (workspace, toilet) and dwelling (living room / bedroom, kitchen, toilet). Part C contains a summary of this research - shows the amount of the proposed grouping and divisions (Neufert 2000)
Used by author, above façade division into three parts, and implementation of the requirements of the climate and space had to be traced on the basis of the model, which allows a comparable results (Fig. 10). The simulation model is based on the module construction grid span of 0.3 m - thus 7.20 m is the width that was considered as appropriate, because of f.ex. the possibility of placing 3 parking spaces between columns/walls - in the case of buildings with garage in the ground floor/basement. For above ground levels grid allows the use of most types of ceilings. Hence, the span can refer to most existing buildings. Height of the base of the room is 3.5 m. This is the optimal amount of netto height of office space, bearing in mind the possibility of installing a suspended ceiling, obscuring mechanical ventilation ducts. The depth of the room is 6m plus an additional 2m of optional communication. These simulation model requirements largely relate to office premises, because there is a greater likelihood of conversion of office buildings to housing than vice versa (Section 2.1 Problem statement ). Requirements of the housing spaces are within the requirements of office space. The height differences of the storeys in relation to the location of the devices in the panels can be controlled by adjusting the top part of the panel (overlight), where the middle section (view) and lowest (sill) are always the same.
In order to determine the ability to generate energy in, free from the function of the illumination interior, panel elements (Fig. 13) in research were used solar and wind diagram (Figures 11 and 12). According to the analysis carried out, it shows that the southern, south east and south west facades, may become a generator of electricity, through the use of photovoltaic panels and/or heat by solar systems. Facades North and South (with the help of fans) and the south western, western and north western facade can use of natural ventilation, thanks to the favorable orientation with respect to the blowing winds. Elevations of the north eastern, eastern and south-eastern must use the fan in order to ensure an adequate exchange of indoor air.
In the further parts of research, in order to ensure an adequate amount of light penetrates the interior, tests were performed to determine the minimum size of the holes that can provide > 500 lux (in the limit 6m from the window). After the tests carried out in dedicated specialized programs (Dialux 2013), it was estimated, that the (minimal) optimum amount of glazing façade is 36% (with transparent overlight). Then, set forth the following values of glazing - 55 %, 66 % and 80 % (80% because takes into account the maximum glazing installation and window frames). To determine the energy requirements needed to maintain the interior of the climatic conditions, in all the above presented percentage of glazing, were used simplified calculations (Figures 15 and 16). Simulations were carried out under extreme conditions - housing function 4 person, office - 15 people in the simulation model (Fig. 10), all on the southern facade. The results show that while the value of the energy needed for

Fig. 13 – by author - graph shows the dependence of the orientation of the façade and the capability of it's use, in terms of solar energy and natural ventilation

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heating does not change significantly depending on the amount of glazing, energy needed for cooling increases significantly with the increasing size of window openings with no sun shading. In the simulation, basically was not taken into consideration the recovery of heat, but in further simulation has shown that in the case of heating, the energy demand can reduce by more than half by using heat recovery unit. In the case of cooling, heat recovery unit application had no drastic energy demand decrease. When using a fixed glazing values - 36 %, 55 %, 66 % and 80 % - remaining free space in the case of a single panel (W) x 1.2 m (H) 3.5 m, was respectively - 2.58 m2, 1.96 m2, 1.44 m2 , 0.6 m2 (Figures 15 and 16). Results, by using the base model (Fig. 10), the amount of space that could be used for energy generation is as follows - 15.48 m2 (36 %), 11.76 (55 %), 8.64 m2 (66%), 3.6 m2 (80%) (Fig. 18).

Fig. 14 – by author – Visualizations of the exemplary panels (different glazing ratio).
The table presents the energy requirements depending on the size of the glazing and the available space for additional installations – for housing functions (Solar calc. 2013) (PV calc. 2013)
The table presents the energy requirements depending on the size of the glazing and the available space for additional installations – for office functions (Solar calc. 2013) (PV calc. 2013)
Free space, depending on the orientation of the facade, may be used in various ways. It is possible to mount fans in each panel, which will provide fresh air into the room. It will still need a fan that meets the requirement of the volume of work 30dB. In this case, with 6 panels and 6 fans (one fan on the panel) minimum fan efficiency is 75 m³/h/p, which will provide air exchange rate of 30 m³/h/p, for test model circumstances (Fig. 10), for 15 people. It is possible to mount air intakes, which could act as a passive aeration elements, however, it should be taken into account the need for outdoor air heating in winter and cooling in summer. There is a possibility of installing photovoltaic panels or solar panels which can significantly reduce the energy demand of an interior (Fig. 17). The use of test results show that, for example, the use of 13.3 m² of PV panels on the facade, while maintaining 36% glazing, ensure electricity supply for a family of 4 (test model). In the case of solar panels, to provide hot water at 60% of annual demand for 4 person family, just 4.9 m² of solar panels have to be install. In the case of office function, it is impossible to provide a self-sufficient in electricity (min. 25.6 m²), even while maintaining the desired glass ratio of the minimum 36 %.
Table presents the optional installation in free space (see figures 15 and 16) - photovoltaic installations and solar panels, depending on the number of people in the interior.

Fig. 17 – by author - The table presents the optional installation in free space (see figures 15 and 16) - photovoltaic installations and solar panels, depending on the number of people in the interior.
Fig. 18 – by author - figure shows the optional configurations of the panels based on user needs
4.1 Conclusion & discussion

The aim of the research was to determine the feasibility of implementation of the services in the facade and the legitimacy of the project in terms of technical, economic and energy. Integrated facade, which components can be subjected to biodegradation, and its modularity facilitates the transformation of selected fragments or whole stories of the building, seems to be the ideal answer to the idea of flex - buildings (Heijne 2011) and asked a technical question (chapter 2.3 Technical research question and sub questions). Panels of bio - composites can be installed on the older and newly raised buildings. The ability to freely convert integrated, but replaceable, façade elements (ventilation, glazing, sunshading, heating/cooling - defined during design process), allows fast and economic transformation of the interior features. Also, in terms of energy, customize the free space elevation to users' needs will help reduce bills.

Unfortunately, the seemingly miraculous solution for hundreds of abandoned buildings also has a few significant drawbacks. It is strongly limited the validity of assembling the panels in a very old, even historic buildings, where the strongest value of buildings is their authenticity. However, the main drawback of integrated panels is their limited “influence”. For some orientation of facades, free façade spaces, instead of glazing, has no other features beyond the protective (protection against the outdoor conditions). One orientated facades are ideally suited for the production of electricity or hot water, and other for natural ventilation of the interior. One of the features of modern, energy-efficient buildings is their holistic planning, implementing and maintaining both centralized and decentralized systems. In the case of decentralized interchangeability of panels, purchased by individual consumers, it is hard to say about holistic planning. Functional building renovation must take into account all the advantages and disadvantages of the location and strive to develop the most beneficial spatial arrangement where the benefit can be achieved with a variety of complementary panels.
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Illustrations:

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Fig. 2 by author

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Fig. 5, 6, 7, 8 by author

Fig. 9 i-module facade (2012), website, posted by Diana, published 11 October 2012, viewed 15 December 2013, URL: <http://filt3rs.net/case/fragmented-window-i-module-dusseldorf-131>

Fig. 10 by author

Fig. 11 Solosol (2009), website, viewed 11 December 2013, URL: <http://www.solosol.net/Solar-Design-Tools/sun_path_calculator.html>

Fig. 12 wind rose, Climate Consultant 5.4

Fig. 13 to 18 by author

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